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Characterization and Suitability Evaluation of Upland Soils for Maize, Cassava and Oil Palm Production in Kogi East, Nigeria

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Abstract

This research aimed at characterization and suitability evaluation of upland soils in Kogi East for maize, cassava, and oil palm production with the specific objective of optimizing production as ensuring food security in the region through adequate data generation. The survey adopted a free technique method, using four dug soil profiles denoted as $22a_1$, $22a_2$, $22a_3$ and $22a_4$. The soil profiles and the environs were adequately characterized following the standard of United States Department of Agriculture (USDA). Among the parameters used for evaluation are soil texture, structure, bulk density, pH, organic carbon, cation exchange capacity, base saturation, and others. The results showed that Hues of 2.5 YR and 7.5 YR dominate the surface and subsurface soils. The coarse sand, fine sand, silt, and clay fractions ranged from 350 to 560 g kg^{-1}, 200 to 390 g kg^{-1}, 110 to 130 g kg^{-1} and 90 to 130 g kg^{-1} with mean values of 468, 295, 120 and 110 at the surface soils, respectively. Among the list of the chemical characteristics, the pH (H_2O) was higher at the surface soils, having a mean value of 5.4, than at the subsurface soils with a mean value of 5.6 while the percentage base saturation ranged from 25 to 63% and 13 to 70% with mean values of 42% and 29% at the surface and subsurface soils, respectively. By qualitative approach, the soils are currently not suitable for maize, cassava and oil palm owning to fertility limitations.

Keywords

Characterization, Suitability, Maize, Cassava, Oil palm, Upland soils, Kogi

Introduction

The natural resources like soil and water and associated climatic features deeply influence the cropping pattern and crop productivity in specified areas. Each plant species requires definite soil and site conditions for its optimum growth. Since the availability of both water and plant nutrients is largely controlled by the physico-chemical properties as well as the microenvironment of the soils, therefore the success and failure of cropping any plant species in a particular area is largely determined by these factors [1]. Land evaluation identifies the most limiting land qualities and provides a good basis for advising farmers for optimum production [2]. Dent and young [3] stated that land evaluation is a prediction process of land potential for various alternative uses, and it is one important component in the process of land-use planning. Land evaluation has provided the needed solution to the issue of making soil survey information useful to farmers and other land users [4]. The basic principle of land evaluation is the identification of the characteristics of the soil in a given landscape, identification of the soil requirement for the land utilization type of interest and matching the two to establish the extent to which they match [5]. Soil suitability evaluation according to Ande [6] involves characterizing the soils in a given area for specific land use type. According to Akamigbo [7], land suitability is the fitness of a given type of land for a defined use, which may be considered in its present condition or after improvements. In order view, the suitability of a given piece of land is its natural ability to support a specific purpose [8].

Maize is a cereal crop that is grown widely throughout the world in a range of agro-ecological environments. In the sub-Saharan Africa, it is one of the most important cereals. It is a staple food in Nigeria and accounts for about 40% of daily calories with per capita consumption of 98 kg [9]. It

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thrives best in a warm climate [10]. Although maize is found to grow throughout Nigeria under a wide range of agro-climatic conditions, three broad agro-ecological zones can be distinguished for maize production. The production of cassava in Nigeria has been estimated to be approximately 34 million tonnes (FAO, 2004) [11]. Kogi state is one of the largest producers of cassava in Nigeria with a production figure of 2.854 million metric tonnes [12]. Cassava grows well under a wide range of soils but prefers porous, friable soils with some organic matter content and depth of 30-40 cm [10]. Oil palm is a single stemmed plant which attains the height of 10 to 18 meters tall with different varieties. Palm oil is currently the second largest traded edible oil and accounts for about one quarter of the world's fats and oil supply [13]. Unfavourable climate and soil water levels could restrict adequate growing of oil palms in tropical soil orders such as *Ultisols*, *Oxisols* and *Inceptisols* [14]. Nutrient requirements of oil palms are higher than what can be sustained by any soil for economical yields [14]. The goal of any sustainable agricultural venture is to maximize profit through optimum production. The achievement of this objective is supported by objective and careful study of the medium of production (soil) through characterization, as well as evaluating individual pedon to ascertain their status which is matched with the actual crop requirements. This will be achieved through the suitability evaluation. Due to dearth of adequate soil information to achieve this agricultural goal, a need arises to characterize and evaluate the upland soils in Kogi state of Nigeria for the production of maize, cassava and oil palm.

Materials and Methods

Study area

The study was conducted in the eastern zone of Kogi State, Nigeria. It lies within 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 the Niger River, north by the river Benue, east by Benue state and south by Anambra state (Figure 1). There are two distinct seasons in the study which are rainy season which lasts from April to October and the dry season observed between November and March [15]. A part of the dry season is very dusty and cold as a result of the north- easterly winds which bring about the harmattan. This zone has an annual rainfall ranging from 1100 to 1300 mm with a mean of 1200 mm per annum with average monthly temperature varies between 17 and 36°C [16]. The highest temperature (36°C) has been recorded during the dry season while the mean relative humidity is lowest during the dry season and highest during the rainy season of the years, giving 15 and 67% respectively [17].

