Original Research Article

Semi-Detail Soil Survey and Land Suitability Evaluation for Sugarcane Production at Tungan Ahmadu District, Koko-Besse LGA Kebbi State Nigeria

Abstract

A semi-detailed soil survey and land suitability evaluation for sugarcane production was conducted at Tungan Ahmadu Koko-Besse LGA, of Kebbi State Nigeria to obtain comprehensive soil data for characterization and classification. The aim was to generate detailed information on the properties, genesis, land characteristics, and classification of soils for their suitability for sugarcane production. The study was carried out in a 4,000ha land area. An interval of 250x250m was used for augering and surface sampling of the soils at a scale of 1:25.000. In each soil mapping unit that was identified a soil profile pit was dug, described and soils sampled in each horizon from bottom-up, to minimize contamination by falling debris and was analyzed in the laboratory. Each soil profile pit was dug to a standard size (200 cm long, 100 cm wide, and a maximum depth of 200 cm or until an impenetrable layer or water table was encountered. Each pit was described regarding its full range of morphological characteristics according to International Standard these include soil depth, horizon thickness, the color of matrix and mottles, texture, structure, consistency, porosity, included materials, roots, and horizon boundary. In addition, records of vegetation/land use, slope, depth to the water table, and internal drainage status was obtained for each profile. Measured variables in the data set were analyzed using descriptive statistics such as means and weighted average. Seven soil mapping units tagged TGA1, TGA2, TGA3, TGA4, TGA5, TGA6, and TGA7 were identified based on landforms and soil properties. The physical properties of the soils indicate a relatively high bulk density and low porosity. The soils are slightly acidic (6.30) to moderately acidic (5.60) had low total nitrogen, organic carbon, and CEC hence low fertility. The soils in the study area are moderately deep, poorly drained, and generally loamy sand to sandy in texture. Based on the USDA Soil Taxonomy classification system, three soil units were identified as TGA1, TGA4, TGA5 and TGA6 (Haplustepts), TGA2 and TGA7 (Haplustalfs), and TGA3 (Terriorthents) which correlate according to the World Reference Base (WRB) as Arenosols, Luvisols, and Fluvisols.

INTRODUCTION

Soil is one of the most important natural resources and proper understanding of its properties is necessary for judicious, beneficial, and optimal use on sustainable basis (Jagdish *et al.,* 2009). Basic information about the soils is provided by soil survey (Ray *et al.,* 2000) which involves characterization and categorization of soils into groups at varying levels of generalization according to their morphological, physical, chemical, and mineralogical properties. Classification includes organization of knowledge, which ease in remembering properties, clearer understanding of relationships, ease of technology transfer and communication between scientist and end users (Boul *et al.,* 2003).

Land suitability evaluation is the process of making predictions of land performance over time based on specific types of uses (Rossiter, 1996). This assessment is always carried out separately for each category of land use (Reshmidevi *et al.,* 2009).

Non-usage of soil survey information has resulted in plant nutrient depletion, nutrient toxicity, heaving of architectural structures, and collapse of engineering structures. Others include compaction, flooding, poor yield, and general food insecurity. Marginal and derelict lands are erroneously converted to agricultural farmlands and pastures. Consequently, there is increased soil degradation, especially by mismanagement by the farmers in the study area. In the light of the above, Wilson (2001) suggested the application of scientific information in solving sub-Saharan African food needs so long as such information are presented in customized forms (Kufoniyi, 2000) possibly using geographic information systems.

MATERIALS AND METHODS

Study Area

The study was carried out in selected area of Tungan Ahmadu village of Koko-Besse Local Government Area Kebbi State Nigeria for sugarcane production. The research site lies on latitude 11°22'25.4"N and longitude 4°32'15.6"E. Tungan Ahmadu of Koko-Besse falls within the Sudan savannah of the semi-arid zone of Nigeria. The annual rainfall is variable and ranges from 600mm to 700mm with an average of 650mm during the period 1997 to 2014 (Usman *et al.,* 2016). It has an average relative humidity of 51-79%. Harmattan period which is the drier and coolest period of the year has a temperature range of 17-22°C experienced between Decembers to February yearly. However, the vegetation in the study area is related to grassland savannah forest, short medium forest (scattered clustered), dwarf vegetation (scattered isolated), grass vegetation, thick vegetation, stony-grass vegetation (scattered sparse) and short-trees (Usman *et al.*, 2016).

