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CHARACTERIZATION, CLASSIFICATION AND SUITABILITY EVALUATION OF SOILS IN UKUM, BENUE STATE, NIGERIA FOR MAIZE AND YAM PRODUCTION

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ABSTRACT: *Soil characterization, classification and evaluation provide useful information for the understanding of soil, its potentials and limitations for crop production. The study was to determine the morphological, physical and chemical properties of the soils; classify the soils; and evaluate their suitability for maize, cassava and yam production. Three land utilization types (maize, cassava and yam) with a control plot each were used for the study. One soil profile pit was dug in each land utilization type and control. The pedons were described in-situ following the procedures in FAO' s guidelines for soil profile description. A total of 23 samples were collected from the diagnostic soil horizons. The soils were classified using USDA Soil taxonomy and correlated with FAO/UNESCO World Resource Base. The suitability of the soils for maize, cassava and yam production was assessed using the non parametric and parametric methods of land evaluation. Morphologically, the soils were well drained and very deep with predominantly brownish gray (5YR5/1) and dark gray (2.5Y 5/2). The soil structures varied from weak fine granular structure to weak/moderately medium angular and sub-angular blocky structures. Soil texture varied from sand to sandy loam. The soil bulk density and total porosity varied from 1.42 to 1.72 g cm^{-1} and 36.98 to 46.42 %, respectively. The pH of the soils varied from slightly acidic to moderately acidic. Organic matter and total nitrogen in the soils were rated very low to low. The soils were classified at various great group levels of ultisols. The soils were moderately suitable.*

KEYWORDS: Organic matter, Soil pH, Characterization, Classification, Pedon.

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INTRODUCTION

Soil characterization and land evaluation provides a power resource for the benefit of mankind especially in the area of food security and environmental sustainability (Sharu *et al*., 2013). Sustainable agricultural production cannot be achieved if the soils are not properly evaluated (Ezeaku, 2011). Fadare *et al.* (2019) attributed food insecurity in Nigeria to lack of land evaluation for crop production. Land evaluation enables management guidelines in order to promote a more sustainable use of the soil and environmental resources (Maniyunde *et al*., 2007). The need for land evaluation arose from the fact that soil survey, soil maps and the accompanying legends do not meet the needs of farmers and other land users (Ogunkunle, 2016). Proper recognition of land qualities and allocation of them to the best and most profitable use and stable revenue operation systems have critical importance for preventing of ecosystem destruction (Shahram and Bennam, 2011). Sustainability in agricultural production is a measure of how well the qualities of a land unit match the requirements of a particular form of land use (FAO, 2007). Developing and adapting an ideal land use plan based on the soil quality and constraints for plant growth is of immense use for achieving sustainable crop production system without degrading soil health and environmental quality (Amaresh and Rajkumar, 2014). Therefore, this study was designed to characterize, classify and evaluate the soils of Ukum Local Government Area of Benue State for maize and yam production

MATERIALS AND METHODS

Site Description

The study was carried out in Sankara, Jotar and Kyado in Ukum Local Government Area of Benue State. Ukum L.G.A which is located between latitude 7^0 25'N and 7^0 45'N, and longitude 9^0 15'E and 9^0 43'E (Fig 1). There are essentially two major seasons: the rainy and the dry seasons. The former, which starts from March and ends in October, is characterized with an annual rainfall ranging from 1200 to 1400 mm (Dada, 2006) The distribution is bimodal with peaks in July and September. The dry season lasts from November to February. The temperature fluctuates between $21^0$and 30^0C, with an average of 27^0c in a year. The relative humidity is between 60 and 80% with an average of 70 % (Akpan *et al.*, 2019). The parent material is derived from sandstone and basement complex formations. The soils belong to the red - yellow Ferralitic soils of the humid tropic (Duze and Afolabi, 1981). The land is generally low-lying ranging from 100 – 200 m, and gently undulating with occasional inselbergs, knoll, and laterite (Federal Government of Nigeria, 2009) the main vegetative cover of the study area is secondary due to the influence of man through bush burning, clearing and land cultivation. The variety of trees found in the study area includes; Cashew (*Anacardium occidentale)* Raphia palm *(Raphia spp)*, Gmelina *(Gmelina arbora)* and Castor oil beans *(Ricinus spp)* (Ajaero, 2007). Majority of the people in the area engages in crop production some of the commonly cultivated crops in the area includes; Yam *(Dioscora spp)* Cassava *(Manihot spp)* Maize *(Zea mays)* Rice *(Oryza sativa)* Sweet potatoes *(Ipomoea batatas)* Groundnut *(Arachis hypogaea)* Ugu-Pumpkin *(Telferia occidentalis)* and Cowpea *(Vign unguiculata)*

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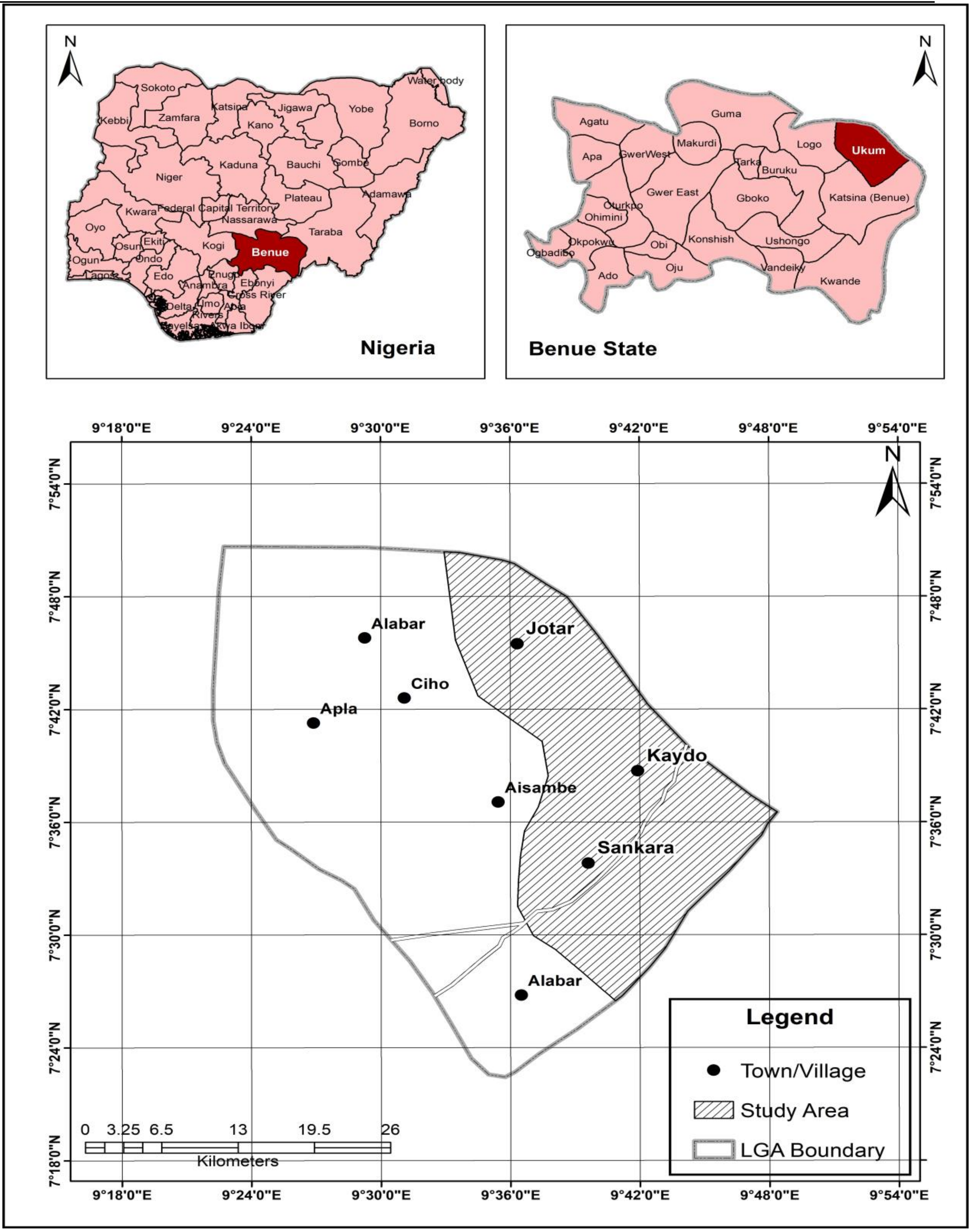