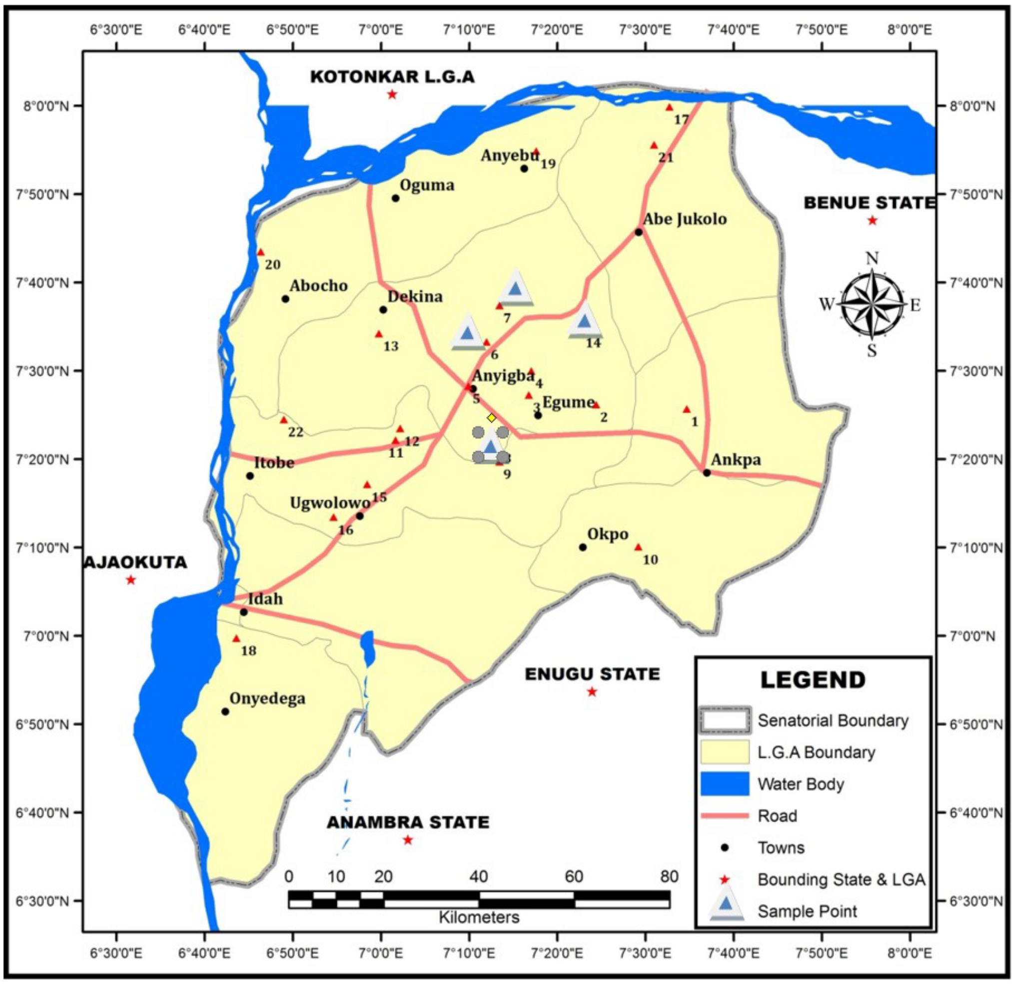

Figure 1: A map of Kogi East showing sample points.

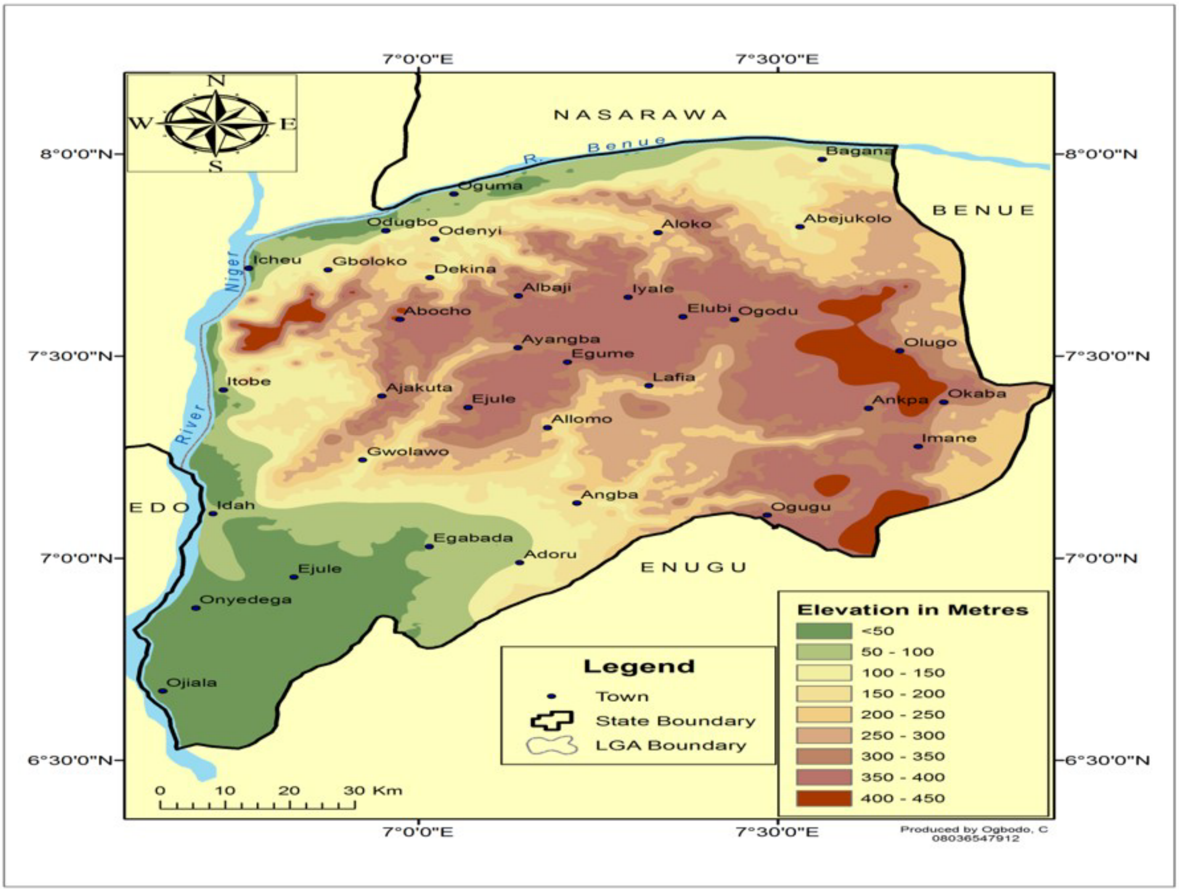

Figure 2: A topographical map of Kogi East.

Field work

A topographical map of Kogi east (Figure 2) was used as base map for the study adopting free soil survey technique. Four soil profiles denoted as $22a_1$, $22a_2$, $22a_3$ and $22a_4$ were sited and dug with the aid of digger and spade for the study. These pedons occur within Dekina Local Government Area in Kogi East. The dimensions of the profile pits were 200 × 150 × 200 cm for length, breadth and depth depending on respectively the depth to impenetrable layers. 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 [18]. Abney level equipment was used to determine the slope angles on the sites of the profile pits. Core samples were taken with core samplers of 99.6 cm^3 by volume from the pits at the surface and subsurface horizons. 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 Soil Science Laboratory for physicochemical analyses.

Laboratory Analyses

The various physical and chemical analyses through specific procedures in the laboratory were carried out. The soil samples collected from the field were air-dried in the laboratory and later sieved with a sieve of 2 mm mesh size. The particle size distribution (PSD) < 2 mm was determined using Bouyoucos [19] Hydrometer method. Sodium hydroxide was used as dispersant. The textural classes were read out from the USDA soil textural triangle, while Bulk density was determined by the core and excavation methods described by Landon [20].

Soil bulk density = oven dry weight of soil/volume of soil (Equation 1)

Soil porosity was calculated with the values of the bulk density using the method outlined in Vomicil [21] and Brady and Weil [22].

