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CHARACTERIZATION, CLASSIFICATION AND SUITABILITY EVALUATION OF SOME SOILS IN THE FLOODPLAINS OF RIVER NIGER, KOGI EAST, NIGERIA FOR RICE, MAIZE, CASSAVA AND OIL PALM PRODUCTION

[1,2]Ukabiala M.E.

[1]Department of Soil Science, University of Agriculture & Environmental Sciences,
Umuagwo, Imo State, Nigeria
[2]Department of Soil Science, University of Nigeria, Nsukka, Nigeria
Corresponding email: successfulmadu@yahoo.com

ABSTRACT

This study was conducted to characterize, classify and evaluate four soils along River Niger in Kogi East for rice, maize, cassava and oil palm production. The soils developed predominantly from alluvium. The soils were located in four communities namely Ejule-Ojebe, Shintaku, Bagana and Kpata all in the floodplains of River Niger in Kogi East. The soils were investigated using a free survey technique. Four pedons representing four soils located at different sites in the floodplain were studied. The environs and the profiles of the soils were described according to standard field procedures. Soil samples were then taken from genetic horizons for laboratory analysis. The soils were also characterized and classified according to Soil Taxonomy and the World Reference Base for Soil Resources (WRB). The colour of the soils ranged from shades of brown to grey generally due to poor drainage. The soils also varied in depth and horizonation due to differences in profile development. Due to the relatively higher sand content of the soils, especially in the surface and subsurface horizons, the texture of the soils generally ranged from sand to clay loam. The pH (H_2O) of the soils ranged from 4.8 to 7.3, strongly acidic to slightly alkaline, and tended to increase with depth. The soils contained moderate amounts of organic carbon in the surface soils but lower levels in the lower horizons. Based on their properties, the soils were classified according to Soil Taxonomy as Alfisols (Ejule-Ojebe), Entisols (Shintaku), Inceptisols (Bagana) and Alfisols (Kpata) and according to WRB as Planosols, Arenosols, Gleysols and Planosols, respectively. The soils were found to be highly suitable for rice production but moderately suitable for maize, cassava and oil palm. Apart from rice cultivation, wetness of soil was found to be the major limiting factor for optimum rainfed cultivation of maize, cassava and oil palm.

Key words: characterization, classification, suitability, soil profile, horizonation

INTRODUCTION

Characterization of soils gives detailed information about the different soil properties and identifies their potentials and production constraints. Soil characterization has been reported to be the first aspect/study discipline towards developing database for formulating land use models (Bassanta *et al*., 2013). Soil characterization studies are a major building block for understanding the soil and classifying it for getting the best knowledge of the environment (Akamigbo, 2005). Thus, soil characterization provides information on morphological, physical and chemical properties of soils as well as insights into their behaviour (dynamics) (Raju *et al*., 2005). Soil classification is the systematic arrangement of soils into categories based on their properties. The purposes of classification include organizing knowledge for ease of remembering properties used and clearer understanding of relationships between soils (Buol *et al*., 1997). For technical classification which is used in the FAO/UNESCO (WRB) system, the purpose may be for specific application such as land-use regulation (Buol *et al*., 1997). This knowledge is essential for utilizing soil potentials (Kumar *et al*., 2013). It provides a powerful resource for the benefit of mankind especially in the area of food security and environmental sustainability. Soil suitability evaluation involves characterizing the soils in a given area for specific land use type (Ande, 2011). To assess the suitability of soils for crop production, soil properties and crop requirements must be known. Also, these requirements must be understood within the context of limitations imposed by landforms and other features which do not form a part of the soil but may have significant influence on use that can be made of the soil (FAO, 1976).

The dearth of adequate information on the physicochemical of the soils of the study area is a contributory challenge towards achieving the goal of maximum productivity (Amhakhian and Osemwota, 2012). Characterization, classification and suitability evaluation of the soils of this region for agricultural purposes will not only establish relationship between soil properties and the landscape parameters, but also

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provide preliminary information on the nutrient status, limitations and ensure sound judgement on the behaviour or response of the soils to specific uses. The objectives of this research were to characterize, classify and evaluate the suitability of four soils in the floodplain of River Niger at Kogi East, Nigeria for the cultivation of rainfed rice, maize, cassava and oil palm.

MATERIALS AND METHODS

Study Area

The study sites were located at Ejule-Ojebe, Shintaku, Bagana and Kpata all within the Eastern zone of the Kogi State. This zone falls in the middle belt of Nigeria. It lies between latitudes 6°51′N to 7°54′N and longitudes 6°45′E to 7°38′E. Kogi East is bounded on the West by Niger River, North by the River Benue, East by Benue State and South by Anambra State. The study area experiences two major climatic seasons namely the rainy season which lasts from Apr. to Oct. and the dry season which starts from Nov. and ends in Mar. (Weatherbase, 2011). Part of the dry season is very dusty and cold as a result of the north-easterly winds which bring about the harmattan. The annual rainfall ranges from 1100 to 1300 mm with mean of 1200 mm. The average monthly temperature varies between 17 and 36°C (Amhakhian and Osemwota, 2012). The highest temperature (36°C) has been recorded during the dry season (Gideon and Fatoye, 2012). The mean relative humidity in the study area falls to a minimum of 15% in the dry season and rises to a maximum of 67% in the rainy season (Gideon and Fatoye, 2012).

The geology of the area comprises two main rock types namely basement complex rocks and older granite extending towards the lower Niger valley. The various sedimentary rocks of River Niger and Benue extend southeastwards through Enugu and Anambra States (www.onlinenigeria.com). Amhakhian and Osemwota (2012) reported geological formations of Cretaceous age within the study area. A study of sediment geochemistry of River Okura confirmed study area as falling within the Anambra sedimentary basin which is Cretaceous in age (Gideon and Fatoye, 2012). The study further revealed that the rocks had low silica (SiO_2) but high iron (Fe) content suggesting lithic arenite type of sandstone. Some parts of the study area have also been found to be made up of geologic materials such as Awgu shale group (Fagbami and Akamigbo, 1986; Ukabiala, 2012). The area is naturally drained to the Niger and Benue Rivers through their tributaries, rivers and streams forming various lowlands and floodplains.

Field Study

In general, landscape carrying the floodplain soils within Kogi East covers the area adjoining Rivers Benue and Niger at Ejule-Ojebe, Shintaku, Bagana and Kpata in Ibaji, Bassa and Omala Local Government Areas. They are areas that are seasonally inundated by surface or ground water. They are low-lying at an elevation ranging from 38 to 59 m above mean sea level. The soils are derived from mostly sand, clay and other forms of alluvial and colluvial deposits. Depending on the topographic positions, the soils are poorly to moderately drained. They are nearly level to level plain (2 to 4% slope).