Fig. 1: Map of UKUM L. G. A. showing the study area

Source: Ministry of Land and Survey Makurdi (2021)

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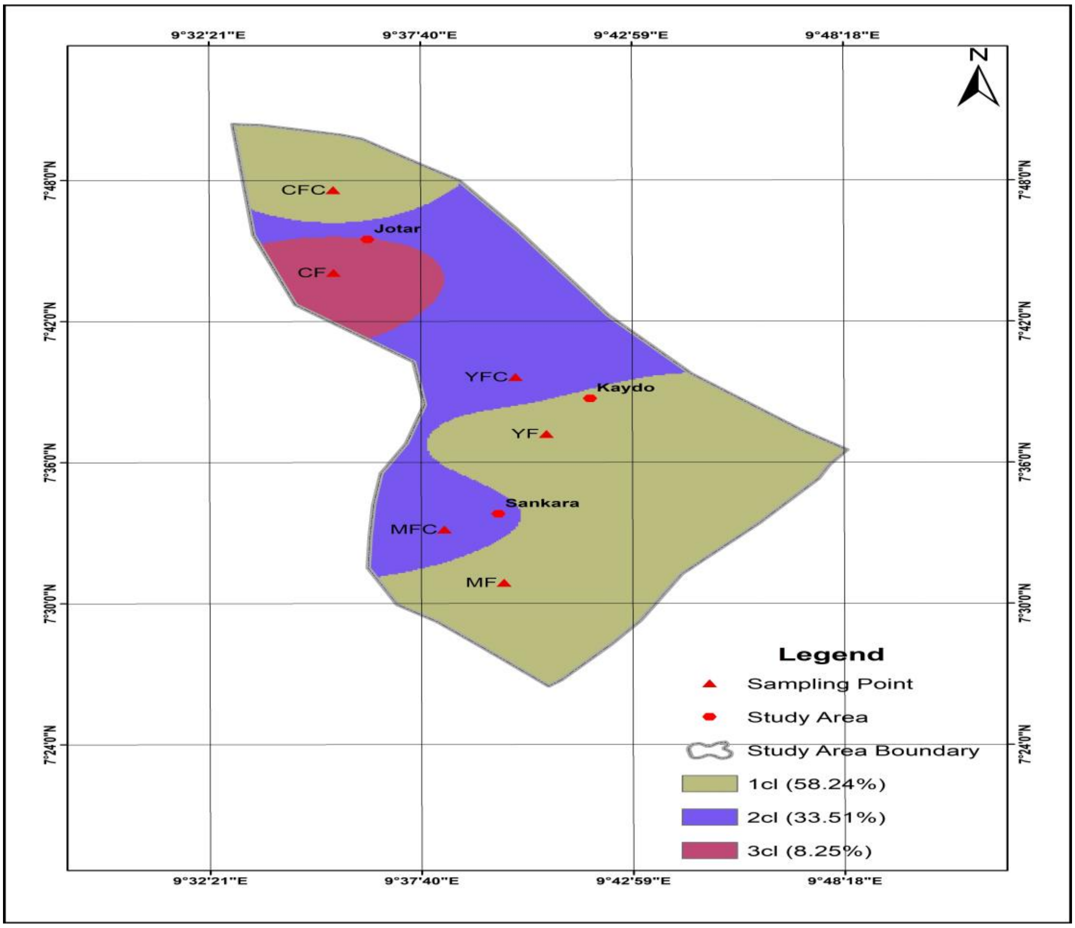

Fig 2. Map of the study area showing the sampling points

Field work

Three communities (Sankara, Jotar and Kyado) were selected in Ukum Local Government Area based on crop (yam, cassava and maize) production dorminance. A 2.0 m x 1.5 m x 2.0 m profile pit was dug in each land utilization type {maize farm (MF), cassava farm (CF) and yam farm (YF)} and in adjacent grassland/control {maize farm control (MFC), cassava farm control (CFC) and yam farm control (YFC) (Fig 2). The distance of the adjacent grasslands / controls was 120m away from each land use type. Each of the profile pit was georeferenced with a Global Positioning System (GPS) (DC 5V 1.5A) which also gave the altitude as shown in Table 7. The pedons were described in situ following the procedures in the FAO, s guidelines for soil profile description (FAO, 2006) and horizon designations of the Soil Survey Staff (2006). Soil colours were described using Munsell Soil Colour Chart (Munsell, 2009). Physical observation and general site information were recorded. Soil samples were collected from each of the identified diagnostic horizons from the bottom upwards to avoid contamination. Undisturbed core samples were also collected (from the bottom upwards to avoid contamination) for bulk density and pore size distribution determinations. A total of 23 samples were collected from the six pedons into a well labelled polyethene bags for onward transportation to the laboratory. The samples collected were air dried, crushed and sieved using 2mm sieve and subjected to standard methods of soil analysis at the Laboratory Department of Soil Science, University of Nigeria Nsukka laboratory as indicated below:

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Soil analyses

Particle size distribution of the soils were determined on the < 2 mm soil properties using Bouycous hydrometer method (Gee and Or, 2002), using sodium hydroxide as a dispersant Bulk density was determined using core method after oven drying the soil samples to constant weight at temperature 105^0 C for 24hrs (Grossman and Reinsch, 2002). Saturated hydraulic conductivity was measured by core measured as described by Klute and Dirksen (1986). Soil porosity was calculated with the values of the bulk density using the method outlined by Jaiswal, (2003).

Soil pH was determined in water and in 0.1 N KCl solution using a soil to liquid ratio of 1:2:5 with the aid of a glass electrode pH meter (Soil Survey Staff, 2014). Soil organic carbon (SOC) was determined using the method described by Nelson and Sommers (1982). Soil organic matter (SOM) was calculated by multiplying the value of organic carbon with 1.724. Total Nitrogen was determined by the Kjeldahl digestion and distillation method (Bremmer and Mulvaaney, 1982). Available phosphorus of the soil samples was determined using Bray 2 method as described by Olson and Sommers (1982). Cation exchange capacity (CEC) was determined titrimetrically using Ammonium acetate (NH4OAc) displacement method (Rhoades, 1982). NH_4OA_C) method (Jackson, 1958). Exchangeable cations of calcium (Ca) and (Mg) was determined by the complexometric titration method (Jaiswal, 2003). Exchangeable sodium and potassium were determined in 1 N NH_4OA_C (ammonium acetate) leachate using the flame photometer method. Exchangeable acidity (EA) was determined by titration method as outlined in selected methods for soil and plant analysis by Jaiswal (2003). Percentage base saturation was calculated by dividing the total exchangeable bases (Ca, K, Mg and Na) by the CEC and multiplied by 100. Total Exchangeable Acidity (TEA) was calculated by summing up the values of exchangeable aluminum and that of the exchangeable hydrogen.

Soil Classification

The pedons were classified using USDA Soil Taxonomy System (Soil Survey Staff, 2014) and correlated with FAO. UNESCO World Reference Base (WRB) (FAO, 2014).

Evaluation procedure

The suitability of the soils for yam and maize production was assessed using linear additive model as stated in Ezeaku and Tyav (2013);

$$L1 = A + \frac{B}{100} + \frac{C}{100} + \frac{D}{100} + \cdots \frac{F}{100}$$

Where LI, is the land suitability index (%)

A is the overall lowest characteristics ratings (%)

B, C, D …. F are the ratings for each property (%).