Soil total porosity (%) = 100 - (bulk density/Particle density x 100) (Equation 2)

The Soil Saturated Hydraulic Conductivity (K_{sat}) was determined based on Klute and Dirksen [23] method and calculated by using the transposed Darcy's equation for vertical flows of liquids.

$K_{sat} = (Q/At)/L/DH)$ (Equation 3)

Where, K_{sat} is the saturated hydraulic conductivity (cm h^{-1}), Q is steady-state volume of water outflow from the entire soil column (cm^3), A is the cross-section area (cm^2), t is the time interval (h), L is length of the sample (cm), and DH is the 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 [24]. Organic carbon was determined by wet dichromate acid oxidation method [25]. Total nitrogen was estimated by the macro-kjeldahl digestion method [26]. Available phosphorus was obtained using Bray II bicarbonate extraction method [27], 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. Potassium and sodium in the extract were determined with Flame Photometer while Ca and Mg were determined by atomic absorption spectrophotometry [28].

Exchangeable sodium percentage (ESP) was calculated using the standard of Soil Survey Staff [29] formula:

$$ESP = \frac{\text{Exchangeable sodium}}{\text{Cation exchange capacity 1}} \times 100 \quad \text{(Equation 4)}$$

The titration method, as outlined in Selected Methods for soil and plant analysis [28], was used in the determination of the exchangeable acidity. 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) were obtained by the summation of the exchangeable bases (Na, K, Ca, and Mg) [30]. The cation exchange capacity of the soils was determined with 1N NH_4OAc, pH 7.0 [30]. The effective cation exchange capacity of the soil samples was estimated by the summation of the exchangeable bases and the exchangeable acidity [30].

$ECEC = Ca^{2+} + Mg^{2+} + K^{+} + Na^{+} + EA$, where EA is the exchangeable acidity (Equation 5)

The percentage base saturation was derived by dividing the total exchangeable bases (Ca, Mg, K and Na) by the CEC obtained and multiplying by 100 [30].

$$PBS = \frac{Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}}{CEC} X \frac{100}{1} \quad \text{(Equation 6)}$$

Aluminium saturation percentage (ASP) was obtained by multiplying the ratio of aluminium concentration and ECEC with 100 [29].

ASP = Al/ECEC X 100 (Equation 7)

The soil physico-chemical characteristics were rate with the established standards in (Table 1, Table 2, and Table 3). The pedons were classified according to the nomenclature of the USDA Soil Taxonomy [31] and correlated with the FAO [32] Word Reference Base for Soil Resources.

Soil Suitability Evaluation

The suitability of the soils for maize, cassava and oil palm were evaluated using the qualitative (conventional) and quantitative (parametric) methods [14,33,34]. The qualitative approach involved the matching of the crop requirements with the soil characteristics. The most limiting characteristic was identified which determined the class of suitability of each pedon for each crop. Under this approach, the soils were classified as been 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. The limitations were indicated by lower-case letters with mnemonic significance. The parametric (quantitative) approach to this evaluation was the numerical rating of some selected land qualities on a scale of 0 to 100 indicating very low to optimum values and according to the intended land utilization type (Table 4). The ratings were referenced to the established land requirements for each crop. 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 [33] as thus.

Li = A+B/100+ C/100 +D/100 + …. + F/100 (Equation 8)

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. (Table 5 to Table 7) show the established land use requirements for cultivation of rain-fed rice, maize, cassava, and oil palm.

Table 1: Critical limits for interpreting soil depth.

Soil depth (cm)	Interpretation
< 25	Very shallow
25 - 50	Shallow
50 -100	Moderately deep
100 - 150	Deep
> 150	Very deep

Results

Soil morphological characteristics of upland soils in Kogi East

The morphological characteristics of the soils are presented in (Table 8). Deep profiles were encountered except in the profiles of Ologba (65 cm) and Abejukolo-Egume (88 cm) which were not deep as a result of lithic and paralithic contacts. Hues of 2.5 YR and 7.5 YR dominate the surface and subsurface soils. The moist colour showed predominant brown (7.5 YR4/6), dark reddish brown (2.5 YR3/6) and red (10 R5/8). The texture varied between sandy loam and loamy sand at the surface, sandy clay and sandy clay loam at the subsurface soils. The structure varied between granular, crumb, subangular blocky and angular blocky at the surface and subsurface soils. Non-sticky and non-plastic, slightly sticky and slightly plastic as well as sticky and plastic were the consistence of the soils. The common boundaries encountered in the profiles were abrupt wavy, clear smooth, diffuse smooth and gradual smooth. Roots were common as well as few faint clay films on ped faces.

Physical characteristics of soils of upland soils in Kogi East

The physical characteristics of upland soils in Kogi east are presented in (Table 9 and Table 10). In all the profiles of this mapping unit, coarse sand, fine sand, silt, and clay fractions ranged from 350 to 560 g kg^{-1}, 200 to 390 g kg^{-1}, 110 to 130 g kg^{-1} and 90 to 130 g kg^{-1} with mean values of 468, 295, 120 and 110 at the surface soils, respectively. At the subsurface

Table 2: Critical limits for interpreting fertility levels of soil analytical parameters.

Parameter	Very low	Low	Moderate	High	Very High
*Ca^{2+}(cmol kg^{-1})		< 2.0	2.1 - 5.0	> 5.0	
*Mg^{2+}(cmol kg^{-1})		< 0.30	0.31 - 1.0	> 1.0	
*K^{+} (cmol kg^{-1})		< 0.15	0.16 - 0.3	> 0.3	
*Na^{+}(cmol kg^{-1})		< 0.10	0.11 - 0.3	> 0.3	
CEC (cmol kg^{-1})	< 6.0	6.0 -12.0	12.1 - 25.0	25.1 - 40.0	> 40.0
*ECEC (cmol kg^{-1})		< 6.0	6.1 - 12.0	> 12.0	
EA (cmol kg^{-1})		< 2.0	2.1 - 5	> 5	
Org. C (%)	< 0.4	0.4 - 1.0	1.1 - 1.4	1.5 - 2.0	
*Total N (%)	< 0.05	0.06 - 0.10	0.11 - 0.15	0.16 - 0.20	> 0.20
Avl. P (mg kg^{-1})	< 3.0	3.0 -7.0	7.1 - 20.0	> 20.0	
BS (%)	< 20	20 - 40	41 - 60	60 - 80	80 - 100
ESP (%)	< 0.1	0.1 - 2.0	2.1 - 8.0	8.1 - 15.0	> 15.0
*B (mg kg^{-1})		< 0.2	0.21 - 2.0	> 2.0	
*Zn (mg kg^{-1})		< 0.8	0.81 - 2.0	> 2.0	
*Mn (mg kg^{-1})		< 1.0	1.1 - 5.0	> 5.0	
*Fe (mg kg^{-1})		< 2.5	2.51 - 5.0	> 5.0	

Source: *Shehu, et al. [48], Enwezor, et al. [49].