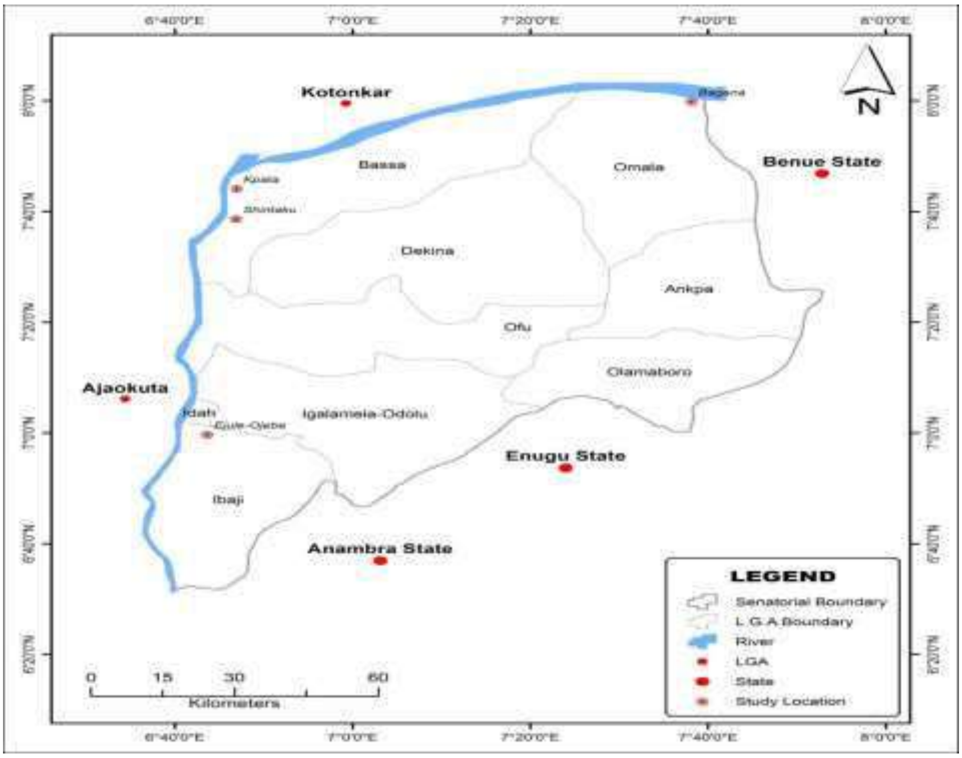

Figure 1: Map showing the sample points within the study area

Four pedons which fall within the floodplain in Kogi East were selected and designated at Ejule-Ojebe, Shitaku, Bagana and Kpata (Figure 2), following the physiographic pattern of the landscape. The agroecology is wetland while the geology is recent alluvium. The relief is characterized by nearly level to gently undulating plains. The soils are poorly drained and made up of dominantly sand, sandy loam, loamy sand or sandy clay loam surfaces. The profiles at Ejule-Ojebe and Kpata were dug to 200 cm while those at Shintaku and Bagana were 35 and 60 cm deep, respectively due to the presence of perched water table in the two soils. The locations of the pedons of the four soils were georeferenced with a hand-held Etrex High Sensitivity Global Positioning System (GPS). The soil profile pits and their environs were described following Field Book for Description and Sampling Soils (Schoeneberger *et al*., 2012). Abney level was used to determine the slope angles on the sites of the soil profile pits. Core samples were taken in duplicates from the surface and subsurface horizons of each soil profile for the determination of selected physical properties. 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 labelled polyethylene bags and transported to the University of Nigeria Nsukka Soil Science Laboratory for physicochemical analyses.

Laboratory Analyses

The particle size distribution (PSD) of the soils (< 2 mm) was determined using Bouyoucous (1962) hydrometer method. Sodium hydroxide was used as dispersant and then the textural classes were read out from the USDA soil textural triangle. Bulk density was determined by the core and excavation method described by Landon (1981). Soil porosity was calculated with the values of the bulk density using the method outlined by Vomicil (1965) and Brady and Weil (2002). 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:

$$K_{sat} = (Q/At)/L/\Delta H);$$

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-section 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 in a soil solution ratio of 1:2.5 using a glass electrode pH meter (McLean, 1982). Organic carbon was determined by the wet dichromate acid oxidation method (Nelson and Sommers, 1982). Total nitrogen content was estimated by using the macro-Kjeldahl digestion method (Bremmer and Mulvaney, 1982). The available phosphorus content was determined according to the Bray II bicarbonate extraction method (Olsen and Sommers, 1982), using 0.03 N 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-solution ratio. The levels of K^+ and Na^+ in the extract were determined with the flame photometer while the levels of Ca^{2+} and Mg^{2+} were determined with the atomic absorption spectrophotometry (Thomas, 1982). Total exchangeable bases (TEB) were obtained by the summation of the exchangeable bases (Na^+, K^+, Ca^{2+} and Mg^{2+}) (Rhoades, 1982). The cation exchange capacity of the soils was determined with 1N NH_4OAc, pH 7.0 (Rhoades, 1982).

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

$$ESP = \frac{\text{Exchangeable sodium}}{\text{Cation exchange capacity}} \times \frac{100}{1}.$$

Exchangeable acidity was determined using the method outlined by Thomas (1982). Extraction was done with 1 N KCl and the extract titrated with 0.05 N NaOH to a permanent pink end point using phenolphthalein. Effective cation exchange capacity (ECEC) was determined as a summation of TEB and exchange acidity (Rhoades, 1982). The percentage base saturation (PBS) of the soils was determined as; PBS = (TEB/CEC) × 100 (Rhoades, 1982). The values obtained from analysing the chemical properties of the soils were compared with critical limits used for interpreting soil fertility (Table 1).