The value of the land suitability index will be used to determine the aggregate suitability class. The land use requirements for study crops is presented in Tables 1 and 2.

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Table 1: Land use requirements for maize production

(Modified from Sys *et al.*, 1993)

Key: S_1; highly suitable; S_2: moderately suitable; S_3: marginally suitable; N: not suitable;

MAR: mean annual rainfall; MAT: mean annual rainfall; MAT: mean annual temperature; SCL: sandy clay loam; L: loam; CL: clay loam; LS: loam sand; SL: sandy loam; C; clay; S: sand; CEC: cation exchange capacity.

Table 2: Land use requirement for yam production

Land Qualities	S_1 (100-85)	S_2 (85- 60)	S_3 (60- 40)	N (<40)
Climate (c):				
MAR (mm)	1000-750/1200-1600	750-600	600-500	<500
MAT (c)	25-35	20-25	15-20	<15
Soil, physical properties (s):				
Soil texture	SCL, SL, CS, SiC, L,CL, L	LC, LS,	C, LS,	SC, S
Depth (cm)	>100	100-75	75-50	<50
Soil fertility (f):				
Soil P^H	6.1-7.3	7.4-7.8/5.1-6.0	>8.4/<4	Any
CEC (cmolkg)	>16	>10	<10	<5
Base saturation (%)	>35	>15	15-10	<10
Organic matter (gkg)	>15	>8	>5	<3
Available. Phosphorus (mg/ kg)	>25	6-25	<6	Any
Wetness (w):				
Soil drainage	Well drained	Imperfectly drained	Poorly drained	Very poorly drained
Topography (t)				
Slope (%)	0-5	5-12	12-20	>20

(Modified from Sys *et al.*, 1993)

Key: S_1; highly suitable; S_2: moderately suitable; S_3: marginally suitable; N: not suitable;

MAR: mean annual rainfall; MAT: mean annual rainfall; MAT: mean annual temperature; SCL: sandy clay loam; L: loam; CL: clay loam; LS: loam sand; SL: sandy loam; C; clay; S: sand; CEC: cation exchange capacity.

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RESULTS AND DISCUSSION

Morphological Properties of Soils

The summary of the morphological properties of the soils in the study area are presented in Tables 3-5. All the pedons were well drained with depth of > 200cm excluding the pedon of the soils of Jotar which had a depth of 153cm. The profiles were rated very deep according to Soil Survey Staff (1999) as they have depth > 150cm. The Ap horizons of all the profile were brownish gray (5YR 5/1, 7.5YR 4/1, 5YR 6/1) and reddish gray (10R 5/1) to dark gray (2.5Y 5/2) in colour underlined by light to bright yellow orange (7.5YR 8/4, 10YR 7/8, 10YR 6/6 and 10YR 7/8) and light gray (7.5YR 8/2 and 10YR 8/2) with the exception of the pedon of Sankara and that of Jotar which had dull brown (7.5YR 8/4) and reddish orange (10R 6/6). Mottles of bright yellow orange (7.5YR 8/4 and Bright yellow brown (10YR 7/6) were observed in Bt_2 horizon of the soils of Sankara and Bt_1 horizon at Kyado This serves as an evidence of oxidation-reduction reactions caused by seasonal rise in the water table or water logging during some period of the year (Akamigbo *et al.*, 2001: Brady and Weil, 2006).

The textural characteristic of the soils by feel varied from sand to sandy clay loam. The textural variation from one horizon to another may be attributed to the variation in weathering intensity. The structure of the soil varied from fine granular structure at the top soils to moderately medium sub angular blocky structures at the sub-soil in all the pedons. The presence of higher organic matter and root populations was responsible for the granular structure (Yitbarek *et al.*, 2016: Kebede *et al.*, 2017) while low organic matter, low root population and higher clay content accounted for the angular or sub-angular blocky structures (Fadaku *et al.*, 2018). Soil consistence varied from Friable (Moist) and not sticky (Wet) to friable (moist), sticky slight sticky (wet) in all the pedons. Friable consistencies in the surface horizons are been attributed to higher originate matter content (Fedaku *et al.*, 2018) while slightly sticky and sticky consistencies in the sub horizons was attributed to higher clay contents (Abay *et al.*, 2015). Roots varied from very few to few roots in all the pedons. Ants and pores were observed in Ap horizon of the soils of Kyado (yam farm). The presence of the roots, ants and pore were indications of considerable number of biological activities in the soils.

Table 3: Morphological Properties of the Soils of Sankara

Horizon Designation	Horizon Depth (cm)	Color Matrix (Moist)	Structure	Mottle	Texture	Root Presence	Consis-tencies	Other Features	Horizon Boundary
				Maize farm (MF)					
Ap	0 – 31	Brownish gray (5YR 5/1)	Mod sab	None	LS	Few fibrous root	Very Friable	Perfectly drained	Wavy
Bt_1	31 – 72	Dull brown (7.5 YR 6/3)	Mod sab	None	SL	Few woody roots	Very Friable	Perfectly drained	Abrupt wavy

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Bt_2	72 -131	Light yellow orange (7.5 YR 8/4)	Mod sab	None	SL	Very few wooden roots	Friable	Perfectly drained	Abrupt and wavy
BC	131 - 200	Light gray (7.5 YR 8/2)	Mod sab	None	SL	Very few wooden roots	Friable	Perfectly drained	Abrupt wavy
			Adjacent fallow grassland/ Maize Farm Control (MFC)						
Ap	0 – 31	Reddish gray (10 R 5/1)	Vf ma g	None	LS	Few fibrous roots	Very friable	Perfectly drained	Clear wavy
Bt_1	36 – 63	Bright yellowish brown (10 YR 7/6)	G	None	LS	Very few rhizobial roots	Very friable	Perfectly drained	Abrupt wavy
Bt_2	63 -122	Yellow orange (10YR 7/6)	wf sab	None	LS	Very few rhizobial roots	Friable	Few clays skin	Abrupt
BC	122-200	Bright yellow orange (10 YR 8/4)	wf sab	None	LS	Very few rhizobial roots	Friable	Few clays skin	Abrupt

Structure: Mod: moderate, ab: angular blocky, sab: sub angular blocky, vf: very fine, ma: massive, g: granular, wf: wavy fine,

Textuure: L S: Loam Sand; SL: Sandy Loam

Table 4: Morphological properties of the Soils of Jotar

Horizon designation	Horizon depth (cm)	Colour matrix (moist)	Structure	Mottle	Texture	Root presences	Consistence	Other features	Horizon Boundary
				Cassava farm (CF)					
Ap	0-40	Brownish gray (5YR 6/1)	Ma g	None	S	Few rhizobial roots	Friable and sticky	Perfectly drained	granular
B_1	40-69	Light yellow orange	G	None	S	Few rhizobial root	Friable	Perfectly drained	granular

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		(7.5YR 8/4)							
B_2	69-114	Dull yellow orange (10YR 7/4)	w sab	None	S	Very few rhizobial root	Friable	Clay skin prsent	Abrupt
C	144-153	Light gray (10YR 8/2)	w sab	None	S	Very few rhizobial root	Friable	Clay skin present	Abrupt
			Adjacent fallow grassland / Cassava Farm Control (CFC)						
Ap	0-35	Brownish gray (7.5 YR 4/1)	w sab	None	L S	rhizobial roots	Friable	Perfectly drained	Clear smooth
AB	35-94	Light yellow (2.5Y 7/4)	m sab	None	L S	Few rhizobial roots	Friable and sticky	Perfectly drained	Clear smooth
B_1	94-163	Reddish orange (10YR 6/6)	m sab	None	S L	Very Few roots	Friable and sticky	Perfectly drained	Clear smooth
B_2	163-200	Orange (2.5 YR 7/6)	m sab	None	S L	Very few rhizobial root	Friable	Perfectly drained	Clear smooth