Table 3: Critical limits for interpreting soil pH.

Soil reaction pH	Interpretation
< 4.5	Extremely acid
4.5 - 5.0	Very strongly acid
5.1 - 5.5	Strongly acid
5.6 - 6.0	Moderately acid
6.1 - 6.5	Slightly acid
6.6 - 7.3	Neutral
7.4 - 7.8	Slightly alkaline
7.9 - 8.4	Moderately alkaline
8.5 - 9.0	Strongly alkaline
> 9.0	Very strongly alkaline

Source: Soil Survey Staff [29].

Table 4: 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 [35].

soils, ranges of 210 to 580 g kg^{-1}, 120 to 290 g kg^{-1}, 50 to 230 g kg^{-1} and 110 to 370 g kg^{-1} with mean values of 403, 203, 130 and 261 g kg^{-1} were obtained for coarse sand, fine sand, silt and clay fractions, respectively. The mean value of the silt/clay ratio was 1.13 and 0.50 at the surface and subsurface soils, respectively. The dominant soil textural classes are loamy sand and sandy loam at the surface soils while at the subsurface soils, they ranged from sandy loam through sandy clay to sandy clay loam. The bulk density of the surface soils ranged from 1.55 to 1.77 g cm^{-3} (mean: 1.67 g cm^{-3}). At the subsurface soils, it ranged from 1.67 to 1.88 g cm^{-3} with a mean value of 1.77 g cm^{-3}. The total porosity values ranged from 33.21 to 41.51% and 29.06 to 36.98% with mean values of 37.17 and 33.18% at the surface and subsurface soils, respectively. The saturated hydraulic conductivity values ranged from 65.78 to 136.61 cm hr^{-1} and 1.21 to 97.15 cm hr^{-1} with mean values of 96.47 and 29.27 cm hr^{-1} at the surface and subsurface soils, respectively.

Chemical characteristics of soils of upland soils in Kogi East

(Table 11) shows the chemical characteristics of the soils in Kogi east. The pH (H_2O) was higher at the surface soils, having a mean value of 5.4, than at the subsurface soils with a mean value of 5.6. The OC and TN decreased irregularly with depths in the profiles of this soil unit. The values ranged from 8.40 to 16.40 g kg^{-1}(OC) and 0.40 to 1.70 g kg^{-1} (TN) at the surface soils, as well as 1.30 to 5.50 g kg^{-1} (OC) and 0.30 to 1.10 g kg^{-1}

Table 5: 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	Ø 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_20)	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

F0 = no flooding; F1 = 1-2 months flooding in > 10years; 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
P = Phosphorus; K= Potassium; Ca = Calcium; Mg= Magnesium; N = Nitrogen; CEC = Cation exchange capacity
Modified from Sys [10].

Table 6: 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
Lenght 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	any	Si
Coarse fragments (Vol %) 0 - 10 cm					
	< 3	< 15	< 35	Any	> 35
Soil Depth (cm)	> 100	> 75	> 50	any	< 50
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_20)	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

CL = Clay Loam; SL = Sandy Loam; SCL = Sandy Clay Loam; L = Loam; LFS = Loamy Fine Sand; C = Clay; Si = Silt; FS = Fine Sand; SiCL = Silty Clay Loam; SiL = Silty Loam
P = Phosphorus; K = Potassium; Ca = Calcium; Mg = Magnesium; N = Nitrogen; CEC = Cation Exchange Capacity
Modified from Sys [10].

Table 7: 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, Cs,
Structure	blocky	any	any	any	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_2O)	6.5 - 7.0	5.5 - 6.0	< 5.5; > 7.0	< 4; > 7.0	< 4; > 7.0
Organic carbon (gkg^{-1}), 0 -15 cm	> 8	< 8	-	-	-
Available P ($mgkg^{-1}$)	> 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

F0 = no flooding; F1, 1-2 months flooding in > 10years; 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; CS = Clayey 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
Adapted from Ogunkule [14].

(TN) at the subsurface soils, respectively. The mean value of OC at the surface and subsurface soils was 11.70 g kg^{-1} and 1.00 g kg^{-1}, respectively. The mean value of TN at the surface and subsurface soils was 4.10 and 0.60 g kg^{-1}, respectively. The mean C/N ratio of the surface and subsurface soils was 14 and 9, respectively. The available phosphorus values ranged from 0.93 to 1.87 mg kg^{-1} and 0.93 to 6.53 mg kg^{-1} with mean values of 1.24 and 2.55 at the surface and subsurface soils, respectively. The exchangeable Ca, Mg, K and Na had respective mean value of 1.24, 2.97, 1.27 and 0.07 $cmol_c$ kg^{-1} for the surface soils; 1.73, 0.92, 0.03 and 0.02 $cmol_c$ kg^{-1} at the subsurface soils, respectively. The mean EA was 1.43 and 1.45 $cmol_c$ kg^{-1} at the surface and subsurface soils, respectively. The CEC was higher at the surface soils, having a mean value of 10.80 $cmol_c$ kg^{-1}, than at the subsurface soils with a mean value of 8.44 $cmol_c$ kg^{-1}. The PBS ranged from 25 to 63% and 13 to 70% with mean values of 42% and 29% at the surface and subsurface soils, respectively. The PAS ranged from 9 to 44% and 11 to 75% with mean values of 24% and 38% at the surface and subsurface soils, respectively. The ESP had range of 0.23 to 0.44% at the surface soils while the subsurface soils had 0.10 to 0.51%. The mean values of ESP and ASP were 0.36% and 12% at the surface soils; 0.25% and 16% in the subsurface soils of this mapping unit.

Suitability of upland soils in Kogi East for maize cultivation

The suitability class scores and classification of soils of various mapping units in Kogi east for the cultivation of rain-fed maize are summarized in (Table 12 and Table 13). The result showed that qualitatively, the soils were not suitable (N_1) for rain-fed maize cultivation due to limitations posed by soil physical, soil chemical and wetness, characteristics. Potentially, they are not suitable for rain-fed maize cultivation due to poor fertility limitations. Using the current productivity index of the parametric system of land evaluation [35], the soils are marginally suitable (S_3). Potentially, they are moderately suitable (S_2) for rain-fed maize cultivation.

Suitability ratings and classes of soils for cassava production in Kogi East

The results of the qualitative approach of evaluation (Table 14 and Table 15) revealed that currently the soils are currently not suitable (N_1) for cassava cultivation due to common limitations of poor soil physical and chemical characteristics. Adopting the parametric model of suitability evaluation, the soils are marginally suitable for cassava cultivation under the current parametric productivity index. The potential parametric productivity index showed that they are moderately suitable (S_2) for growing cassava.

