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

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**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 pedogenetic 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 respectively. 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.

**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 Obawum, 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 km² (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 36°C (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 Dulce (*Carissa edulis*), African Rosewood (*Pterocarpus erinaceus*), Amboina wood (*Pterocarpus indicus*), Persimmon (*Diospyros virginiana*), Venus’s Flytrap (*Dionaea muscipula*), 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 babylonica*) and ferns (*Filicinophyta* spp.) (White, 1983).

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 (SiO₂) 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 Itohe (19a1), Ugwolawo (19a2), Ajegwu (19a3) and Obakwume (19a4). 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 cm³ 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.
Soil porosity was calculated with the values of the bulk density using the method outlined by Vomicil (1965) and Brady and Weil (2002):

\[
\text{Total porosity} (\%) = (1 - \frac{\text{Bulk Density}}{\text{Particle Density}}) \times 100
\]

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 \(\Delta H\) 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).

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\(_4\)OAc (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):

\[
\text{ESP} = \frac{\text{Exchangeable Sodium}}{\text{Cation Exchange Capacity}} \times 100
\]

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\(_4\)OAc, 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).

**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:

\[
\text{Soil bulk density} = \frac{\text{oven dry weight of soil}}{\text{volume of soil}}
\]
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 signifi-
cance. 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:

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

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 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 2: Land/crop requirements for rainfed rice cultivation

| Land qualities | Land suitability | Unit | $S_1$ (100-85) | $S_2$ (84-60) | $S_3$ (59-40) | $N_1$ (39-20) | $N_2$ (19-0) |
|----------------|------------------|------|---------------|---------------|---------------|---------------|---------------|
| Climate (c)    |                  | mm   | > 1400        | 1200-1400     | 950-1100      | 850-900       | < 850         |
| Soil physical  |                  | cm   | > 20          | 10-20         | 5-10          | < 5           | any           |
| characteristics |                  | %    | 45-25         | 25-15         | 15-5          | < 5           | any           |
| Wetness (w)    |                  |      |               |               |               |               |               |
| Texture        |                  |      |               |               |               |               |               |
| Drainage       |                  |      |               |               |               |               |               |
| F.D.           |                  | months | > 4          | 3-4          | 2-3           | < 2           | any           |
| G.W.T.         |                  | cm   | 0-15          | 15-30         | 30-60         | > 60          | any           |
| pH (H2O)       |                  |      | 5.5-7.5       | 5.2-5.5       | $\leq 5.2, \geq 8.2$ | $\leq 5.2, \geq 8.2$ | 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 kg$^{-1}$ | 10-15       | 5-10         | 1-5           | < 1, > 15     | any           |
| Exchangeable Mg|                  | cmol kg$^{-1}$ | 2-5        | 1-2          | 1-1, > 5      | < 1, > 5      | any           |
| Exchangeable K |                  | cmol kg$^{-1}$ | > 0.2      | 0.1-0.2      | < 0.1         | < 0.1         | any           |
| CEC (soil)     |                  | cmol 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).
RESULTS