Structure: ma, massive., g: granular, sab: sub angular blocky, w: weak, Texture: LS: loam sand; SL: Sandy loam, S: Sand, m: medium

Table 5: Morphological Properties of the Soils of Kyado

Horizon description	Horizon depth (cm)	Colour matrix (moist)	Structure	Mottle	Texture	Root presence	Consistence	Other features	Horizon Boundary
					Yam farm (YF)				
Ap	0 -45	Brownish gray (5YR 6/1)	Mod sab	None	LS	Very few fibrous root	Friable	Perfectly drained	Granular
B_1	45 – 102	Bright yellow brown (10YR 6/6)	Mod sab	None	SL	Few fibrous roots	Friable	Cracks	Abrupt
B_2	102-200	Dull orange (5YR 6/3)	Mod sab	None	SL	Few root	Friable	Clay skin present	Abrupt

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Adjacent fallow grassland/ Yam Farm Control (YFC)									
Ap	0 – 38	Dark gray (2.5Y 5/2)	F ma g	None	L5	Few fibrous roots	Friable	Perfectly drained	Abrupt
B_1	38 – 79	Bright yellow brown (10YR 7/6)	Mod sab	None	LS	Very Few roots	Friable	Clay skin present	Clear
B_2	79-136	Yellow orange (10YR 7/8)	Mod sab	None	SL	Very few root	Friable	Clay skin present	Abrupt
Bt	136-200	Yellow orange (7.5 YR 7/8)	Mod ab	None	SL	Few medium root	Friable	Clay skin present	Abrupt

Structure: Mod: moderate, ab: angular blocky: sab: sub angular blocky Texture: LS; loam sand: LS: loam sand:

Clay skins were observed in the BC and Bt_2 horizons of the soils of Sankara (maize farm) (Table 9) and Kyado (yam farm) (Table 11) respectively. The presence of clay skin in the soils is an indication that eluviations /illuviation processes had probably taken place in the soils, hence the movement of clay down the profiles (Esu, 2010). The presence of cracks at B_2 horizon of the soils of Kyado (yam farm) indicates that the soil has expanding clay minerals (Alhassan *et al*., 2012). Stones and very fine gravels were present in surface and sub-surface horizons of the profiles at Sankara, Jotar and Kyado respectively, though not significant enough to hinder agricultural production. The horizon boundary varied from clear smooth, clear wavy, abrupt smooth to gradual smooth.

The physical properties of soils of the study area

Tables 6-8 showed the physical properties of the soils in Sankara, Jotar and Kyado respectively. The sand fraction varied from 750 to 870 g kg^{-1} with CV of 6 % in the soils of Sankara (Table 6), 790 to 890 g kg^{-1} with CV of 3 % in the soils of Jotar (Table 7) and 730 to 870 g kg^{-1} with CV of 6 % in the soils of Kyado (Table 8). High sand content in the soils was in agreement with studies on similar soils in different parts of Nigeria (Malgwi *et al*., 2000: Lawal *et al*., 2014: Maniyunda *et al*., 2015). The sand fraction decreased with depth in the soils of Kyado, Sankara (maize farm) and Jotar (adjacent fallow/Grassland) respectively. The decrease in sand fraction or content with depth might be attributed to the selective transport of finer soil particles into the lower horizon by illuviation process (Akamigbo, 2001; Mustapha *et al*., 2003). The highest mean of sand (865 g kg^{-1}) was recorded in the soils of Jotar while the lowest mean (792 g kg^{-1}) was recorded in soils of Sankara.

The silt fraction varied from 60 to 140 g kg^{-1} with CV of 32 % in the soils of Sankara (Table 12), 40 to 60 g kg^{-1} with CV of 8 % in the soils of Jotar and 60 to 100 g kg^{-1} with CV of 16 % at Kyado soils. There was increase with depth in silt distribution in soils of Sankara (maize farm), and Kyado (yam farm) while soils of Jotar (adjacent fallow) showed irregular silt

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distribution with depth. Sharu *et al*. (2013) suggested that the development of soils in-situ is responsible for the irregular distribution of silt down the soil profiles.

The highest mean (87.5 g kg^{-1}) was recorded in soils of Sankara while the lowest mean (60 g kg^{-1}) was recorded in soils of Jotar. The clay fraction varied from 70 to 130 g kg^{-1} with CV of 26 % in the soils of Sankara; 50 to 130 g kg^{-1} with CV of 36 % in the soils of Jotar and 50 - 190 g kg^{-1} with CV of 26 % at Kyado soils respectively. Clay increased with depth in most of the pedons (maize farm, adjacent fallow of Cassava farm and adjacent fallow of yam farm) in the study area. The increase of clay with depth agrees with Kefas *et al*. (2020) that most soils within the region are course textured, porous, deep with friable surface horizons which is usually underlain by a clay rich sub soil (argillic horizon or plinthite). Nuga et al. (2008) suggested that the higher clay content observed in the sub surface horizons might be as a result of illuviation and faunal activities taking place in the soils. Generally, the trend in particle size distribution is sand > clay> silt which Asadu and Akamigbo (1983) found in most soils in Nigeria. Ezeaku and Tyav, (2013); Kefas, (2016) and kefas *et al*. (2020) had similar trend for the soils in the region. The dominance of sand fraction in profiles may be attributed to high content of quart mineral in the parent material (Kefas, 2020).

Silt/clay ratio ranged from 0.85 to 1.14 with CV of 15 % at Sankara soils; 0.4 to 1.2 with CV of 25 % in the soils of Jotar (cassava farm) and 0.31 to 0.66 with CV of 45 % at Kyado soils (Tables 12, 13 and 14). The silt /clay ratios of the soils are ≥ 0.3 and < 2. The soils also had silt clay ratio > 1, this indicates that the soils had undergone ferralitic pedogenesis (Ashaye 1969). The entire soils had values of silt clay ratio greater than the separating limit of 0.15, a further indication that the soils were not highly weathered. Sharu et al (2013) also reported similar results for some soils in the northern guinea savanna. The values of the bulk density varied from 1.42 to 1.67 gcm^3 with CV of 5 % at Sankara soils; 1.44 to 1.66 gcm^3 with CV of 3 % at Jotar soils and 1.48 to 1.72 g cm^3 with CV of 4 % in soils of Kyado respectively. Bulk density values of the surface horizons were observed to be lower than those of the sub-soils horizons as the values increased with soil depth, especially in the Bt and Bc horizons with maximum clay accumulation. Higher bulk density values of the subsurface horizons might likely be ascribed to surface compaction due to animal tractions; similar finding have earlier been reported in the Nigeria savannah soils (Raji, 1995; Yaro, 2005, Kefas *et al*. 2016; kefas 2020).

Table 6: Physical properties of the soils of Sankara

Horizon Designation	Depth	Sand (gkg^{-1})	Silt (gkg^{-1})	Clay (gkg^{-1})	TC	SCR	BD (gcm^{-3})	TP (%)	Ksat (cmhr^{-1})
				Maize farm (MF)					
Ap	0-31	850	80	70	LS	1.14	1.51	43.02	14.14
Bt_1	31-72	790	100	110	SL	0.90	1.67	36.98	17.17
Bt_2	72-131	750	120	130	SL	0.92	1.67	36.98	19.19
BC	131-200	850	140	110	SL	1.27	1.63	38.49	16.16
	Mean	810	110	105		1.05	1.62	38.87	16.66
				Adjacent fallow grassland/Maize Farm Control (MFC)					
Ap	0-36	850	80	70	LS	1.14	1.42	46.42	13.64
Bt_1	36-63	870	60	70	LS	0.85	1.65	37.74	11.62
Bt_2	63-122	870	60	70	LS	0.85	1.63	38.49	12.63
BC	122-200	870	60	70	LS	0.85	1.67	36.98	18.18

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	Mean	865	65	70		0.92	1.59	39.90	14.01
	CV(%)	**6**	**32**	**26**		**15**	**5**	**8**	**16**