Table 1: Critical limits for interpreting fertility levels of soils

Parameters	Very low	Low	Moderate	High	Very high
[1]Ca^{2+} (cmol kg^{-1})		< 2.0	2.1-5.0	> 5.0	
[1]Mg^{2+} (cmol kg^{-1})		< 0.30	0.31-1.0	> 1.0	
[1]K^+ (cmol kg^{-1})		< 0.15	0.16-0.3	> 0.3	
Na^+ (cmol kg^{-1})		< 0.10	0.11-0.3	> 0.3	
[2]CEC (cmol kg^{-1})	< 6.0	6.0-12.0	12.1-25.0	25.1-40.0	> 40.0
[1]ECEC (cmol kg^{-1})		< 6.0	6.1-12.0	> 12.0	
[2]EA (cmol kg^{-1})		< 2.0	2.1-5.0	> 5.0	
[2]Org. C (%)	< 0.4	0.4-1.0	1.1-1.4	1.5-2.0	> 2.0
[1]Total N (%)	< 0.05	0.06-0.10	0.11-0.15	0.16-0.20	> 0.20
[2]Avl. P (mg kg^{-1})	< 3.0	3.0-7.0	7.1-20.0	> 20.0	
[2]BS (%)	< 20.0	20.0-40.0	41.0-60.0	60.0-80.0	80.0-100.0
[2]ESP (%)	< 0.1	0.1-2.0	2.1-8.0	8.1-15.0	> 15.0

[1] - Shehu *et al.* (2015), [2] - Enwezor *et al.* (1989). Ca^{2+}, Mg^{2+}, K^+, Na^+ - exchangeable calcium, magnesium, potassium and sodium; CEC - cation exchange capacity, ECEC - effective cation exchange capacity, EA - exchangeable acidity, Org. C - organic carbon, Total N - total nitrogen, Avl. P - available phosphorus, BS - base saturation, ESP - exchangeable sodium percentage

Soil Classification

The soils were classified according to the Keys to Soil Taxonomy (Soil Survey Staff, 2014) and the World Reference Base for Soil Resource (IUSS Working Group WRB, 2015).

Land/Soil Suitability Evaluation

The suitability of the soils for rice, maize, cassava and oil palm cultivation was evaluated using the conventional method (Sys, 1985; Udoh and Ogunkunle, 2012). This involved matching of the requirements of the crops with the characteristics of the soils. The most limiting characteristic was identified which determined the class of suitability of soil for each crop. Under this approach, the soils were classified as highly suitable (S_1), moderately suitable (S_2), marginally suitable (S_3), currently not suitable (N_1) and permanently not suitable (N_2), based on the limitations identified. The limitations were indicated by lower-case letters with mnemonic significance. In order to properly match the crop requirement with soil characteristics, numerical rating of some selected land qualities on a scale of 0 to 100 indicating very low to optimum values (Table 2) and according to the intended land utilization type was adopted. The ratings were referenced to the established land requirements for each crop (Tables 3, 4, 5 and 6). The average score guided the determination of final class of suitability of soil for each crop.

Table 2: Rates of soil suitability classes for agricultural uses

Classes	Suitability classes	Rates	Potential Agricultural 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 3: Land/crop requirements for rain-fed 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	> 1400.0	1200.0-1400.0	950.0-1100.0	850.0-900.0	< 850.0
Soil physical characteristics (*s*)	Soil depth	cm	> 20.0	10.0-20.0	5.0-10.0	< 5.0	any
	Clay	%	45.0-25.0	25.0-15.0	15.0-5.0	< 5.0	any
	Texture	-	Loam	Clay loam	Clay	Sandy clay	Sand
Wetness (*w*)	Drainage	-	VPD	PD	MD	MWD	WD
	F.D.	months	> 4.0	3.0-4.0	2.0-3.0	< 2.0	any
	G.W.T.	cm	0-15.0	15.0-30.0	30.0-60.0	> 60.0	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}	5.0-6.0	3.0-4.0	1.0-2.0	<1.0	any
	Available phosphorus	mg kg^{-1}	> 20.0	15.0-20.0	10.0-15.0	< 10.0	any
	Exchangeable Ca	$cmol_c\ kg^{-1}$	10.0-15.0	5.0-10.0	1.0-5.0	< 1; > 15.0	any
	Exchangeable Mg	$cmol_c\ kg^{-1}$	2.0-5.0	1.0-2.0	< 1.0	< 1.0, > 5,0	any
	Exchangeable K	$cmol_c\ kg^{-1}$	> 0.2	0.1-0.2	< 0.1	< 0.1	any
	CEC (Soil)	$cmol_c\ kg^{-1}$	> 16.0	10.0-16.0	5.0-10.0	< 5.0	any
	Active Fe	g kg^{-1}	< 0.75	0.75-1.0	1-1.25	>1.25	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; any - values outside the range stated. Adapted from Sys (1985)

Table 4: Land/crop requirements for suitability classes for rain-fed 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, FS	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, FS - fine sand, S - sand; P - phosphorus, K - potassium, Ca - calcium, Mg - magnesium, N – nitrogen, CEC - cation exchange capacity; any - values outside the range stated. Modified from Sys (1985)

Table 5: Land/crop requirements for rain-fed cassava 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)	1000-1800	600-1000	500-600	400	< 400
Length of dry season (months)	3-5	5-6	6-7	any	> 7
Mean annual temperature (°C)	20-30	> 30	any	any	any
Topography (*t*)					
Slope (%)	0-8	8-16	16-30	30-50	> 50
Wetness (*w*)					
Drainage	Well	Moderate	Poor	Very poor	Non-drainable
Soil physical properties (*s*)					
Texture	L, SCL, SL, SiC, SiCL, CL, SiL, SC	LFS, LS, FS	C, FS	Si	Sand
Coarse fragments (Vol. %) 0-10 cm	< 3	< 15	< 35	> 35	any
Soil depth (cm)	> 100	> 75	> 50	< 50	any
Fertility (f)					
CEC (cmol$_c$ kg^{-1})	> 16	10-16	3-9	< 3	any
Base saturation (%)	> 35	20-35	10-19	< 10	any
Organic carbon (g kg^{-1}), 0-15 cm	8-15	5-7	3-6	1-2	< 1
pH-H$_2$O	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; L - loam, SCL - sandy clay loam, SL - sandy loam, SiC - silty clay, SiCL - silty clay loam, CL - clay loam, SiL - silty loam, SC - sandy clay, LFS - loamy fine sand, LS - loamy sand, FS - fine sand, C - clay, Si - silt; P - phosphorus, K - potassium, Ca - calcium, Mg - magnesium, N - nitrogen, CEC - cation exchange capacity; any - values outside the range stated. Modified from Sys (1985)