Suitability ratings and classes for oil palm production in the Kogi East.

The results of the qualitative evaluation (Table 16 and Table 17) show that in spite of the favourable climatic conditions, fertility limitations currently group the soils are placed at N_1 (currently not suitable) for oil palm production.

Table 8: Morphological characteristics of upland soils in Kogi East.

Pedon/ Coordinate	Location	Horizon depth	Horizon designation	Colour	Texture	Structure	Consistence		Boundary	Pores	Roots	Others
		(cm)		Matrix			Wet	Moist				
$22a_1$	Anyigba	0 - 19	Ap1	2.5YR3/2	sl	24c	Nsnp	L	Aw	Mfi	mfi	-
07°28'17.4" N		19 - 58	Ap2	5YR4/6	sl	14sbk	Nsnp	vfr	Cs	Mfi	mmeco	-
007°09'55.8" E		58 - 102	AB	5YR5/8	scl	25sbk	Sssp	vfr	Ds	Ffico	ffi	Medium nodules
		102 - 151	Btv1	2.5YR5/8	cl	25sbk	Nsnp	Fr	Ds	Fvfi	fvfi	Few fine clay films on ped faces
		151 - 208	Btv2	10R5/8	c	25sbk	Sp	F	-	Fvfi	fvfi	Few fine clay films on ped faces
$22a_2$	Okabo	0 - 15	Ap1	5YR3/2	ls	14g	Nsnp	L	Gw	Ffi	cfi	-
07°33' 17.0" N		15 - 34	Ap2	5YR3/6	ls	25c	Nsnp	L	Ds	Cmfi	cmme	-
007°12'06.9" E		34 - 74	AB	10R4/8	scl	25c	Sssp	vfr	Ds	Mfi	mco	-
		74 - 132	Btv1	10R4/6	sc	245sbk	Sssp	Fr	Ds	Fvfi	fco	Few faint clay films on ped faces
		132 - 170	Btv2	7.5R4/8	sc	25sbk	Sssp	Fr	Ds	Ffi	fme	Few faint clay films on ped faces
		170 - 200	Btv3	7.5R4/8	sc	25sbk	Sssp	Fr	-	Ffi	ffi	Few ants
$22a_3$	Ologba	0 - 19	Ap	5YR4.5/1.2	cl	25c	Nsnp	vfr	Cw	Cme	cme	-
07°37'25.2" N		19 - 42	Btv	2.5YR3/6	c	25sbk	Sp	F	Gs	Mme	mmeco	Few faint clay films on ped faces
007°13'15.0" E		42 - 65	Btvx	2.5YR4/8	c	26abk	Sp	F	-	Fvfi	fvfi	Few shiny mica flakes, clay films, mud stone
$22a_4$	Abejukolo-Egume	0 - 20	Ap	7.5YR4/4	scl	14g	Nsnp	L	Cw	Ffi	cfime	Few medium charcoal
07°26'05.1" N		20 - 51	Bt	7.5YR4/6	scl	124c	Nsnp	vfr	Cs	Ffi	cmeco	Few medium charcoal
007°12'00.1" E		51 - 88	Btc	7.5YR5/8	c	14sbk	Sssp	Fr	-	Ffime	cmeco	Few clay films on ped faces, few medium black ants, Bed rock

Structure: 1 = weak, 2 = moderate, 3 = strong, 4 = fine, 5 = medium, 6 = coarse, c = crumb, g = granular, sbk = subangular, abk = angular blocky, s = single grain

Texture: l = loam, s = sand, c = clay, si = silt, cl = clay loam, sl = sandy loam, scl = sandy clay loam, sc = sandy clay, g = gravelly, v = very, e = extremely, st = stony

Consistency: sp = sticky and plastic, sssp = slightly sticky and slightly plastic, nsnp = non sticky and non plastic, l = loose, vfr = very friable, fr = friable, f = firm, v = very firm. **Pores and Roots:** f = few, v = very, m = many, c = common, fi = fine, me = medium, co = coarse

Boundary: a = abrupt, c = clear, g = gradual, d = diffuse, s = smooth, w = wavy, I = irregular

Table 9: Textural characteristics of soils of upland soils in Kogi East.

Pedon	Location	Depth (cm)	Horizon designation	Coarse sand (g kg^{-1})	Fine sand	Silt	Clay	Silt:Clay	Textural class
22a$_1$	Anyigba	0 - 19	Ap1	440	360	110	90	1.22	ls
07°28’17.4” N		19 - 58	Ap2	540	280	70	110	0.64	ls
007°09’55.8” E		58 - 102	AB	480	120	110	290	0.38	sc
		102 - 151	Btv1	290	130	210	370	0.57	cl
		151 - 208	Btv2	290	170	190	350	0.54	scl
22a$_2$	Okabo	0 - 15	Ap1	550	230	130	90	1.44	sl
07°33’ 17.0” N		15 - 34	Ap2	580	240	70	110	0.64	ls
007°12’06.9” E		34 - 74	AB	470	230	50	250	0.20	scl
		74 - 132	Btv1	400	140	170	290	0.59	scl
		132 - 170	Btv2	440	160	90	310	0.29	scl
		170 - 200	Btv3	450	170	90	290	0.31	scl
22a$_3$	Ologba	0 - 19	Ap	350	390	130	130	1.00	sl
07°37’25.2” N		19 - 42	Btv	250	270	170	310	0.55	scl
007°13’15.0” E		42 - 65	Btvx	210	210	230	350	0.66	scl
22a$_4$	Abejukolo-	0 - 20	Ap	560	200	110	130	0.85	sl
07°26’05.1” N	Egume	20 - 51	Bt	430	290	70	210	0.33	scl
007°12’00.1” E		51 - 88	Btc	430	230	150	190	0.79	sl
Surface range				**350 - 560**	**200 - 390**	**110 - 130**	**90 - 130**	**0.85 - 1.44**	**sl-ls**
Subsurface range				**210 - 580**	**120 - 290**	**50 - 230**	**110 - 370**	**0.20 - 0.79**	**sl-sc-scl**
Surface mean				**468**	**295**	**120**	**110**	**1.13**	**ls**
Subsurface mean				**403**	**203**	**130**	**261**	**0.50**	**scl**

Ls = loamy sand, sc = sandy clay, scl = sandy clay loam, sl = sandy loam

Table 10: Physical characteristics of soils of upland soils in Kogi East.