TC: textural class, LS; loam sand, SL; sandy loam. SCR: silt/clay ratio, BD: buck density, TP: total porosity

Table 7: physical properties of the soils of Jotar

Horizon Designation	Depth (cm)	Sand (gkg^{-1})	Silt (gkg^{-1})	Clay (gkg^{-1})	TC	SCR	BD (gcm^{-3})	TP (%)	Ksat ($cmhr^{-1}$)
		Cassava farm (CF)							
Ap	0-40	890	60	50	S	1.2	1.53	42.26	23.23
B_1	40-69	890	60	50	S	1.2	1.57	40.75	25.25
B_2	69-114	890	60	50	S	1.2	1.6	39.62	19.39
C	114-153	910	40	50	S	0.8	1.49	43.77	25.25
	Mean	895	55	50		1.1	1.54	41.6	23.28
				Adjacent fallow grassland/ Cassava Farm Control (CFC)					
Ap	0-35	870	60	70	LS	0.8	1.44	45.66	23.76
AB	35-94	870	60	70	LS	0.8	1.65	37.74	15.15
B_1	94-163	790	80	130	SL	0.6	1.62	38.87	13.64
B_2	163-200	810	60	130	SL	0.4	1.66	37.36	17.68
	Mean	835	65	100		0.65	1.59	39.91	17.55
	CV(%)	**3**	**8**	**36**		**25**	**3**	**5**	**19**

TC: textural class, S: sand, LS: loamy sand, SL: sandy loam, SCR: silt/clay ratio, BD: buck density, TP: total porosity.

Table 8: physical properties of the soils of Kyado

Horizon Designation	Depth (cm)	Sand (gkg^{-1})	Silt (gkg^{-1})	Clay (gkg^{-1})	TC	SCR	BD (gcm^{-3})	TP (%)	Ksat ($cmhr^{-1}$)
					Yam farm (YF)				
Ap	0-45	770	60	170	LS	0.35	1.57	40.75	18.69
B_1	45-102	750	80	170	SL	0.47	1.72	25.09	14.06
B_2	102-200	750	100	150	SL	0.6	1.54	41.89	13.13
	Mean	790	80	163		0.47	1.61	35.91	15.29
				Adjacent fallow grassland/ Yam Farm Control (YFC)					
Ap	0-38	870	80	50	LS	1.60	1.48	44.15	15.15
B_1	38-79	830	60	110	LS	0.54	1.64	38.11	14.44
B_2	79-136	730	80	190	SL	0.47	1.63	38.89	16.16
Bt	136-200	750	60	190	SL	0.31	1.66	37.38	16.67
	Mean	795	70	135		0.73	1.60	39.63	15.60
	CV(%)	**6**	**16**	**26**		**46**	**4**	**10**	**9**

TC: textural class, LS; loam sand, SL; sandy loam, SCR: silt/clay ratio, BD: buck density,

TP: total porosity

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Total porosity values varied from 36.98 to 46.42 % with CV 8 % in soils of Sankara; 37.36 to 45.66 % with CV of 5 % in soils of Jotar, and 25.09 to 44.15 % with CV of 10 % in soils of Kyado respectively. The highest porosity mean (40.75 %) was recorded in Jotar soils while the lowest 38.03 was recorded in kyado soils. Total porosity values were higher in the surface soils than in the subsurface soils. The mean soil surface values of total porosity appear to pose no limitations to crop production as Kefas et al. (2018) reported that total porosity of the surface soils supports free water movement, good aeration and ease of root penetration. The total porosity of the soils decreases with increase depth in all the pedons. The decrease of total porosity with depth might be attributed to the decrease in organic matter content with depth (Hassen and Shuaibu, 2006). However, it was also observed that the lower the total porosity value the higher the bulk density and vice –versa. This is in agreement with Crual (1992) and Ajoagu, (2020) that bulk density is inversely related to porosity. Saturated hydraulic conductivity (Ksat) ranged from 12.63 to 19.19 cm hr^{-1} with CV of 16 % at Sankara soils; 13.64 to 25.25 cm hr^{-1} with CV of 19 % at Jortar soils, and 13.13 to 18.69cm hr^{-1} with CV of 9 % at Kyado soils respectively. The highest mean value for Kyado (20.41cm hr^{-1}) was recorded in Jotar soils while the lowest ksat mean value (15.34 cm hr^{-1}) was recorded in Sankara soils.

Chemical Properties of Soils

The chemical properties of the soils are presented in Tables 9, 10 and 11. At Sankara soils, pH in H_20 and KCl ranged from 5.5 to 7.3 with CV of 6 % and 4.3 to 6.1 with CV of 10 % respectively. At Jotar soils, pH in H_20 and KCl ranged from 5.9 to 7.2 with CV of 5 % and 4.7 to 6.1 with CV of 7 % respectively. At Kyado, pH in H_20 and KCl ranged from 5.7 to 7.2 with CV of 5 % and 4.4 to 6.2 with CV of 9 % respectively. The highest P^H mean value (6.5) was recorded in Jotar soils while the lowest mean (6.22) was recorded in Sankara soils. The soil P^H in H_20 mean values obtained in the study area were within the range suitable for maize, yam and cassava production (Maniyunda, *et al*., 2007: Ogbomo and Nwachokor, 2010).

The values of organic matter (OM) ranged from 2.67 g/kg^{-1} to 7.07 gkg^{-1} with CV of 27 % for soils of Sankara, 2.67 gkg^{-1} to 14.68 gkg^{-1} with CV of 48 % at Jotar soils, 5.34 gkg^{-1} to 12.01gkg with CV 25 % for soils of Kyado. These values were rated very low to low according to the rating by Enwezor *et al*. (1989). Fekadu *et al*. (2018) affirmed that continuous cultivation leads to oxidation of organic materials which in turns reduces organic matter content of soils. There was a regular decrease in OM with increase depth in soils of Jotar (cassava farm) and Kyado (YLU) of the study area. The decrease in OM in depth might be attributed to the decrease in organic material in depth (Kefas *et al*., 2020). The OM contents were higher in the AP horizons and were lower in the sub-horizons in the study area. The higher content of OM in the AP horizon were due to organic matter addition while the lower OM content in the sub-horizons was due to decrease in microbial pedoturbation and zero tillage activities (Nsor, 2017). Total Nitrogen (TN) in soils of Sankara, Jotar and Kyado varied from 0.42 to 1.12gkg^{-1} with CV of 28 %, 0.28 to 0.70gkg^{-1} with CV of 21%, and 0.42 to 0.98gkg^{-1} with CV of 23 %, respectively. TN values were rated very low to low based on the scale by Enwezor et al. (1989). The low values of TN might be attributed to low OM content of the soils as OM accounts for 93 to 97% of TN (Meysner *et al*., 2006).