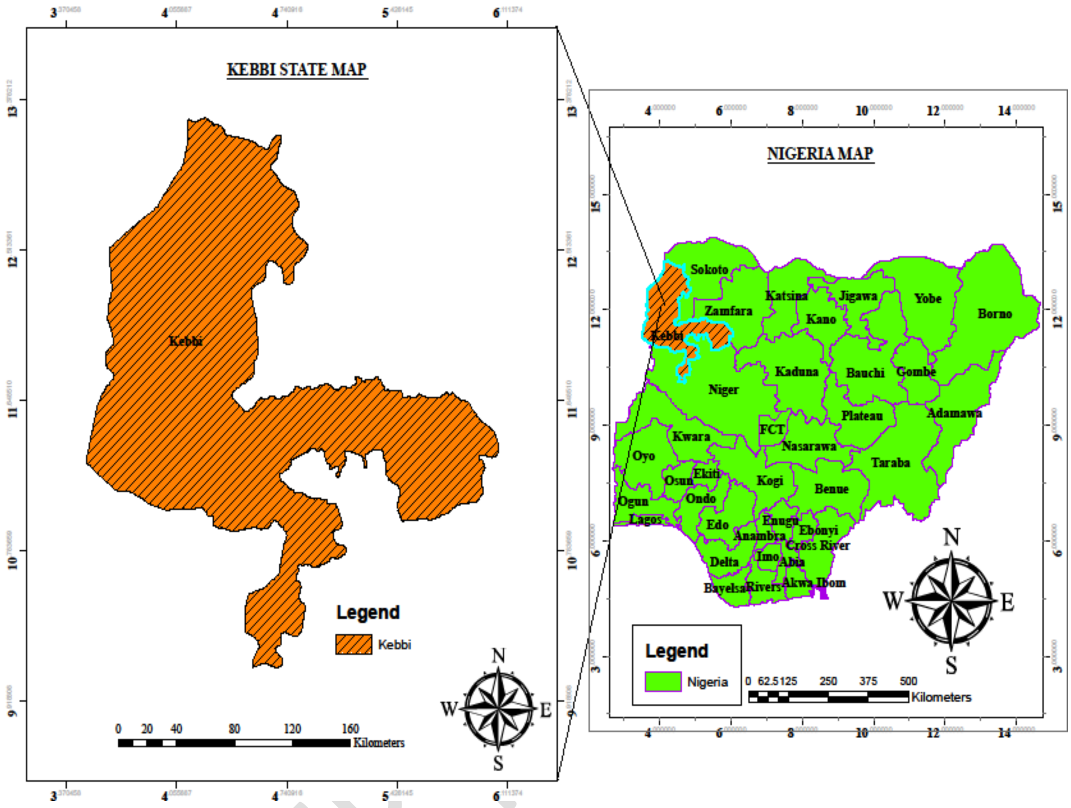

Fig. 1: Map of Kebbi State (Orange colour left) extracted from Map of Nigeria.

Field study

A semi-detailed soil survey was conducted in Tungan Ahmadu District of Koko-Besse Local Government Area of Kebbi State at a scale of 1:25,000 covering a 4,000ha land. This was done by first establishing a baseline followed by soil augering along transects to identify soil types and plot boundaries within the area. However, Visual Soil Assessment (VSA) as well as environmental assessment was conducted.

Each soil profile pit was dug to standard size (200 cm long, 100 cm wide and maximum depth of 200 cm or until an impenetrable layer or water table is encountered.

Each pit was described regarding its full range of morphological characteristics according to International Standard (FAO, 2006; Soil Survey Staff, 2012). These include soil depth, horizon thickness, colour of matrix and mottles, texture, structure, consistency, porosity, included materials, roots and horizon boundary. In addition, records of vegetation/land use, slope, depth to water table and internal drainage status was obtained for each profile. However, following the descriptions, soil samples (disturbed and bulk) were collected from each genetic horizon for laboratory analyses.

Laboratory Methods

Particles Size Analysis

Particle size distribution was determined by the method of Gee and Or (2002). Sand, silt and clay were determined by the Bouyoucos hydrometer using sodium hexametaphosphate as dispersant.

Soil Reaction (pH)

Soil pH was determined in both water and solution at 1:1 soil/water or solution ratio. Using a pye Unicam Model 290Mk pH meter.

Electrical Conductivity (EC)

Electrical conductivity was determined in 1:2.5 soil/water ratio using a Wheatstone bridge at 25^{O}C.

Organic Carbon (OC)

The organic carbon was determined by Walkey-Black dichromate wet oxidation method as described by Nelson and Sommers (1986).

Organic Matter (OM)

The organic matter was determined by colorimetric method (Datta *et al.*, 1962). Organic matter is oxidized with the chromic acid.