Pedon/Coordinate	Location	Depth (cm)	Bulk density (g cm^{-3})	Total porosity (%)	K_{sat} (cm hr^{-1})
22a$_1$	Anyigba	0 - 25	1.55	41.51	80.95
07°28’17.4” N		25 - 50	1.79	32.45	20.24
007°09’55.8” E		50 - 75	1.81	30.69	1.21
22a$_2$	Okabo	0 - 25	1.70	35.85	65.78
07°33’ 17.0” N		25 - 50	1.88	29.06	8.10
007°12’06.9” E		50 - 75	1.67	36.98	6.07
22a$_3$	Ologba	0 - 25	1.65	37.74	136.61
07°37’25.2” N		25 - 50	1.68	36.60	97.15
007°13’15.0” E		50 - 75	1.76	33.58	3.04
22a$_4$	Abejukolo- Egume	0 - 25	1.77	33.21	93.10
07°26’05.1” N					
007°12’00.1” E					
Surface range			**1.55 - 1.77**	**33.21 - 41.51**	**65.78 - 136.61**
Subsurface range			**1.67 - 1.88**	**29.06 - 36.98**	**1.21 - 97.15**
Surface mean			**1.67**	**37.17**	**96.47**
Subsurface mean			**1.77**	**33.18**	**29.27**

K_{sat}= Saturated hydraulic conductivity

Potentially, they are classified as N_1 (currently not suitable). The current productivity index of the parametric system of evaluation revealed that the soils are marginally suitable (S_3), for production of oil palm.

Discussion

The soils have deep profiles in 22a$_1$ and 22a$_2$ but paralithic and lithic contacts were encountered in 22a$_3$ and 22a$_4$ at the depths of 65 cm and 88 cm, respectively. This could be an indication of some variation in the geomorphological properties such as the basement complex rocks encountered directly at 22a$_4$ [36,37]. The variations of brownish and reddish colours of the soils are clear expressions of braunification, rubifaction and ferrugination in the surface and subsurface horizons. In 22a$_1$, 22a$_2$ and 22a$_3$, K_{sat} values were higher at the surface and decreased regularly down the profiles. This could in part be due to higher amounts of organic matter in the surface layers much more than in the subsurface layers.

Table 11: Chemical characteristics of soils of upland soils in Kogi East.

Pedon/ coordinate	Location	Depth	Horizon	pH		OC	TN	C:N	Av. P	Exchangeable cations					
										Ca^{2+}	Mg^{2+}	K^+	Na^+	H^+	Al^{3+}
		(cm)		(H_2O)	(KCl)	(g kg^{-1})			(mg kg^{-1})	($cmol_c$ kg^{-1})					
22a$_1$	Anyigba	0 - 19	Ap1	5.8	5.0	11.30	1.70	7	0.93	2.00	2.00	0.07	0.04	0.60	0.20
07°28'17.4" N		19 - 58	Ap2	6.3	5.3	3.40	1.10	3	2.80	1.80	0.20	0.02	0.01	1.20	0.20
007°09'55.8" E		58 - 102	AB	6.3	5.3	5.50	0.70	8	0.93	2.20	1.00	0.03	0.02	0.60	0.40
		102 - 151	Btv1	6.0	5.0	3.40	0.60	6	0.93	2.20	0.20	0.02	0.02	0.40	0.40
		151 - 208	Btv2	5.7	5.1	3.50	0.30	12	0.93	4.40	2.40	0.02	0.01	0.60	0.20
22a$_2$	Okabo	0 - 15	Ap1	5.8	5.0	9.20	0.90	10	0.93	2.00	1.20	0.05	0.03	0.80	0.20
07°33' 17.0" N		15 - 34	Ap2	5.9	4.8	3.80	0.60	6	6.53	1.00	1.60	0.03	0.02	0.60	0.20
007°12'06.9" E		34 - 74	AB	5.1	4.0	3.80	0.30	13	0.93	1.00	0.60	0.03	0.02	0.80	0.40
		74 - 132	Btv1	5.2	4.0	3.80	0.40	10	1.87	1.20	0.40	0.03	0.02	1.00	0.60
		132 - 170	Btv2	5.6	4.1	1.30	0.30	4	1.87	0.60	1.00	0.07	0.04	1.00	0.40
		170 - 200	Btv3	5.6	4.1	5.00	0.30	17	1.87	0.60	0.80	0.02	0.02	0.20	0.60
22a$_3$	Ologba	0 - 19	Ap	5.4	4.7	16.40	1.10	15	0.93	4.40	1.60	0.09	0.04	0.20	0.40
07°37'25.2" N		19 - 42	Btv	5.6	4.9	4.20	0.60	7	3.73	2.00	1.80	0.03	0.02	1.00	0.60
007°13'15.0" E		42 - 65	Btvx	5.8	4.6	5.50	0.90	6	1.87	2.20	0.80	0.03	0.02	0.60	0.20
22a$_4$	Abejukolo-Egume	0 - 20	Ap	4.7	3.8	8.40	0.40	21	1.87	3.00	0.40	0.06	0.04	1.20	1.60
07°26'05.1" N		20 - 51	Bt	4.6	3.7	5.50	0.60	10	4.66	0.80	0.20	0.04	0.02	1.60	1.60
007°12'00.1" E		51 - 88	Btc	5.3	4.1	5.50	0.40	14	1.87	1.00	0.20	0.04	0.02	1.20	1.20
Surface range				**4.7 - 5.8**	**3.8 - 5.0**	**8.40 - 16.4**	**0.40 - 1.70**	**7 - 21**	**0.93 - 1.87**	**2.00 - 4.40**	**0.40 - 2.00**	**0.05 - 0.09**	**0.03 - 0.04**	**0.20 - 1.20**	**0.20 - 1.60**
Subsurface range				**4.6 - 6.3**	**3.7 - 5.3**	**1.30 - 5.50**	**0.30 - 1.10**	**3 - 17**	**0.93 - 6.53**	**0.6 - 4.40**	**0.2 - 2.4**	**0.02 - 0.07**	**0.01 - 0.04**	**0.20 - 1.60**	**0.20 - 1.60**
Surface mean				**5.4**	**4.6**	**11.70**	**1.00**	**14**	**1.24**	**2.97**	**1.27**	**0.07**	**0.04**	**0.70**	**0.70**
Subsurface mean				**5.6**	**4.5**	**4.10**	**0.60**	**9**	**2.55**	**1.73**	**0.92**	**0.03**	**0.02**	**0.84**	**0.59**

OC = Organic carbon, TN = Total Nitrogen, Av. P = Available Phosphorus, Ca^{2+} = Exchangeable Calcium, Mg^{2+} = Exchangeable Magnesium, K^+ = Exchangeable Potassium, Na^+ = Exchangeable Sodium, Al^{3+} = Exchangeable Aluminium