Table 6: Land/crop requirements for oil palm 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)	1800-2500	1250-1799	1000-1250	500-1000	< 500, > 2500
Mean annual temp. (°C)	24-33	20-22	> 33, < 20	any	any
Relative humidity (%)	70-75	65-70	50-65	30-50	< 30
Topography (*t*)					
Slope (%)	0-3	4-8	9-16	16-45	> 45
Wetness (*w*)					
Flooding	F0	F1	F2	F3	F4
Drainage	WD	MWD	MD	PD	VPD
Soil physical properties (*s*):					
Texture	CL, SCL, L	SCL	SCL-LFS	any	C, S
Structure	granular	crumb	blocky	prismatic	massive, single grain
Depth (cm)	> 100	50-100	25-49	20-25	< 25
Fertility (*f*)					
Cation exchange capacity (cmol$_c$ kg^{-1})	> 10	6-10	< 6	any	any
Base saturation (%)	> 35	< 20	any	any	any
pH-H$_2$O	6.5-7.0	5.5-6.0	< 5.5, > 7.0	< 4, > 7.0	< 4, > 7.0
Organic carbon (g kg^{-1}), 0-15cm	> 8	< 8	-	-	-
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 Mg (cmol$_c$ kg^{-1})	2-5	1-2	< 1	< 1, > 5	any
Exchangeable Ca (cmol$_c$ kg^{-1})	10-15	5-10	1-5	< 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; F0 - no flooding, F1 - 1-2 months flooding in > 10 years, F2 - not more than 2-3 months in 5 years out of 10, F3 - 2-4 months almost every year, F4 - > 4 months in almost every year; CL - clay loam, SCL - sandy clay loam, L - loam, LFS - loamy fine sand, C - clay, S - sand; WD - well drained, MWD - moderately well drained, MD - moderately drained, PD - poorly drained, VPD - very poorly drained; P - phosphorus, K - potassium, Ca - calcium, Mg - magnesium, N - nitrogen, CEC - cation exchange capacity; any - values outside the range stated. Adapted from Ogunkule (1993)

RESULTS

Morphological Characteristics of the Soils

The morphological characteristics of the soils studied are shown in Table 7. The boundaries between the identified soil horizons varied between clear smooth, diffuse smooth, gradual wavy, gradual irregular and abrupt irregular. The moist colour of the soils in this flood plain was dominated by hues of 10YR, 7.5YR and 2.5Y in the surface and subsurface layers except 5B in Bagana profile. These gave variation of colours such as 10YR5/2 (greyish yellow brown), 10YR6/3 (dull yellow orange), 7.5YR7/2 (pinkish grey), 2.5Y6/6 (olive yellow), and 5B5/1 (bluish grey).

The field texture observation (feel method) showed variation of clay, clay loam, loamy sand and sandy clay loam in the surface and subsurface soils with a discontinuity observed in Bagana profile as expressed by sharp textural difference of underlying silty loam from the surface. Soil structural variations of various grades and classes of granular crumb and subangular blocky structure were observed. Single grain structure was observed in the surface and subsurface soils of Shintaku profile. The consistence throughout the profiles varied from non-sticky and non-plastic to very sticky and very plastic in both surface and subsurface horizons under wet condition and loose to friable under moist condition. Other morphological characteristics observed in the profiles studied included roots, manganese concretions and surface cracks of about 5 × 12 cm in Ejule Ojebe and Bagana profiles.

Physical Characteristics of Soils

Tables 8 and 9 show the physical characteristics of the soils while Figure 2 shows the sand and clay distribution down the profiles of the soils. In all the profiles studied, coarse sand, sand, silt and clay fractions of the soils had ranges of 120 to 410 g kg^{-1}, 250 to 600 g kg^{-1}, 20 to 350 g kg^{-1} and 0 to 280 g kg^{-1}in the surface soils, 10 to 400 g kg^{-1}, 270 to 640 g kg^{-1}, 20 to 390 g kg^{-1} and 0 to 400 g kg^{-1}in the subsurface soils respectively. The surface soils had a mean value of 250 g kg^{-1} for coarse sand. The subsurface soils had respective mean value of 425, 199 and 236 g kg^{-1} for fine sand, silt and clay. The dominant soil textural classes are clay loam and loamy sand in the surface soil, and sand, sandy clay loam and clay in the subsurface soils.

The bulk density of the soils ranged from 1.21 to 1.52 g cm^{-3} and 1.27 to 1.86 g cm^{-3} with mean values of 1.39 and 1.59 g cm^{-3} in the surface and subsurface soils, respectively. The percentage total porosity values of the soils ranged from 46.96 to 53.01% with a mean value of 46.96% in the surface and 28.12 to 51.21% (mean: 39.33%) in the subsurface. The K_{sat} values ranged from 1.32 to 2.91 and from 1.02 to 2.82 with mean values of 2.17 and 1.97 in the surface and subsurface soils, respectively.

Chemical Characteristics of the Soils

The chemical characteristics of the soils are presented in Table 10. The pH in H_2O and KCl increased with depth, having higher mean values of 6.0 and 4.9 in the subsurface soils. The organic carbon (OC), total nitrogen (TN) and carbon:nitrogen (C:N) ratio of the soils had ranges of 0.20 to 51.0 g kg^{-1}, 0 to 0.88 g kg^{-1} and 0 to 15 at the surface, and 0.20 to 15.60 g kg^{-1}, 0 to 0.33 g kg^{-1} and 0 to 13 in the subsurface soils. The mean values of OC, TN and C:N were higher in the surface soils, having 21.40 g kg^{-1}, 0.34 g kg^{-1} and 7 than 4.70 g kg^{-1}, 0.08 g kg^{-1} and 6 in the subsurface soil, respectively. Available phosphorus (AvP) was irregularly distributed within the depths in all the profiles, varying from 1.87 to 5.60 mg kg^{-1} at the surface and 1.87 to 18.65 mg kg^{-1} in the subsurface. The highest value of 18.65 mg kg^{-1} occurred in the subsurface of Egule-Ojebe soil. The AvP mean value of 4 and 8.07 mg kg^{-1} was recorded in the surface and subsurface soil respectively.

Total exchangeable bases (TEB) were higher in the subsurface soils, having mean value of 14.46 $cmol_c\ kg^{-1}$ than 12.48 $cmol_c\ kg^{-1}$ of the surface soils. The TEB was dominated by Ca^{2+} and Mg^{2+} which increased down the profiles. Higher value of Ca^{2+} (17.80 $cmol_c\ kg^{-1}$) was recorded in the soil from Ejule-Ojebe. The soil exchangeable acidity (EA) was dominated by H^+. There were no traces of Al^{3+} in the soils of this mapping unit. The EA was higher at the surface soils (range, 0.08-1.80 $cmol_c\ kg^{-1}$; mean, 0.93 $cmol_c\ kg^{-1}$) compared with the subsurface soils (range, 0.16-1.40 $cmol_c\ kg^{-1}$; mean, 0.71 $cmol_c\ kg^{-1}$).