General Characteristics of the Research Area

The soils of the research area were mainly derived from fluvioluvial sand deposits (Plate 1) and sandstones. 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. However, silty clay was obtained in the subsurface soils of Ugwolawo (19a). Most of the soil structures were single-grained and subangular blocky as observed in 19a 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 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\(^{-1}\), 32.82% and 44.19 cm h\(^{-1}\) respectively, while respective mean value of 1.79 g cm\(^{-1}\), 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 H₂O 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 7.3 and 2.6 mg kg⁻¹ respectively. The exchangeable bases which irregularly decreased with depths had ranges of 1.00 to 10.6 cmol, kg⁻¹, 0.20 to 5.50 cmol, kg⁻¹, 0.08 to 0.14 cmol, kg⁻¹ and 0.04 to 0.50 cmol, kg⁻¹ at the surface soils; 0.60 to 6.60 cmol, kg⁻¹, 0.20 to 4.20 cmol,kg⁻¹, 0.03 to 0.50 cmol, kg⁻¹ and 0.02 to 0.05 cmol, 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, kg⁻¹ than in the subsurface soils with a mean value of 6.39 cmol 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/ Location | Horizon | Colour | Texture | Structure | Consistence | Boundary | Fines | Roots | Other |
|-----------------|---------|--------|---------|-----------|-------------|----------|-------|-------|-------|
| 19a1 Obake | 0-15 | Ap1 | 10YR/4 | sl c | nsp | 1g | lw | mce | mmeco |
| 07°24'29.7"N | Ap2 | 10YR5/2 | sl s | nsp | 1 | lw | c | c | c |
| 006°49'00.3"E | AB | 5Y7/2 | sl s | nsp | 1 | c | c | c | c |
| 32-64 | BC1 | 5Y8/2 | sl s | nsp | 1 | c | c | c | c |
| 64-101 | BC2 | 7.5Y8/2 | sl s | nsp | 1 | c | c | c | c |
| 101-160 | BC3 | 7.5Y8/3 | sl s | nsp | 1 | c | c | c | c |
| 160-219 | BC4 | 7.5Y8/4 | sl s | nsp | 1 | c | c | c | c |
| 19a2 Ugwa | 0-2 | Ap1 | 10YR4/1 | sl c | nsp | 1g | lw | mce | mmeco |
| 07°13'26.2"N | Ap2 | 10YR4/4 | sl s | nsp | 1 | lw | c | c | c |
| 006°54'39.3"E | AB | 10R4/8 | sl s | nsp | 1 | lw | c | c | c |
| 72-120 | B1 | 2.5YR4/8 | sl s | nsp | 1 | lw | c | c | c |
| 120-167 | B2 | 2.5YR5/8 | sl s | nsp | 1 | lw | c | c | c |
| 167-202 | B3 | 2.5YR5/8 | sl s | nsp | 1 | lw | c | c | c |
| 19a3 Ajegu | 0-2 | Ap | 7.5Y5/1 | sl c | 145 | nsp | 1 | lw | c | c | c |
| 07°23'51.2"N | Ap2 | 7.5Y5/4 | sl c | 145 | nsp | 1 | lw | c | c | c |
| 006°47'11.0"E | A | 5YR5/4 | cl s | 24c | nsp | 1 | lw | c | c | c |
| 60-110 | Bc | 2.5Y6/4 | cl s | 25c | nsp | 1 | lw | c | c | c |
| 110-152 | C1 | 2.5Y6/3 | cl s | 25c | nsp | 1 | lw | c | c | c |
| 152-180 | C2 | 2.5Y7/3 | cl s | 25c | nsp | 1 | lw | c | c | c |
| 19a4 Obake | 0-15 | Ap | 2.5YR3/2 | sl s | 25c | nsp | 1 | lw | c | c | c |
| 07°55'35.7"N | Ap2 | 2.5YR4/4 | sl s | 25c | nsp | 1 | lw | c | c | c |
| 15-40 | Bw1 | 2.5YR3/4 | sl s | 25c | nsp | 1 | lw | c | c | c |
| 40-101 | Bw2 | 2.5YR3/4 | sl s | 25c | nsp | 1 | lw | c | c | c |
| 101-197 | Bw3 | 2.5YR5/4 | sl s | 25c | nsp | 1 | lw | c | c | c |

19a refers to soil mapping unit while 19a1, 19a2, 19a3, and 19a4 are the pedons in the unit.

Table 5: Textual characteristics of the soils research area

| Pedon/ Location | Horizon | C.sand | F. Sand | Silt | Clay | Silt:Clay | Texture |
|-----------------|---------|--------|---------|------|------|----------|---------|
| 19a1 Obake | 0-15 | Ap1 | 570 | 210 | 130 | 1.44 | sl |
| 15-32 | Ap2 | 550 | 310 | 50 | 0.56 | ls |
| 32-64 | AB | 610 | 270 | 30 | 0.33 | ls |
| 64-101 | BC1 | 550 | 310 | 50 | 0.56 | ls |
| 101-160 | BC2 | 540 | 340 | 30 | 0.33 | ls |
| 160-219 | BC3 | 540 | 340 | 30 | 0.33 | ls |
| 19a2 Ugwa | 0-29 | Ap1 | 430 | 410 | 70 | 0.76 | ls |
| 29-72 | Ap2 | 540 | 340 | 30 | 0.33 | ls |
| 72-120 | AB | 350 | 490 | 50 | 0.45 | ls |
| 120-167 | B1 | 350 | 470 | 70 | 0.64 | ls |
| 167-202 | B2 | 420 | 400 | 50 | 0.38 | sl |
| 19a3 Ajegu | 0-24 | Ap | 700 | 160 | 70 | 1.00 | sl |
| 24-60 | A | 600 | 220 | 110 | 1.57 | ls |
| 60-110 | BC | 530 | 350 | 50 | 0.71 | ls |
| 110-152 | C1 | 620 | 280 | 30 | 0.43 | s |
| 152-180 | C2 | 510 | 290 | 130 | 1.86 | ls |
| 19a4 Obake | 0-15 | Ap | 70 | 410 | 230 | 0.79 | scl |
| 15-40 | ABw | 90 | 430 | 190 | 0.66 | scl |
| 40-101 | Bw1 | 50 | 470 | 170 | 0.35 | scl |
| 101-197 | Bw2 | 40 | 480 | 150 | 0.45 | scl |