Available phosphorus ranged from 11.19 to 17.72 $mgkg^{-1}$ with CV of 13 %, 11.19 to 14.92 $mgkg^{-1}$ with CV of 7 % and 3.73 to 12.12 $mgkg^{-1}$ with CV of 21 % at Sankara, Jotar and

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kyado, respectively. The values of available P were rated low as they were below or slightly above the 10mgkg^{-1} critical limit recommended for most commonly cultivated crops (Uponi and Adeoye, 2000; Obigbesan, 2009). The low values of available P might be partly due to the nature of the parent material and partly to the fixation of phosphorus by iron and aluminium oxides under well drained condition (Nuga *et al*., 2006). According to Amhakhian and Osemuota, (2012) tropical soils are generally low in available P due to low apatite content of the soil forming materials. Exchangeable hydrogen ranged between 1.60 and 2.6 cmolkg^{-1} with CV of 15 % at Sankara, 1.2 to 2.6 with CV of 22 % in the soils of Jotar and 1.4 to 2.0 with CV of 14 % in the soils of Kyado respectively. Exchangeable aluminum varied from 0.4 to 0.6cmolkg^{-1} with CV of 17 % and exchangeable acidity varied from 2.0 to 3.2 cmolkg^{-1} with CV of 14 **%** for soils of Sankara. Jotar soils had their exchangeable hydrogen, aluminum and acidity in the range of 1.20 to 2.6 cmolkg^{-1} with CV of 22 %, 0.2 to 0.6cmolkg^{-1} with CV of 42 %, and 1.4 to 3.2 cmolkg^{-1} with CV of 25 % (Table 16). In the soils of Kyado the exchangeable hydrogen, aluminum and acidity ranged from 1.4 to 1.8 Cmolkg^{-1} with CV of 14 %, 0.2 to 0.4 cmolkg^{-1} with CV of 34 %, and 1.6 to 2.4 with CV of 17 **%**. The exchangeable acidity values were rated low according to the rating by Enwezor *et al*. (1989). The trend in dominance of the exchangeable bases at the colloid is $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$. Exchangeable calcium (0.40 to 2.4cmolkg^{-1}), magnesium (0.2 to 1.6cmol kg^{-1}), potassium (0.03 to 0.05 cmol kg^{-1}) was all rated low on the scale by Shehu *et al*. (2015). The values of exchangeable Ca, Mg, K and Na obtained in this work are lower compared to basic requirement of 4 - 20, 1 - 8, 0.3 - 2 and 0.3 - 2.0 and 0.3 - 2 cmolkg^{-1} respectively for soils in the tropics (Enwezor *et al*., 1989). Total exchangeable bases (TEB) were also rated low, and the low values of the TEB might probably be as a result of leaching that the soils had undergone and the nature of the parent material. Ritter, (2006) noted that soils developed over sandstone have course texture which facilitates leaching.

The CEC values varied between 4.80 cmol kg^{-1} and 10 cmolkg^{-1} with CV of 15 %, at Sankara; between 6.4 cmolkg^{-1} and 11.0 cmolkg^{-1} with CV of 17 % at Jotar; and between 6.0 cmol kg^{-1} and 11.6cmol kg^{-1} with CV of 23 % at kyado respectively. The values of CEC were rated very low to low based on the scale by Enwezor *et al.* (1989). The values of base saturation (BS) varied from 17.14 to 67.77 % with CV of 30 %; 19.31 to 42.81 % with CV of 19% and 18.44 to 51.09 % with CV of 26% for soils of Sankara, Jotar and kyado respectively. The values of BS were rated low to high according to the ratings of Enwezor *et al.* (1989). Fedaku *et al*. (2018) attributed low BS due to leaching of bases resulting in low and unbalanced availability of exchangeable bases for plants uptake while Sekhar et al. (2014) attributed higher values of BS to higher amount of Ca^{2+} on soil colloid. The highest CEC mean value (32.72%) was recorded in soils of Sankara, while the lowest mean value (26.45 %) was recorded in Jotar soils in the range of 1.20 to 2.6 cmolkg^{-1} with CV of 22 %, 0.2 to 0.6cmolkg^{-1} with CV of 42 %, and 1.4 to 3.2 cmolkg^{-1} with CV of 25 %. In the soils of Kyado the exchangeable hydrogen, aluminum and acidity ranged from 1.4 to 1.8 Cmolkg^{-1} with CV of 14 %, 0.2 to 0.4 cmolkg^{-1} with CV of 34 %, and 1.6 to 2.4 with CV of 17 **%**. The exchangeable acidity values were rated low according to the rating by Enwezor *et al*. (1989).

The trend in dominance of the exchangeable bases at the colloid is $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$. Exchangeable calcium (0.40 to 2.4cmol kg^{-1}), magnesium (0.2 to 1.6cmkg^{-1}), potassium (0.03 to 0.05 cmolkg^{-1}) was all rated low on the scale by Shehu *et al*. (2015). The values of exchangeable Ca, Mg, K and Na obtained in this work are lower compared to basic requirement of 4 - 20, 1 - 8, 0.3 - 2 and 0.3 - 2.0 and 0.3 - 2 cmolkg^{-1} respectively for soils in

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the tropics (Enwezor *et al*., 1989). Total exchangeable bases (TEB) were also rated low, and the low values of the TEB might probably be as a result of leaching that the soils had undergone and the nature of the parent material. Ritter, (2006) noted that soils developed over sandstone have course texture which facilitates leaching.

The CEC values varied between 4.80 cmol kg^{-1} and 10 $cmolkg^{-1}$ with CV of 15 %, at Sankara; between 6.4 cmol kg^{-1} and 11.0 $cmolkg^{-1}$ with CV of 17 % at Jotar; and between 6.0 $cmolkg^{-1}$ and 11.6cmol kg^{-1} with CV of 23 % at kyado, respectively. The values of CEC were rated very low to low based on the scale by Enwezor *et al*. (1989). The values of base saturation (BS) varied from 17.14 to 67.77 % with CV of 30 %; 19.31 to 42.81 % with CV of 19% and 18.44 to 51.09 % with CV of 26% for soils of Sankara, Jotar and kyado, respectively. The values of BS were rated low to high according to the ratings of Enwezor *et al.* (1989). Fedaku *et al*. (2018) attributed low BS due to leaching of bases resulting in low and unbalanced availability of exchangeable bases for plants uptake while Sekhar et al. (2014) attributed higher values of BS to higher amount of Ca^{2+} on soil colloid. The highest CEC mean value (32.72%) was recorded in soils of Sankara while the lowest mean value (26.45 %) was recorded in Jotar soils

Table 9: Chemical properties of soils of Sankara

Depth (cm)	pH (H_20)	pH (KCl)	OM (gkg^{-1})	TN	AV. P (mgkg$^{-1)}$)	H^+	AL^{3+}	EA	Ca^{2+}	Mg^{2+} **(Cmol kg^{-1})**	Na	K^+	TEB	CEC	BS (%)
					Maize farm (MF)										
0-31	7.3	6.1	7.07	0.56	17.72	2.0	0.6	2.6	1.0	1.4	0.04	0.07	2.51	7.2	35
31-72	5.9	4.5	6.67	0.70	15.86	2.6	0.6	3.2	1.8	0.8	0.02	0.05	2.67	10.0	37
72-131	5.5	4.3	6.01	0.56	11.19	1.8	0.6	3.0	1.6	1.6	0.02	0.05	3.27	9.2	36
131-200	5.7	4.5	4.6	1.12	15.86	1.6	0.6	2.4	1.6	0.8	0.01	0.03	2.44	7.6	32
Mean	6.1	4.8	6.08	0.73	15.15	2.0	0.6	2.8	1.5	1.15	0.02	0.05	2.72	8.5	35
			Adjacent fallow grassland/ Maize Farm Control (MFC)												
0-36	6.5	5.5	6.01	0.70	14.92	1.6	0.4	2.0	0.6	0.8	0.02	0.05	1.47	6.8	19
36-63	6.2	5.4	3.34	0.42	13.99	2.4	0.6	3.0	0.8	0.6	0.01	0.03	1.44	8.4	17
63-122	6.2	5.4	3.00	1.12	11.19	1.8	0.4	2.2	1.2	0.8	0.01	0.03	2.04	7.2	28
122-200	6.5	4.7	2.67	0.56	13.06	1.8	0.4	2.2	0.8	1.6	0.01	0.03	2.44	4.8	68
Mean	6.3	5.25	3.75	0.7	13.29	1.9	0.41	2.35	0.8	0.9	0.01	0.03	1.84	6.8	33
CV(%)	**6**	**10**	**30**	**28**	**13**	**15**	**17**	**14**	**31**	**34**	**42**	**29**	**20**	**15**	**30**

OM: organic matter, TN: total nitrogen, AV.P: available phosphorus, H: hydrogen, AL: alluminium, Mg: magnesium, K: potassium, TEB: total exchangeable bases, CEC: cation exchange capacity, BS: base saturation

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Table 10: chemical Properties of the Soils of Jotar