The values of CEC by NH_4AO_c were higher than the ECEC which irregularly increased with depth. The CEC and ECEC mean values were 28.70 and 13.59 $cmol_c\ kg^{-1}$ in the surface soils, 25.94 and 15.13 $cmol_c\ kg^{-1}$ in the subsurface soils. The percentage base saturation (PBS) generally increased with depth, having mean value of 61 and 62% at the surface and subsurface soils respectively. The surface soils had higher mean exchangeable sodium percentage (ESP) value of 0.61% when compared to subsurface soils with 0.59%.

Classification of the Soils

The summary of the classification of the pedons are presented in Table 11. Ejule-Ojebe pedon has layers 50 cm from the mineral soil surface with aquic conditions for some time in normal years with redox concentrations as well as ochric epipedon and therefore classified as Inceptisol. It is further placed as Aquept having ground water within 100 cm of the mineral soil surface for some time during the year. At the great group level, it is classified as Vermaquept, having about 25% recognizable bioturbation as expressed by wormholes. At the subgroup level, it placed as Typic Vermaquept. The FAO/WRB equivalent of the soil is Gleyic Alisol.

Shintaku pedon had no clear evidence of development of pedogenic horizons by sandy-skeletal particle size class and is classified as Entisols. This is a wet Entisols, having occurred on a floodplain along the River Niger where the soils are saturated at some time of the year. Therefore, it is set at the suborder of Aquents. At the great group level, this pedon is classified as Psammenquents, having a sandy texture without redox concentrations. Also, the water table is near the surface for long periods. This Psammaquents had a weakly developed ochric epipedon and no lithic contact within 50 cm of the soil surface, very low exchangeable sodium percentage (5-6%) and therefore set as Typic Psammaquents at the subgroup level of the USDA soil taxonomy. The FAO-WRB equivalence of this pedon is Fluvic Arenosols being a young soil in fluvial deposit with weighted average texture class of sand (fluvic material) from mineral soil surface.

The Bagana pedon in which was just beginning to develop with an ochric epipedon and having formed in loamy and clayey parent materials is placed as Inceptisols at the order level. This pedon is a wet Inceptisols with redox concentrations, and having occurred on a flood plain is placed as Aquepts at the suborder level. This Aquepts has endosaturation and so is set as Endoaquepts at the great group level.

Table 7: Morphological characteristics of soils

Location	Horizon depth (cm)	Horizon designation	Colour		Texture	Structure	Consistence		Boundary	Pores	Roots	Others
			Matrix	Mottles			Wet	Moist				
Ejule-Ojebe	0-13	Ap1	10YR3/2	-	cl	245c	sssp	fr	cs	cfi	mfi	Surface cracks
	13-31	Ap2	10YR5/4	10YR6/8	cl	25sbk	sp	f	gw	fvfi	cfime	-
	31-67	AC	2.5YR7/1	2.5YR7/8	cl	25sbk	sp	f	gw	ffi	ffi	-
	67-113	Cg1	10YR5/1	10YR5/4	cl	14sbk	sp	fr	gi	ffi	fvfi	-
	113-173	Cg2	10YR7/1	10YR5/6	c	25abk	sp	f	db	ffme	fvfi	Many earthworms
	173-200	C	10YR7/1	-	c	25sbk	vsvp	f	-	fme	fvfi	Few earthworms
Shintaku	0-19	A	10YR7/8	-	s	sg	nsnp	l	ds	mme	-	-
	19-35	C	2.5YR5/6	-	s	sg	nsnp	l	-	c	-	-
Bagana	0-22	Ap1	10YR5/2	10YR8/6	cl	24sbk	sp	f	aw	cme	cfi	5 × 12 cm cracks
	22-30	Ap2	10YR6/3	10YR2/3 10YR4/3	sil	s	sssp	l	ai	ffi	cmeffi	-
	30-60	2Bw	5B5/1	5P3/1	c	256sbk	sp	f	-	ffi	ffi	-
Kpata	0-19	Ap1	10YR4/2	-	ls	24g	nsnp	f	cs	mfi	mfi	Many ants
	19-32	Ap2	7.5YR5/2	-	s	245sbk	nsnp	l	gs	cfi	cfi	Common ants
	32-69	AB	7.5YR7/2	-	ls	s	nsnp	l	ai	mme	ffi	
	69-126	Bt1	10YR6/1	7.5YR6/8	scl	35abk	sssp	f	ds	fvfi	ffi	Many black Mn concretions
	126-200	Bt2	10YR7/2	7.5YR6/4	scl	36abk	sssp	f	-	ffi	fvfi	

Structure: 1 - weak, 2 - moderate, 3 - strong, 4 - fine, 5 - medium, 6 - coarse, c - crumb, g - granular, sbk - subangular, abk - angular blocky, sg - 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, b - broken

Table 8: Textural characteristics of soils

	Location	Horizon depth (cm)	Horizon designation	Coarse sand	Fine sand	Silt	Clay	Textural class
					(g kg^{-1})			
	Ejule-Ojebe	0-13	Ap1	200	250	270	280	cl
		13-31	Ap2	130	300	290	280	cl
		31-67	AC	50	280	270	400	cl
		67-113	Cg1	60	270	310	360	c
		113-173	Cg2	10	320	270	400	c
		173-200	C	10	320	290	380	cl
	Shintaku	0-19	A	410	570	20	0	s
		19-35	C	420	560	20	0	s
	Bagana	0-22	Ap1	120	310	350	220	ls
		22-30	Ap2	110	530	120	240	scl
		30-60	2Bw	60	270	390	280	cl
	Kpata	0-19	Ap1	240	600	110	50	ls
		19-32	Ap2	280	620	60	40	s
		32-69	AB	210	640	120	30	ls
		69-126	Bt1	140	470	130	260	scl
		126-200	Bt2	200	460	110	230	scl
Surface range				120-410	250-600	20-	0-280	s-ls-cl
Subsurface range				10-420	270-640	20-	0-400	scl-c
Surface mean				250	430	187	138	scl
Subsurface mean				151	425	199	236	scl

s - sand, ls - loamy sand, c - clay, cl - clay loam, scl - sandy clay loam

Table 9: Bulk density, total porosity and hydraulic conductivity of the soils

	Location	Depth (cm)	Bulk density (g cm^{-3})	Total porosity (%)	K_{sat} (cm h^{-1})
	Ejule-Ojebe	0-25	1.40	47.17	2.53
		25-50	1.76	33.58	1.72
		50-75	1.58	40.38	1.82
	Shintaku	0-25	1.21	53.01	2.91
		25-50	1.27	51.21	2.82
		50-75	1.27	50.20	2.72
	Bagana	0-25	1.52	42.64	1.32
		25-50	1.46	44.91	2.53
		50-75	1.85	30.19	1.27
	Kpata	0-25	1.42	45.03	1.90
		25-50	1.67	36.05	1.88
		50-75	1.86	28.12	1.02
Surface range			1.21-1.52	42.64-53.01	1.32-2.91
Subsurface range			1.27-1.86	28.12-51.21	1.02-2.82
Surface mean			1.39	46.96	2.17
Subsurface mean			1.59	39.33	1.97