Surface range: 70-700 | 160-410 | 70-230 | 70-290 | 0.76-1.44 | ls-scl |
Subsurface range: 40-620 | 220-490 | 30-190 | 70-330 | 0.33-1.86 | ls-scl |
Surface mean: 423 | 293 | 133 | 150 | 0.10 | sl |
Subsurface mean: 419 | 261 | 80 | 139 | 0.63 | ls |

C. sand - coarse sand, F. sand - fine sand, sl - sandy loam, Is - loamy sand, s - sand, scl - sandy clay loam

*refers to soil mapping unit while 19a1, 19a2, 19a3, and 19a4 are the pedons in the unit.
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\(^{-1}\)) |
|---------|----------|------------|-------------------------------|--------------------|-----------------------------|
| 19a1    | Itole    | 0-25       | 1.87                          | 29.43              | 40.48                       |
|         |          | 25-50      | 1.81                          | 31.69              | 151.79                      |
|         |          | 50-75      | 1.72                          | 35.09              | 101.19                      |
| 19a2    | Ugwolavo | 0-25       | 1.71                          | 35.47              | 26.31                       |
|         |          | 25-50      | 1.87                          | 29.43              | 62.74                       |
|         |          | 50-75      | 1.75                          | 33.96              | 23.27                       |
| 19a3    | 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                      |
| 19a4    | 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                       |

\(^{1}\)19a refers to soil mapping unit while 19a, 19a2, 19a3, and 19a4 are the pedons in the unit. \(K_{sat}\) - saturated hydraulic conductivity

Figure 5: Profile sand and clay distribution in 19a, 19a2, 19a3 and 19a4

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) pedon, redox concentration as shown by mottle colour of 2.5Y7/8 (faint yellow) was observed in the subsurface layer (152-180 cm) (Table 4), indicating evidence of ground water fluctuations and qualifying it as Aquents at the suborder level. The pedon is taken to the Great Group Endoaquents due to the endosaturation. According to the USDA Soil Taxonomy, this pedon is classified as Dystric Endoaquents since the base saturation (by NH\(_4\)OAc) was less than 50% within 100 cm soil depth. The FAO-WRB equivalence of this pedon 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. The 19a1, 19a2, 19a3 and 19a4 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 (\(S_{1}\)) 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 (\(S_{5}\)) for rainfed maize cultivation. Potentially, they are also marginally suitable (\(S_{5}\)).
### Table 7: Chemical characteristics of the soils of the research area