Depth (cm)	pH (H_2O)	pH (KCl)	OM (gkg^{-1})	TN (gkg^{-1})	AV.P (mgkg^{-1})	H^+ (Cmol kg^{-1})	AL^{3+} (Cmol kg^{-1})	EA (Cmol kg^{-1})	Ca^{2+} (Cmol kg^{-1})	Mg^{2+} (Cmol kg^{-1})	Na^+ (Cmol kg^{-1})	K^+ (Cmol kg^{-1})	TEB (Cmol kg^{-1})	CEC (Cmol kg^{-1})	BS (%)
Cassava farm (CF)															
0-40	6.4	5.2	4.67	0.56	11.19	1.6	0.4	2.0	1.0	1.2	0.01	0.03	2.24	11.0	19
40-69	6.1	4.7	3.34	0.28	12.12	1.8	0.4	2.2	0.4	1.2	0.01	0.03	1.64	6.4	26
69-114	6.2	5.4	3.00	0.42	12.12	2.6	0.6	3.2	0.6	0.8	0.01	0.03	1.44	6.8	21
114-153	6.6	5.4	2.67	0.42	13.06	1.4	0.2	1.6	1.0	0.6	0.01	0.03	1.64	7.2	23
Mean	6.3	5.1	3.42	0.42	12.12	1.8	0.4	2.25	0.75	0.95	0.01	0.03	1.74	7.8	22
Adjacent fallow grassland/ Cassava Farm Control (CFC)															
0-35	7.2	6.1	14.68	0.42	12.12	1.2	0.2	1.4	1.6	1	0.05	0.09	2.64	6.4	43
35-94	6.9	5.8	12.67	0.42	12.12	1.6	0.2	1.8	1.6	0.4	0.01	0.03	2.04	8.8	23
94-163	6.7	5.5	5.34	0.70	13.99	1.6	0.2	1.8	1.6	1.2	0.02	0.05	2.80	9.2	31
163-200	5.9	4.4	4.0	0.56	14.92	2.6	0.6	3.2	1.0	0.8	0.01	0.03	1.84	7.2	26
Mean	6.6	5.45	9.1	0.52	13.28	1.7	0.3	2.0	1.45	0.85	0.02	0.05	2.33	7.9	31
CV(%)	**5**	**7**	**58**	**21**	**7**	**22**	**42**	**25**	**34**	**27**	**57**	**37**	**19**	**17**	**19**

OM: organic matter, TN: total nitrogen, AV.P: available phosphorus, H: hydrogen, AL: aluminum, Mg: magnesium, K: potassium, TEB: total exchangeable bases, CEC: cation exchange capacity, BS: base saturation.

Depth (cm)	pH (H_2O)	pH (KCl)	OM (gkg^{-1})	TN (gkg^{-1})	AV.P (mgkg^{-1})	H^+ (Cmol kg^{-1})	AL^{3+} (Cmol kg^{-1})	EA (Cmol kg^{-1})	Ca^{2+} (Cmol kg^{-1})	Mg^{2+} (Cmol kg^{-1})	Na^+ (Cmol kg^{-1})	K^+ (Cmol kg^{-1})	TEB (Cmol kg^{-1})	CE(
Cassava farm (CF)														
0-40	6.4	5.2	4.67	0.56	11.19	1.6	0.4	2.0	1.0	1.2	0.01	0.03	2.24	11.(
40-69	6.1	4.7	3.34	0.28	12.12	1.8	0.4	2.2	0.4	1.2	0.01	0.03	1.64	6.4
69-114	6.2	5.4	3.00	0.42	12.12	2.6	0.6	3.2	0.6	0.8	0.01	0.03	1.44	6.8
114-153	6.6	5.4	2.67	0.42	13.06	1.4	0.2	1.6	1.0	0.6	0.01	0.03	1.64	7.2
Mean	6.3	5.1	3.42	0.42	12.12	1.8	0.4	2.25	0.75	0.95	0.01	0.03	1.74	7.8
Adjacent fallow grassland/ Cassava Farm Control (CFC)														
0-35	7.2	6.1	14.68	0.42	12.12	1.2	0.2	1.4	1.6	1	0.05	0.09	2.64	6.4
35-94	6.9	5.8	12.67	0.42	12.12	1.6	0.2	1.8	1.6	0.4	0.01	0.03	2.04	8.8
94-163	6.7	5.5	5.34	0.70	13.99	1.6	0.2	1.8	1.6	1.2	0.02	0.05	2.80	9.2
163-200	5.9	4.4	4.0	0.56	14.92	2.6	0.6	3.2	1.0	0.8	0.01	0.03	1.84	7.2
Mean	6.6	5.45	9.1	0.52	13.28	1.7	0.3	2.0	1.45	0.85	0.02	0.05	2.33	7.9
CV(%)	**5**	**7**	**58**	**21**	**7**	**22**	**42**	**25**	**34**	**27**	**57**	**37**	**19**	**17**

OM: organic matter, TN: total nitrogen, AV.P: available phosphorus, H: hydrogen, AL: aluminum, Mg: magnesium, K: potassium, TEB: total exchangeable bases, CEC: cation exchange capacity, BS: base saturation.

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Table 11: Chemical properties of the soils of Kyado

Depth (cm)	pH (H_2O)	pH (KCl)	OM (gkg⁻¹)	TN	AV.P (mgkg⁻¹)	H^+ (Cmol kg⁻¹)	AL^{3+}	EA	Ca^{2+}	Mg^{2+}	Na^+	K^+	TEB	CEC	BS (%)
						Yam farm (YF)									
0 – 45	6.6	5.7	12.01	0.84	8.39	1.4	0.2	1.6	1.4	0.6	0.05	0.09	2.14	11.6	18.
45-102	5.8	4.7	6.01	0.98	3.73	1.4	0.2	1.6	2.2	0.4	0.02	0.05	2.67	10	27
102-200	6.2	4.8	5.34	0.56	8.39	2.0	0.4	2.4	2.4	0.8	0.02	0.05	3.27	6.4	51.
Mean	6.2	5.1	7.78	0.79	6.83	1.6	0.26	1.8	2.0	0.6	0.09	0.06	2.69	9.33	32
			Adjacent fallow grassland/ Yam Farm Control (YFC)												
0-38	7.2	6.2	9.34	0.56	9.33	1.40 0	0.2	1.6	1.4	0.02	0.04	0.07	1.71	6.0	29
38-79	6.2	5.1	5.34	0.42	10.26	1.6	0.2	1.8	1.2	0.06	0.02	0.05	1.87	6.0	31
79-163	5.7	4.4	8.01	0.56	12.12	2.0	0.4	2.4	1.4	0.06	0.02	0.06	3.00	7.2	43
136-200	6.2	4.8	6.67	0.70	11.19	1.8	0.4	2.2	1.6	0.06	0.02	0.05	2.27	9.2	25
Mean	6.3	5.1	7.34	0.56	10.72	1.7	0.3	2.0	1.4	0.05	0.02	0.05	2.21	7.1	32
CV(%)	**5**	**9**	**25**	**23**	**21**	**14**	**34**	**17**	**22**	**42**	**37**	**19**	**19**	**23**	**26**

OM: organic matter, TN: total nitrogen, AV.P: available phosphorus, H: hydrogen, AL: aluminum, Mg: magnesium, K: potassium, TEB: total exchangeable bases, CEC: cation exchange capacity, BS: base saturation.