K_{sat} - saturated hydraulic conductivity

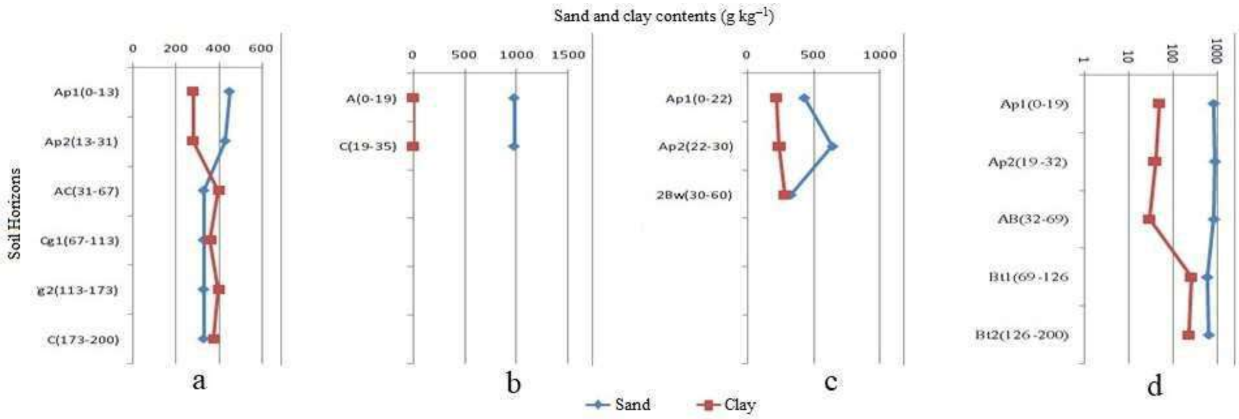

Figure 2: Distribution of clay and sand in the soil profiles at Ejule-Ojebe (a), Shintaku (b), Bagana (c), and Kpata (d)

The soils are fine textured with surface cracks that were more than 5 mm in thickness and so classified as Vertic Endoaquepts according to the USDA Soil Taxonomy. The FAO-WRB of this pedon is Vertic Gleysols, having gleying properties within 40 cm from mineral soil surface, reducing conditions in some parts of every sub-layer as well as an umbric horizon.

The Kpata pedon has ochric epipedon, argillic horizon and a moderate to high base saturation which classifies it Alfisol at the order level of Soil Taxonomy. This soil is further classified as Ustalf being Alfisol that have as ustic soil moisture regime. At the Great Group level of Soil Taxonomy, the soil is categorized as Paleustalf having in the lower one-half of the argillic horizon with Hue of 7.5YR and chroma of 5 an an abrupt textural change between the eluvial horizon and the upper boundary of the argillic horizon. At the Subgroup level, it is classified as Typic Paleustalf. The FAO/WRB equivalence is Haplic Lixisol.

Land/Soil Suitability Evaluation for Crops

Table 12 shows the suitability evaluation of the soils of the study area for the cultivation of rice, maize, cassava and oil palm. The soils were found to be highly suitable (S_1) for rice cultivation but moderately suitable for maize, cassava and oil palm cultivation, with average class scores of 62, 66 and 70, respectively.

The major limitations to the optimum production of maize, cassava and oil palm are fertility and wetness properties. The wetness properties include drainage, flood duration and ground water table, while among the fertility parameters, total nitrogen and exchangeable calcium and magnesium had low scores.

DISCUSSION

The soils studied occurred generally in the lowlands of Kogi East. They were normally inundated with water from the River Niger at certain periods of the year. The inundation results in high water table in the soils. The dark colour of the surface horizons of the soils, except Shintaku, reflects their relatively higher organic matter and C:N ratios compared to those of the subsurface soils (Table 10). The presence of redoximorphic features are possible indications of alternate wet and dry conditions that result in the reduction and subsequent release of iron and manganese compounds in the soils (Akpan-Idiok *et al*., 2013).

Apart from the single-grain soil from Shintaku, the soils had good structure that could support crop growth. The texture in the rooting depth of the soils was predominantly clay loam and loamy sand. The vertical and horizontal variations in the texture of the soils could be due to sedimentation as had been reported for similar soils by Ogban and Babalola (2009) and Hossain *et al.* (2011). The boundaries of the horizons depict nascent stage of profile development as had been reported by Akpan-Idiok (2002). The bulk density, total porosity and K_{sat} values of these soils are moderate. This may be as a result of the moderate to high contents of organic matter in these soils. Similar findings were documented by Akamigbo (2005) and Egbuchua and Ojobor (2011).

The soil reaction of the soils varied from strongly alkaline to slightly acid. The exchangeable acidity was low while the CEC values were generally high. The low values of phosphorus in the soils may be attributed not only to their acidic nature (Obalum *et al.,* 2012a; Obalum and Chibuike, 2017), but also to the absence of effectual P-fertility management practices. The high values of percentage base saturation of these soils are attributed to the specific cations in soil solution, as similarly reported on various floodplains (Igwe *et al*., 2004; Akpan-Idiok *et al*., 2006; Ogban and Babalola, 2009; Akpan-Idiok *et al*., 2013; Ukabiala *et al*., 2021).

The C:N ratio of the soils would have been facilitated by the vermic property which placed Ejule-Ojebe pedon as Vermaqualf. The many earthworms found in the pedon facilitate breakdown of organic matter which gives positive pool to mineralization. Movements of the earthworms and other insects in the soils might have enhanced porosity and increased hydraulic conductivity. The soil from Shintaku had a texture of sand and single-grain structure because of the very high (98%) sand content. The pedons had aquic moisture regime which positively influenced their suitability for rice cultivation. Similar suitability evaluation was reported by Ajala *et al.* (2021).