| Pedon     | Location | Depth (cm) | Horizon | Designation | pH | OC (g kg⁻¹) | TN (g kg⁻¹) | C:N | AvP | Exchangeable cations | EA (mol kg⁻¹) | CEC | ECEC | TEB | PBS | ESP | ASP (%) |
|-----------|----------|------------|---------|-------------|----|-------------|-------------|-----|-----|---------------------|--------------|------|------|-----|-----|-----|--------|
| 19a       | Ife       | 0-15       | Ap1     | 6.2          | 5.5 | 9.60        | 0.40        | 24  | 1.87 | Ca²⁺               | 0.60         | 0.40 | 1.0  | 7.80| 0.64| 1   |
|           |           | 15-52      | Ap2     | 6.3          | 5.3 | 4.20        | 0.40        | 11  | 4.66 | Mg²⁺               | 0.60         | 0.40 | 1.20 | 6.60| 0.30| 0.4 |
|           |           | 32-64      | AB      | 5.7          | 4.6 | 6.20        | 0.30        | 21  | 2.80 | K⁺                 | 0.60         | 0.40 | 0.8  | 5.60| 0.54| 6   |
|           |           | 64-101     | BC1     | 5.7          | 4.6 | 1.30        | 0.30        | 4   | 1.87 | Na⁺                | 0.80         | 0.40 | 0.4  | 5.40| 0.47| 4.34|
|           |           | 101-160    | BC2     | 6.5          | 5.8 | 1.70        | 0.40        | 4   | 1.87 | H⁺                 | 0.80         | 0.40 | 0.8  | 5.40| 0.93| 15  |
|           |           | 160-219    | BC3     | 6.9          | 5.9 | 1.70        | 0.90        | 2   | 1.87 | Al³⁺               | 0.60         | 0.60 | 1.4  | 5.40| 0.95| 1.35|
| 19b       | Ugbwolawo | 0-29       | Ap1     | 5.9          | 5.1 | 9.00        | 1.50        | 6   | 1.87 | Inceptisols Ustepts | 0.60         | 0.40 | 0.4  | 7.40| 0.76| 12  |
|           |           | 29-72      | Ap2     | 5.5          | 4.0 | 4.50        | 0.40        | 11  | 7.46 | Dystrusteps         | 0.50         | 0.30 | 0.8  | 7.00| 0.34| 11  |
|           |           | 72-202     | B1      | 4.9          | 4.0 | 2.10        | 0.70        | 3   | 3.73 | Typic Dystrusteps   | 0.40         | 0.20 | 0.1  | 7.00| 0.29| 7   |
|           |           | 120-167    | B2      | 4.9          | 4.0 | 3.30        | 0.60        | 6   | 3.73 | Dystric Fluvisols (Arenic) | 0.60         | 0.40 | 0.8  | 7.00| 0.30| 7   |
| 19a       | Ajegwu    | 0-24       | Ap      | 6.2          | 5.3 | 1.10        | 0.90        | 1   | 3.73 | Dystric Fluvisols (Arenic) | 0.60         | 0.40 | 0.8  | 7.00| 0.30| 7   |
|           |           | 24-60      | A       | 5.5          | 4.3 | 2.50        | 0.40        | 6   | 2.80 | Aquepts            | 0.60         | 0.40 | 0.8  | 6.60| 0.40| 1   |
|           |           | 60-110     | BC      | 5.2          | 4.0 | 2.90        | 0.40        | 7   | 4.66 | Ustepts            | 0.60         | 0.40 | 0.8  | 6.60| 0.40| 1   |
|           |           | 110-152    | C1      | 5.9          | 4.6 | 2.10        | 0.40        | 5   | 3.73 | Dystrusteps         | 0.60         | 0.40 | 0.8  | 6.60| 0.40| 1   |
|           |           | 152-180    | C2      | 5.8          | 4.2 | 1.60        | 0.30        | 5   | 9.33 | Dystrusteps         | 0.60         | 0.40 | 0.8  | 7.00| 0.30| 7   |
| 19a       | Obakwume  | 0-15       | Ap      | 5.9          | 4.9 | 22.60       | 0.40        | 56  | 1.87 | Inceptisols Ustepts | 0.80         | 0.40 | 1.0  | 7.00| 0.64| 1   |
|           |           | 15-40      | ABw     | 4.6          | 3.6 | 5.80        | 0.90        | 6   | 2.80 | Dystrusteps         | 0.60         | 0.40 | 1.0  | 7.00| 0.64| 1   |
|           |           | 40-101     | Bw1     | 4.5          | 3.6 | 4.10        | 0.70        | 6   | 1.87 | Dystrusteps         | 0.60         | 0.40 | 1.0  | 7.00| 0.64| 1   |
|           |           | 101-197    | Bw2     | 4.4          | 3.4 | 5.00        | 1.10        | 5   | 9.33 | Dystrusteps         | 0.60         | 0.40 | 1.0  | 7.00| 0.64| 1   |
|           |           | 59-94      | 1.10-1.40 | 1-2      | 1.87 | 1.00-0.20-0.08-0.40 | 0.00-0.04-0.00 | 4-0.4-7.40 | 3.32 | 2.32-3.2-0.29 | 1-12-1.6 |
|           |           | Surface range | 6.2  | 5.5     | 22.60-1.50 | 56  | 3.73 | 10.6-5.60 | 0.14 | 0.08 | 0.60 | 0.40 | 1.0 | 27.20 | 17.42 | 16.42 | 60 | 0.29 |
|           |           | Subsurface range | 4.4-3.4 | 1.30-0.30-0-2 | 0.93-0.60-0.20-0.12 | 0.02-0.20-0.20-0.4-5 | 0.4-5.4-1.95 | 1.25-18-0.08-6-34 | 56.5 | 6.40 |
|           |           | Surface mean | 6.9  | 5.9       | 6.0-1.10 | 21  | 7.46 | 6.60-4.20 | 0.50 | 0.05 | 3.60 | 5.60 | 0.8 | 24.0 | 16.67 | 10.49 | 91 | 0.93 |
|           |           | 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 |