Soil Classification

Kandic horizons were found in the soils of Sankara (maize farm), Jotar (adjacent fallow/grass land) and Kyado (adjacent fallow) and they had base saturation of <35 % throughout the entire horizons, thus classified in to the order Ultisols of the Soil Taxonomy or USDA. The moisture regime was ustics as the study area have more than 90 consecutive dry days in a normal year. The presence of Kandic horizon with no densic, lithic, paralitic or petrolithic contacts within 150 cm of mineral soils and a clay increase of 3 % or more in the fine-earth fractions qualified the soils to be in the great group Kandiustults. At the sub group level, the soils of Kyado (adjacent fallow) were classified as Typic Kandiustults. The sandy skeletal texture throughout a layer extending from the mineral soil surface to the top of the Kandic horizon at a depth of 50 to 100 cm qualified the soils of Sankara (maize farm) in Arenic Kandiustults. The soils of Jotar (adjacent fallow) have sandy skeletal particle-size classes throughout the layers extending from the mineral soil surface to the top of the Kandic horizon at the depth of 100 cm and more, thus classified as Grossarenic Kandiustaults.

The soils were classified as Inceptisols at order lever, and Ustepts at sub order level owing to the presence of Ustic moisture regime. The soils were further classified as Dystrustepts and Typic dystrustepts at the great group and sub group levels respectively. The presence of agric horizon underlain by sandy loam and loamy sand textural classes qualifies the soils of Jotar (cassava farm) in order Entisols. An aquic moisture regime was inferred for the soils and this placed them at sub order Aquents, great group Psammaquents and sub group Typic Psammaquents. According to FAO World Refence Base (WRB), the soils of Sankara, Jotar and Kyado were correlated with Acrisols as they possessed agric horizons with CEC values of < 24 and exchangeable bases of <50 % within the upper 100 cm depth.

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Table 12: Summary of soil classification in the study areas (Sankara, Jotar and Kyado)

Study Area	Pedon	Order	Sub order	Great group	Subgroup	FAO WRB(2014)
Sankara	Maize farm	Ultisols	Ustults	Kandiustults	Arenic Kandiustults	Acrisols
	Adjacent fallow	Inceptisols	Ustepts	Dystrustepts	Typic Dystrustepts	
Jotar	Cassava farm	Entisols	Aquents	Psammaquents	Typic Psammaquents	
	Adjacent fallow	Ultisols	Ustults	Kandiustults	Grossarenic Kandiustults	Acrisols
Kyado	Yam farm	Inceptisols	Ustepts	Dystrustepts	Typic Dystrustepts	
	Adjacent fallow	Ultisols	Ustults	Kandiustults	Typic Kandiustults	Acrisols

Suitability Evaluation of the soils

The land qualities of the pedons were used to evaluate for the suitability of the soils for yam and maize production. Table 13, shows that when climatic data, drainage, slope and soil depth of the study areas (Sankara, Jotar and Kyado) were matched with the land use requirements for maize production, they scored 85 % (S_1), implying optimal conditions for maize, cassava and yam production. Soil texture was moderately suitable (S_3) for the land ultilization types scoring 70 % except in cassava farm (CF) where it scored 35 % thus, not suitable (N). Soil fertility parameters: pH, total nitrogen, organic carbon, available P, CEC and base saturation) were rated highly to not suitable, scoring 85 % (S_1) to 35 % (N) for the land ultilization types. Aggregate suitability evaluation showed that the soils of MF, MFC and YF were moderately suitable (S_2) while the soils of YFC, CFC and CF were marginally suitable (S_3) for maize production

The suitability evaluation for yam showed that when the climatic data, drainage and slope scored 85 % (S_1) implying ideal conditions (Table 14). Amongst the soil characteristics investigated soil texture was moderately suitable for the land ultilization types but it was not suitable (N) only in cassava farm (CF). Soil depth was optimal for all the land uses scoring 85 % (S1) (table 26). Data on soil fertility (pH, total nitrogen, organic carbon, Available phosphorus, CEC and base saturation) were rated highly to marginally suitable, scoring 85 % (S_1) to 55 % (S_3) for the land ultilization types. Aggregate Suitability evaluation using parametric methods indicated that the soils of the study areas were moderately suitable (S_2) for the production of yam excluding only the soils of cassava farm (CF) which was marginally suitable (S_3).

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Table 13: Suitability evaluation for maize production

Land Qualities/ pedon	Sankara		Jotar		Kyado	
	MF	MFC	CF	CFC	YF	YFC
Climate (C):						
MAR (mm)	S_3(55)	S_3 (55)	S_3 (55)	S_3 (55)	S_3 (85)	S_3 (55)
MAT (C)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)
Soil physical properties						
Soil texture	S_2 (70)	S_2 (70)	N (35)	S_2 (70)	S_2 (70)	S_2 (70)
Depth (cm)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)
Soil fertility						
Soil P^H	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)
CEC (cmolkg)	S_3 (55)	S_3 (55)	S_3 (55)	N (35)	S_3 (55)	N (35)
Base saturation (%)	S_3 (55)	S_3 (55)	S_3 (35)	S_1 (85)	S_3 (55)	S_2 (70)
Organic Matter (gkg)	S_2 (70)	S_3 (55)	N (35)	S_3 (55)	S_2 (70)	S_2 (70)
Avail. P (mgkg)	S_2 (70)	S_2 (70)	S_2 (70)	S_2 (70)	S_2 (70)	S_2 (70)
Wetness (W):						
Soil drainage	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)
Topography (t):						
Slope (%)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)
Aggregate suitability class	S_2 (63.00)	S_2 (62.85)	S_3 (42.30)	S_3 (42.95)	S_2 (63.50)	S_3(43.5)

CF: cassava farm, CFC: cassava farm control, MF: maize farm, MFC: maize farm control, YF: yam farm, YFC: yam farm control, S_1: Highly suitable; S_2: Moderate suitable; S_3: Marginally Suitable; N: Not suitable

Table 14: Suitability evaluation of the study areas for yam production

Land Qualities/ pedon	Sankara		Jotar		Kyado	
	MF	MFC	CF	CFC	YF	YFC
Climate (C):						
MAR (mm)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)
MAT (C)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)
Soil physical properties						
Soil texture	S_2 (70)	S_2 (70)	N (35)	S_3 (55)	S_2 (70)	S_2 (70)
Depth (cm)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)
Soil fertility (F)						
Soil Ph	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)
CEC (cmolkg)	S_3 (55)	S_3 (55)	S_3 (55)	S_3 (55)	S_3 (55)	S_3 (55)
Base saturation (%)	S_2 (70)	S_2 (70)	S_2 (70)	S_1 (85)	S_2 (70)	S_2 (70)
Organic Matter (gkg)	S_3 (55)	S_3 (55)	S_3 (55)	S_3 (55)	S_2 (70)	S_2 (70)
Avail. P (mgkg)	S_2 (70)	S_2 (70)	S_2 (70)	S_2 (70)	S_2 (70)	S_2 (70)
Wetness (W):						
Soil drainage	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)
Topography (t):						

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Slope (%)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)	S_1 (85)
Aggregate suitability Class	S_2 (63.30)	S_2 (63.30)	S_3 (46.15)	S_2 (63.30)	S_2 (63.45)	S_2 (63.45)

MF: maize farm, MFC: maize farm control, CF: cassava farm, CFC: cassava farm control, YF: yam farm, YFC: yam farm control, S_1: Highly suitable; S_2: Moderate suitable; S_3: Marginally Suitable; N: not suitable

CONCLUSION

The study showed that the soils of the study areas varies in their characteristics, classes and suitability for a defined use. Sankara and Kyado soils were observed to be mostly moderately suitable (S_2) for the production of the study crops due to limitation posed by some chemical fertility parameters (OM, TN, CEC, BS and avail. P). Therefore, adequate application of organic material (such as adequate incorporation of organic matter) and chemical fertilizers (urea and NPK fertilizers) were recommended for the soils, for this will potentially raise the suitability of the soils to highly suitable (S_1). The soils of Jotar were observed to be mostly marginally suitable (S_3) for the production of the study crops due to the limitation posed by soil texture and soil chemical properties (OM, TN, CEC and avail. P). Therefore, the use of sustainable agronomic practices such as proper tillage system, soil mulching, bush fallowing and adequate application of organic materials were recommended for the soils in order to potentially raise the suitability of the soils to moderately suitable (S_2) or highly suitable (S_1).

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