The soils from Ejule-Ojebe, Bagana and Kpata were highly suitable for rice. However, they are moderately suitable for maize, cassava and oil palm due to their fertility/wetness status. Despite the prevailing favourable climate and the moderate suitability of the soils for cassava, the long duration of wetness may cause tubers to rot thereby reducing yield. For oil palm that adapts readily to wet soil environments (Okolo *et al*., 2019),

Table 10: Chemical characteristics of the soils

Location	Depth (cm)	HD	pH		OC	TN	C:N	Av. P	Exchangeable cations				
									Ca^{2+}	Mg^{2+}	K^+	Na^+	H^+
			(H_2O)	(KCl)	(g kg^{-1})			(mg kg^{-1})	($cmol_c$ kg^{-1})				
Ejule-Ojebe	0-13	Ap1	5.2	4.3	51	8.80	6	5.60	13.80	3.20	0.29	0.17	1.80
	13-31	Ap2	5.7	4.3	10.7	1.40	8	18.65	9.20	8.00	0.06	0.04	1.00
	31-67	AC	5.9	4.4	4.5	0.40	11	3.73	14.80	4.60	0.07	0.03	1.40
	67-113	Cg1	6.5	5.1	4.1	0.70	6	1.87	12.20	5.40	0.07	0.03	0.80
	113-173	Cg2	6.2	4.3	5.0	0.40	13	10.26	17.80	2.00	0.07	0.03	1.00
	173-200	C	5.4	4.3	3.7	1.00	4	4.66	15.40	7.40	0.05	0.02	1.20
Shintaku	0-19	A	5.5	5.4	0.2	-	-	4.00	7.20	1.00	0.10	0.07	0.24
	19-35	C	6.5	5.5	0.2	-	-	5.00	4.20	1.20	0.08	0.06	0.16
Bagana	0-22	Ap1	4.8	4.0	23.4	2.90	8	1.87	12.00	1.80	0.14	0.09	1.60
	22-30	Ap2	5.0	4.1	3.1	0.70	4	1.87	4.40	2.40	0.05	0.02	1.00
	30-60	2Bw	5.5	4.7	15.6	3.30	5	6.53	13.60	3.20	0.10	0.07	1.00
Kpata	0-19	Ap1	6.5	5.2	3.0	0.20	15	3.00	9.00	0.80	0.13	0.11	0.08
	19-32	Ap2	6.0	5.0	1.0	0.10	10	13.00	5.40	1.00	0.09	0.07	0.16
	32-69	AB	5.8	4.8	0.6	0.10	6	13.00	5.80	1.40	0.09	0.08	0.40
	69-126	Bt1	6.3	5.5	0.8	0.10	8	5.00	11.20	4.20	0.14	0.11	0.16
	126-200	Bt2	7.3	6.0	0.4	-	0	9.00	12.60	4.40	0.15	0.12	0.20
Surface range			4.8-6.5	4.0-5.4	0.20-51.0	0.00-0.88	0-15	1.87-5.60	7.20-13.80	0.8-3.20	0.1-0.29	0.07-0.17	0.08-1.80
Subsurface range			5.0-7.3	4.1-6.0	0.20-15.6	0-0.33	0-13	1.87-18.65	4.20-17.80	1.00-8.00	0.05-0.15	0.02-0.12	0.16-1.40
Surface mean			5.6	4.7	21.4	0.34	7	4.00	10.50	1.80	0.18	0.11	0.93
Subsurface mean			6.0	4.9	4.70	0.08	6	8.07	10.61	3.87	0.08	0.05	0.72

HD - horizon designation; OC - organic carbon, TN - total nitrogen, C:N - carbon-nitrogen ratio, Av. P - available phosphorus; Ca^{2+}, Mg^{2+}, K^+, Na^+, H^+ - exchangeable calcium, magnesium, potassium, sodium and hydrogen, respectively

Table 10 cont'd

Location	Depth (cm)	HD	PBS	ESP	EA	CEC	ECEC	TEB
			(%)		($cmol_c$ kg^{-1})			
Ejule-Ojebe	0-13	Ap1	30	0.20	1.80	58.00	19.26	17.46
	13-31	Ap2	44	0.10	1.00	39.20	18.3	17.30
	31-67	AC	49	0.10	1.40	39.60	20.9	19.50
	67-113	Cg1	53	0.09	0.80	33.20	18.5	17.70
	113-173	Cg2	50	0.10	1.00	39.60	20.9	19.90
	173-200	C	53	0.04	1.20	43.20	24.07	22.87
Shintaku	0-19	A	98	0.82	0.24	8.51	8.61	8.37
	19-35	C	97	1.05	0.16	5.70	5.7	5.54
Bagana	0-22	Ap1	40	0.26	1.60	35.20	15.63	14.03
	22-30	Ap2	67	0.20	1.00	10.20	7.87	6.87
	30-60	2Bw	51	1.09	1.00	33.60	17.97	16.97
Kpata	0-19	Ap1	76	1.09	0.08	13.12	10.12	10.04
	19-32	Ap2	67	1.04	0.16	9.72	6.72	6.56
	32-69	AB	68	1.03	0.40	10.77	7.77	7.37
	69-126	Bt1	66	0.70	0.16	23.81	15.81	15.65
	126-200	Bt2	76	1.38	0.20	22.67	17.47	17.27
Surface range			30-98	0.20-1.00	0.08-1.80	8.51-58.0	8.61-19.2	8.37-17.4
Subsurface range			44-97	0.04-1.38	0.16-1.40	5.70-43.20	5.70-24.07	5.54-22.87
Surface mean			61	0.61	0.93	28.70	13.59	12.48
Subsurface mean			62	0.59	0.71	25.94	15.13	14.46

HD - horizon designation; EA - exchangeable acidity, CEC - cation exchange capacity, ECEC - effective cation exchange capacity, TEB - total exchangeable bases, PBS - percentage base saturation, ESP - exchangeable sodium percentage

Table 11: Classification of the soils

Location	USDA				FAO-WRB
	Order	Suborder	Great group	Subgroup	
Ejule-Ojebe	Inceptisol	Aquept	Vermaquept	Typic Vermaquept	GleyicAlisol
Shintaku	Entisol	Aquent	Psammaquent	Typic Psammaquent	Fluvic Arenosol
Bagana	Inceptisol	Aquept	Endoaquept	Vertic Endoaquept	Vertic Gleysol
Kpata	Alfisol	Ustalf	Paleustalf	Typic Paleustalf	Haplic Lixisol

fertility may be the more important factor. On the other hand, Shintaku soil, with very high homogeneous sand content (Figure 2b), > 50% porosity and fairly low bulk density, may not be suitable for any of the crops. This situation caused high K_{sat} (2.72-2.91 cm h^{-1}; Table 9). Also, there might have been little time for N to equilibrate in the highly leached Shintaku soil, as evident in the low total N and C:N ratio in the soil (Table 10). Also, the very high sand content of the soil might have contributed to its low CEC (Obalum *et al.,* 2013).

Soil Management Strategies

The major limiting factors of the soils were low levels of total N, Ca^{2+} and Mg^{2+} Akpan-Idiok *et al.* (2013) reported similar levels of these nutrients in some soils at Kogi East. The high moisture status of the soils might have predisposed them to intense leaching, rapid rate of organic matter mineralization and advanced stage of weathering of their parent materials (Ojanuga *et al.*, 1981). The fertility limitations would affect management of the soils as noted by Enwezor *et al.* (1989).