- is no significant value, OC - organic carbon, TN - total nitrogen, C:N - carbon-nitrogen ratio, AvP - available phosphorus, Ca²⁺ - exchangeable calcium, Mg²⁺ - exchangeable magnesium, K⁺ - exchangeable potassium, Na⁺ - exchangeable sodium, Al³⁺ - 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 Order | Suborder | USDA Group | Subgroup | FAO-WRB |
|---------|----------|------------|----------|------------|----------|---------|
| 19a     | Ife      | Inceptisols | Ustepts  | Dystrusteps | Typic Dysdrusteps | Dystric Fluvisols (Arenic) |
| 19a     | Ugbwolawo| Inceptisols | Ustepts  | Dysstrusteps | Typic Dysdrusteps | Dystric Fluvisols (Arenic) |
| 19a     | Ajegwu   | Inceptisols | Aquuets  | Endoauquets | Dystric Endoauquets | Dystric Fluvisols (Arenic) |
| 19a     | Obakwume | Inceptisols | Ustepts  | Dysstrusteps | Typic Dysdrusteps | 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; (70)                |
| Soil physical characteristics (s) |                    |
| Soil depth (cm)           | S; (90)                |
| Clay (%)                  | S; (40)                |
| Texture                   | S; (50)                |
| Wetness (w)               |                        |
| Drainage                  | N; (10)                |
| F.D. (months)             | S; (40)                |
| G.W.T. (cm)               | N; (15)                |
| Fertility status (f)      |                        |
| pH H₂O                    |                        |
| Total nitrogen (g kg⁻¹)   | S; (50)                |
| Organic carbon (g kg⁻¹)   | S; (70)                |
| Available phosphorus (mg kg⁻¹) | N; (30)              |
| Exchangeable Ca (cmol kg⁻¹) | S; (50)           |
| Exchangeable Mg (cmol kg⁻¹) | S; (50)           |
| Exchangeable K (cmol kg⁻¹) | S; (50)                |
| CEC (cmol kg⁻¹)           | S; (50)                |

F.D. - flood duration, G.W.T. - ground water table, Ca - calcium, Mg - magnesium, K - potassium, CEC - cation exchange capacity, S₁ - highly suitable, S₂ - moderately suitable, S₃ - marginally suitable, N₁ - not currently suitable, N₂ - 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; (90)                |
| Mean annual temperature (°C) | S; (95)      |
| Relative humidity (%) | S; (80)         |
| Topography (f)      |                        |
| Slope (%)           | S; (70)                |
| Wetness (w)         | S; (80)                |
| Drainage            |                        |
| Texture             | S; (70)                |
| Depth (cm)          | S; (100)               |
| Fertility (f)       |                        |
| CEC (cmol kg⁻¹)     | S; (80)                |
| Base saturation (%)  | S; (60)                |
| Organic carbon (g kg⁻¹) | S; (60)           |
| pH H₂O               | S; (50)                |
| Total nitrogen (g kg⁻¹) | S; (50)            |
| Available phosphorus (mg kg⁻¹) | N; (30)       |
| Exchangeable K (cmol kg⁻¹) | S; (40)       |
| Exchangeable Ca (cmol kg⁻¹) | S; (60)       |
| Exchangeable Mg (cmol kg⁻¹) | S; (60)       |

CEC - cation exchange capacity, K - potassium, Ca - calcium, Mg - magnesium, S₁ - highly suitable, S₂ - moderately suitable, S₃ - marginally suitable, N₁ - not currently suitable, N₂ - permanently not suitable

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

|          | Rice | Maize |
|----------|------|-------|
| CC       | N₁f  | N₁f   |
| CP       | N₁w  | S; f  |
| PC       | N₁, (21) | S; (44) |
| PP       | N₁, (22) | S; (54) |

CC - conventional (current), CP - conventional (potential), PC - parametric (current), PP - parametric (potential), S₁ - highly suitable, S₂ - moderately suitable, S₃ - marginally suitable, N₁ - not currently suitable, N₂ - 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 soils. The low clay content of the soils of this unit resulted in higher bulk density and lower total porosity and high Ksat values. Sandy soils generally have higher Ksat 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 Ksat, 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 with a CEC range of 8.67-16.42 cmol kg⁻¹ and higher clay content with evidence of increase down the profile. Similar soils occurred in some inland depression soils of southeastern 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 to 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 (Igwé 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 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; Ndzesha 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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