Pedon/coordinate	Location	Depth	Horizon	EA	CEC	ECEC	TEB	PBS	ESP	ASP
		(cm)		($cmol_c$ kg^{-1})				(%)		
22a$_1$	Anyigba	0 - 19	Ap1	0.80	9.00	4.91	4.11	46	0.44	4
07°28'17.4" N		19 - 58	Ap2	1.40	7.80	3.43	2.03	26	0.13	6
007°09'55.8" E		58 - 102	AB	1.00	10.20	4.25	3.25	32	0.2	9
		102 - 151	Btv1	0.80	10.20	3.24	2.44	24	0.2	12
		151 - 208	Btv2	0.80	9.80	7.63	6.83	70	0.1	3
22a$_2$	Okabo	0 - 15	Ap1	1.00	13.20	4.28	3.28	25	0.23	5
07°33' 17.0" N		15 - 34	Ap2	0.80	6.60	3.45	2.65	40	0.3	6
007°12'06.9" E		34 - 74	AB	1.20	7.80	2.85	1.65	21	0.26	14
		74 - 132	Btv1	1.60	7.80	3.25	1.65	21	0.26	18
		132 - 170	Btv2	1.40	7.80	3.11	1.71	22	0.51	13
		170 - 200	Btv3	0.80	7.80	2.24	1.44	18	0.23	27
22a$_3$	Ologba	0 - 19	Ap	0.60	9.80	6.73	6.13	63	0.41	6
07° 7'25.2" N		19 - 42	Btv	1.60	9.40	5.45	3.85	41	0.21	11
007°13'15.0" E		42 - 65	Btvx	0.80	8.20	3.85	3.05	37	0.24	5
22a$_4$	Abejukolo-Egume	0 - 20	Ap	2.80	10.60	6.30	3.50	33	0.38	25
07°26'05.1" N		20 - 51	Bt	3.20	8.20	4.26	1.06	13	0.24	37
007°12'00.1" E		51 - 88	Btc	2.40	8.20	3.66	1.26	15	0.24	33
Surface range				**0.60 - 2.80**	**9.00 - 13.2**	**4.28 - 6.73**	**3.28 - 6.13**	**25 - 63**	**0.23 - 0.44**	**4 - 25**
Subsurface range				**0.80 - 3.20**	**6.60 - 10.20**	**2.24**	**1.06 - 6.83**	**13 - 70**	**0.10 - 0.51**	**3 - 37**
Surface mean				**1.43**	**10.8**	**5.54**	**4.41**	**42**	**0.36**	**12**
Subsurface mean				**1.45**	**8.44**	**4.03**	**2.72**	**29**	**0.25**	**16**

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 12: Suitability class scores of upland soils in Kogi East for maize cultivation.

Land qualities/units	
Climate (c):	
Annual rainfall (mm)	S_1(90)
Mean annual temperature (°C)	S_1(95)
Relative humidity (%)	S_1(80)
Topography (t)	
Slope (%)	S_2(70)
Wetness (w):	
Drainage	S_1(80)
Soil physical properties (s):	
Texture	S_2(70)
Depth (cm)	S_1(100)
Fertility (f):	
CEC (cmol$_c$ kg^{-1})	S_2(70)
Base saturation (%)	S_2(70)
Organic carbon (g kg^{-1})	S_3(50)
pH (H_20)	S_2(60)
Total N (g kg^{-1})	N_1(20)
Available P (mg kg^{-1})	S_3(40)
Exchangeable K (cmol$_c$ kg^{-1})	S_3(50)
Exchangeable Ca (cmol$_c$ kg^{-1})	S_2(60)
Exchangeable Mg (cmol$_c$ kg^{-1})	S_2(60)
Ca = Calcium, Mg = Magnesium, K = Potassium, P = Phosphorus, N = Nitrogen, CEC = Cation Exchange Capacity, S_1 = Highly Suitable, S_2 = Moderately Suitable, S_3 = Marginally Suitable, N_1 = Not Currently Suitable, N_2 = Permanently not suitable, F.D = Flood Duration, G.W.T = Ground water table	

Table 13: Suitability aggregate scores and classifications of upland soils in Kogi East for rain-fed maize cultivation.

CC	N_1f
CP	S_3f
PC	S_3(42)
PP	S_2(63)

CC = Conventional (Current); CP = Conventional (Potential); PC = Parametric (Current); PP = Parametric (Potential), S_1 = Highly Suitable, S_2 = Moderately Suitable, S_3 = Marginally Suitable, N_1= Not Currently Suitable, N_2 = Permanently Not Suitable, f = Fertility, w = Wetness, s = Soil Physical Characteristics

Table 14: Suitability class scores of upland soils of Kogi east for cassava cultivation.

Land qualities/units	
Climate (c):	S_1(90)
Annual rainfall (mm)	S_1(95)
Lenght dry season (months)	S_1(80)
Mean annual temperature (°C)	S_1(90)
Topography (t):	
Slope (%)	S_1(100)
Wetness (w):	
Drainage	S_1(80)
Soil physical properties (s):	S_2(70)
Texture	
Coarse fragments (Vol %) 0-10 cm	S_1(90)
Soil Depth (cm)	S_1(100)
Fertility (f):	
CEC (cmol$_c$ kg^{-1})	S_2(70)
Base saturation (%)	S_2(70)
Organic carbon (g kg^{-1}), 0-15 cm	S_3(50)
pH (H_20)	S_2(60)
Total N (g kg^{-1})	N_1(20)
Available P (mg kg^{-1})	N_1(30)
Exchangeable K (cmol$_c$ kg^{-1})	S_3(50)
Exchangeable Ca (cmol$_c$ kg^{-1})	S_2(60)
Exchangeable Mg (cmol$_c$ kg^{-1})	S_2(60)

Ca = Calcium, Mg = Magnesium, K = Potassium, P = Phosphorus, N = Nitrogen, CEC = Cation Exchange Capacity, S_1 = Highly Suitable, S_2 = Moderately Suitable, S_3 = Marginally Suitable, N_1 = Not Currently Suitable, N_2 = Permanently not suitable

Table 15: Suitability aggregate scores and suitability classifications of upland soils in Kogi East for cassava cultivation.

CC	N_1f
CP	S_2fw
PC	$S_3(45)$
PP	$S_2(63)$

CC = Conventional (Current); CP = Conventional (Potential); PC = Parametric (Current); PP = Parametric (Potential), S_1 = Highly Suitable, S_2 = Moderately Suitable, S_3 = Marginally Suitable, N_1= Not Currently Suitable, N_2 = Permanently Not Suitable, f = Fertility, w = Wetness, s = Soil Physical Characteristics

Table 16: Suitability class scores of upland soils of Kogi East for oil palm cultivation.