Table 12: Suitability evaluation of the soils for rice, maize, cassava and oil palm production

Land characteristics/units		Rice	Maize	Cassava	Oil palm
Climate (c)	Annual rainfall (mm)	S_2 (90)	S_1 (90)	S_1 (95)	S_1 (90)
	Minimum temperature (°C)	S_2 (95)	S_1 (95)	S_1 (80)	S_1 (95)
	Relative humidity (%)	S_2 (85)	S_1 (80)	S_1 (90)	S_1 (80)
Soil Physical characteristics (*s*)	Soil depth (cm)	S_1 (100)	S_3 (50)	S_1 (100)	S_1 (100)
	Clay (%)	S_1 (90)	S_1 (90)	S_1 (90)	S_2 (80)
	Texture	S_2 (80)	S_1 (80)	S_1 (90)	S_1 (80)
Wetness (*w*)	Drainage	S_1 (100)	N_2 (15)	N_2 (10)	N_2 (15)
	F.D. (months)	S_1 (95)	N_2 (15)	N_2 (10)	N_1 (30)
	G.W.T. (cm)	S_2 (90)	N_2 (15)	N_2 (15)	N_1 (30)
Topography (*t*)	Slope (%)	S_1 (99)	S_2 (70)	S_1 (100)	S_1 (100)
Fertility (*f*)	pH-H_2O	S_1 (80)	S_1 (80)	S_1 (80)	S_2 (80)
	Total nitrogen (g kg^{-1})	S_1 (80)	S_3 (50)	S_3 (50)	S_3 (50)
	Organic carbon (g kg^{-1})	S_2 (60)	S_2 (80)	S_2 (80	S_2 (70)
	Available phosphorus (mg kg^{-1})	S_2 (70)	S_2 (70)	S_2 (70)	S_2 (70)
	Exchangeable Ca ($cmol_c$ kg^{-1})	S_1 (90)	S_3 (40)	S_3 (40)	S_2 (70)
	Exchangeable Mg ($cmol_c$ kg^{-1})	S_1 (80)	S_3 (40)	S_3 (40)	S_1 (86)
	Exchangeable K ($cmol_c$ kg^{-1})	S_1 (80)	S_2 (60)	S_2 (60)	S_2 (70)
	CEC ($cmol_c$ kg^{-1})	S_1 (100)	S_1 (100)	S_1 (100)	S_1 (85)
Toxicity (*t*)	Active-Fe (%)	S_1 (90)	S_3 (50)	S_3 (50)	S_3 (50)
	Suitability	S_1 (87)	S_2fw (62)	S_2fw (66)	S_2fw (70)

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, *s* - soil physical characteristics, Ca - calcium, Mg - magnesium, K - potassium, Fe - iron, CEC - cation exchange capacity;
F.D. - flood duration, G.W.T. - ground water table

Liming is an important management practice used to control soil acidity in the study area (Brady and Weil, 2002). Within a pH range of 5.5 to 6.5, many tropical crops thrive well as most nutrients are available in ionic forms in soil solution to make their absorption relatively easy (Akpan-Idiok *et al*., 2013). Reducing soil acidity and improving crop yields in lowland soils entails liming the plough layer using such materials as limestone (Ukabiala, 2012) and wood ash and/or rice-husk ash (Nwite *et al*., 2011; Nnadi *et al*., 2021). Liming the soils to the subsoil may further improve their productivity. Soares *et al.* (1975) reported that deeper incorporation of lime doubled root growth per unit soil volume in the 15-30 cm depth resulting in more moisture and nutrient absorption at that depth as well as positive response in maize yield on Brazilian Oxisols. In this regard, crops that are tolerant to acidity may be considered for cultivation on these soils. Such crops include cassava, cowpea, banana, rice, pineapple, guava, mango and oil palm (Sanchez and Salinas, 1981).

As a general principle, organic matter needs to be increased in the soil in order to sustain soil health under the various land uses. Organic matter promotes the stability of soil aggregates thereby improving structure. Also, it improves soil consistence and microbial properties (Kpamwang, 2008). Organic matter supplies nutrients like N, P and S as well as micronutrients such as B, Cu, Mo, Zn, Mn and Cl (Brady and Weil, 2002). Organic matter may also improve CEC and increase soil pH and buffering capacity (Ukabiala, 2012). Sources of organic matter include farmyard manure, crop residue, mulch and green leaf manures (Akpan-Idiok *et al*., 2013).

The slash and mulch system may be a suitable alternative to slash and burn which is a predominant practice in most parts of Kogi East (Thomich *et al.* 1998). If returned to the soil, the mulch materials and crop residues affect soil properties and processes (Lal, 1995). Mulches including crop residues generally enhance nutrients cycling, decrease nutrient losses, improve nutrient use efficiency, increase soil organic matter content, enhance soil structure, and influence soil moisture and temperature regimes (Effiong and Akpan, 2013). Above all, crop residues have no soil health risk but increase soil biodiversity of beneficial microbes and serve as good food for earth worms (Effiong and Akpan, 2013).

The soils are generally suitable for paddy rice production based on their properties. Where gleization occurs, such as Ejule-Ojebe, drainage must first be done if crops other than rice have to cultivated. Making of big mounds may also be used to improve drainage for such crops. Furthermore, rice can be successfully grown in the not-too-good-for-rice Shinkatu soil with the *sawah* ecotechnology (Wakatsuki *et al*., 2011a, b; Obalum *et al.,* 2012b); however, the increases in soil aggregate stability due to improved organic matter status may not be expected to be evident in this soil with this ecotechnology (Obalum *et al.,* 2011).

CONCLUSION

This research aimed at characterization and classification of four soils in the floodplains of River Niger in the Kogi East District of Nigeria. The seasonal inundation of water into these land areas gave rise to variations in the various morphological, physical and chemical characteristics of the soils. The soil colour was dominantly brownish and grey as a result of hydromorphism as indicated by the presence of mottles. The dominant loamy textures of the soils influenced the formation of various grades of sub-angular blocky structure. The presence of cracks and earthworms in the soil profiles was important in the classification of the pedons. The moderate to high organic carbon of the soils positively influenced the bulk density and permeability. The pH values could be tolerable to the crops evaluated. The soils were classified to various subgroups of Alfisols, Inceptisols and Entisols. The findings from suitability evaluation showed that the soils are highly suitable for rice, and moderately suitable for maize, cassava and oil palm production.

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