Land characteristics	
Climate (c)	
Annual rainfall (mm)	$S_1(90)$
Mean annual temp (°C)	$S_1(95)$
Relative humidity (%)	$S_1(80)$
Topography (t)	
Slope (%)	$S_1(100)$
Wetness (w):	
Flooding	$S_1(90)$
Drainage	$S_1(80)$
Soil physical properties (s):	
Texture	$N_1(36)$
Structure	$S_2(70)$
Depth (cm)	$S_1(100)$
Fertility (f):	
Cation exchange capacity ($cmol_c kg^{-1}$)	$S_2(80)$
Base saturation (%)	$S_2(80)$
pH (H_2O)	$S_1(85)$
Organic carbon (g kg^{-1}),0 - 15cm	$S_2(80)$
Available P (mg kg^{-1})	$N_1(25)$
Exchangeable K ($cmol_c kg^{-1}$)	$N_1(25)$
Exchangeable Mg ($cmol_c kg^{-1}$)	$N_1(25)$
Exchangeable Ca ($cmol_c kg^{-1}$)	$S_2(60)$

Ca = Calcium, Mg = Magnesium, K = Potassium, P = Phosphorus, N = Nitrogen, CEC = Cation Exchange Capacity, S_1 = Highly Suitable, S_2 = Moderately Suitable, S_3 = Marginally Suitable, N_1 = Not Currently Suitable

Table 17: Suitability aggregate scores and suitability classifications of soils of Kogi East for oil palm cultivation.

CC	N_1f
CP	N_1s
PC	$N_1(20)$
PP	$S_3(42)$

CC = Conventional (Current); CP = Conventional (Potential); PC = Parametric (Current); PP = Parametric (Potential), S_1 = Highly Suitable, S_2 = Moderately Suitable, S_3 = Marginally Suitable, N_1= Not Currently Suitable, N_2 = Permanently Not Suitable, f = Fertility, w = Wetness, s = Soil Physical Characteristics

According to Miller and Donahue [38], the greater the amount of organic matter and coarser it is, the more water that enters the soil. Surface mulches are especially helpful in keeping velocity of flow high because they protect soil aggregates from breakdown by reducing the impacts of raindrops and by continuing to supply the cementing agents for aggregates as the organic matter decomposes. Another reason for lower K_{sat} in the subsurface soil layer could be as a result of compaction caused by the weight of the overlying layers. Ezeaku, et al. [39] and Asadu and Eze [40] made similar finding within *Ultisols* in semi-humid area of Nigeria and suggested that the low K_{sat} in the subsurface layers was as a result of low water transmission rate due to clay accumulation and siltation of the pedogenic horizons. This corresponds to increase in clay contents observed in the subsurface soils. High K_{sat} values found on surface soils could also be associated to abundant biopores, textures coarser than loamy fine sand and strong, fine to medium blocky structure in the subsurface soils [41].

The clay increase in the subsurface soils suggests clay illuviation and subsequent formation of argillic horizons. On the other hand, Soil Survey Staff [29] reported that all of clay increase in an argillic horizon is not the result of illuviation. Although most of the clay increase is the result of translocation, vertical textural differentiation could be enhanced in some soils due to clay dissolution in the epipedon and in-situ clay formation in the B horizons. In the former, the loss of clay in soils as a result of dissolution of clay sized phyllosilicates generally is greatest in the upper horizons where weathering processes are most intense, thus creating a vertical textural differentiation. In the later, the vertical textural differentiation is enhanced when the surface horizon dries and evaporation ceases, but the subsoil remains moist. The presence of water allows hydrolysis in the subsoil and the subsequent production of clay.

The range of soil pH is consistent with other soils within the same agroecological zone. This range of pH is in contrast with the finding of Kefas, et al. [42] who had a range of 6.6 to 7.6. The discrepancy is because some fadama soils may have higher pH than some upland soils [43]. The general high rainfall in the area studied is capable of enhancing leaching of the base-forming cations from the soils' exchange site, thereby encouraging increase in exchangeable acidity. The amounts of soil organic carbon (OC) were higher in the surface soils than in the subsurface of the pedons. Generally, the OC contents of the pedons were low owing to the prevalence of tropical condition, where the degradation of organic matter occurs at a faster rate coupled with low vegetation cover, thereby leaving less organic carbon in the soils [44]. The low contents of nitrogen which changed irregularly with depths could be attributed to the continuous cultivation aggravated by the habit of complete removal of crop residues after harvest by farmers and thus depriving the soils of its organic matter turnover. On the other hand, Sanchez [45] reported that losses of nitrogen from soils are due to volatilization, leaching, denitrification, erosion, and plant uptake. The rapid rate of mineralization in the soils has manifested in not so high C:N ratios for the soil except in 0-19 cm of $22a_3$ and 170-200 cm of $22a_2$ where C:N ratios were higher than 15. Ahn [46] noted that the C:N ratio of humus is 15:1 and then concluded that a C:N ratio close to 15 indicates advanced stage of mineralization. Observing that the West African forest topsoil's C:N ratio stabilizes at about 10 to 15 (but much lower in the lower horizons), Ahn further remarked that raw organic material of plant residues has a C:N ratio of

20 to 30 for plant parts relatively high in nitrogen but as high as up to 90 for straw or cellulose rich woody parts. The higher C:N ratios observed in the horizons mentioned could indicate that nitrification was inhibited [47].

Available phosphorus content was generally low in the pedons. The values were lower at the surface than in the subsurface horizons. This may be attributed to the low organic carbon content and pH. The values of the exchangeable cations and CEC followed the trend of organic matter and total nitrogen giving rise to the low PBS of the soils of the soils. The ESP in all the pedons was low. According to Soil Survey Staff [29], the CEC in *Ultisols* is mostly moderate or low, and that the unique properties common to *Ultisols* include low supply of base, particularly in the lower horizons. The decrease in base saturation with increasing depth reflects cycling of bases by plants or additions in surface than in the subsurface soil horizons. The highly weathered and acidic conditions of the epipedons and subsurface soils, as well as leaching of base-forming cations from the profiles may have as well contributed to the low levels of plant nutrients [22]. The Exchangeable acidity (EA) and Aluminium saturation percentage (ASP) levels were reflections of exchangeable hydrogen and aluminium of the soils.

Conclusion

This research considered the characterization and suitability evaluation of upland soils in eastern part of Kogi state, Nigeria for the cultivation of maize, cassava, and oil palm. The research concluded that the soils which varied in fertility status as judged by the varying physical and chemical properties were not currently and conventionally suitable for the cultivation of maize, cassava, and oil palm. This will reflect on the current yield of these crops. Efforts to enhance the fertility of the soils will involve soil management systems such as addition of organic and inorganic manure. The improvement on the inadequate soil pH will boost production since the results showed that the climate is favourable. The research recommends further studies in the study area to ascertain other crops that would be highly suitable in the soils in their current status or with little improvement.

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