Total Nitrogen (TN)

Total nitrogen content of the soils was determined using the micro-Kjeldahl technique as describe by Bremner and Mulvaney (1982).

Available Phosphorus

Available phosphorus was determined following the procedure described by IITA (1979) using Bray-1 extraction method (Bray and Kurtz, 1945).

Exchangeable Bases

Exchangeable Bases (Ca, Mg, K and Na) were determined using NH_4OACsaturation method as described by Thomas (1982). Potassium and sodium were read from the undiluted extract on a Galenkamp flame analyser. Calcium and magnesium were read on a Pye Unicam model Sp 192 atomic absorption spectrophotometer (AAS) at 423 and 285 nM wavelength respectively.

Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) was determined by the neutral (pH 7.0) NH_4OAC saturation method (Rhoades, 1982). $CEC_{clay} = \frac{CEC_{soil} - (3.5\%C)}{\%Clay} \times 100$

Bulk Density

Undisturbed core samples were used for bulk density determination in the laboratory by oven drying as described by Blake and Hartge (1986).

Particle Density

Particle density was determined using this formula:

$$PD = \frac{Weight\ of\ oven\ dry\ soil\ (g)}{volume\ of\ soil\ particles\ (cm^3)}$$

Total Porosity

Total porosity was calculated mathematically using the formula below:

$$F = 1 - \left(\frac{bd}{pd}\right) \times 100$$

Where:

bd= Bulk density

pd= Particle density

RESULTS AND DISCUSSION

Table 1: Morphological Properties of the Soils

Pedon	Horizon	Depth (cm)	Colour	Mottling	Structure	Consistence	Boundary
				TGA 1 (*Haplustepts*)			
1	Ap	0-22	10YR 4/2	-	Platy	Friable	D
	ABg	22-34	7.5YR 4/2	10YR 5/3	Platy	Friable	G
	BCg_1	34-57	10YR 4/3	7.5YR 4/4	ABK	Friable	D
	BCg_2	57-91	10YR 5/2	10YR 4/6	ABK	Loose	D
				TGA 2 (*Haplustalfs*)			
2	Ap	0-29	10YR 6/2	-	SBK	V. Hard	D
	Bt_1	29-61	10YR 3/3	-	ABK	Hard	D
	Btg_1	61-112	10YR 4/7	10YR 8/8	Platy	Hard	D
	Btg_2	112-156	7.5YR 5/1	7.5YR 5/8	Platy	Hard	D
	BCg	156-170	10YR 5/3	7.5YR 5/6	ABK	Hard	G
				TGA 3 (*Torriorthents*)			
3	Ap	0-21	10YR 6/2	10YR 5/8	SBK	Firm	D
	AC_1	21-60	10 YR 3/3	-	SBK	V. Firm	D
	AC_2	60-112	10YR 3/3	-	ABK	V. Firm	D
				TGA 4 (*Haplustepts*)			
4	Ap	0-21	10YR 3/2	-	SBK	Hard	D
	AB	21-31	10YR 5/2	-	ABK	Hard	G
	ABg	31-77	10YR 6/2	10YR 5/6	Platy	Hard	D
	BCg	77-103	10YR 6/3	7.5YR 5/8	Platy	Hard	D
	Bt	103-137	10YR 5/1	7.5YR 5/6	SBK	Friable	D
				TGA 5 (*Haplustepts*)			
5	Ap	0-20	10YR 4/2	-	SAB	Sticky	D
	AB	20-27	10YR 5/6	-	SG	Loose	G
	Btg_1	27-69	10YR 2/2	2.5YR 7/4	SAB	Sticky	D
	Btg_2	69-120	10YR 3/3	2.5YR 7/6	SAB	Sticky	D
	BC	120-168	10YR 4/3	-	SAB	Sticky	D
				TGA 6 (/*Haplustepts*)			
6	Ap	0-14	10YR 4/4	-	SAB	Loose	G
	ABg_1	14-42	10YR 3/3	2.5YR 3/6	SAB	Loose	D
	ABg_2	42-86	10YR 6/4	7.5YR 5/8	SG	Loose	D
	BCg_1	86-149	5YR 5/8	2.5YR 4/8	SG	Loose	D
	BCg_2	149-182	7.5YR 4/6	-	SG	Loose	D

			TGA 7 (*Haplustalfs*)				
7	Ap	0-33	10YR 6/4	-	SAB	Hard	D
	Bt$_1$	33-51	10YR ¾	-	ABK	Hard	D
	Bt$_2$	51-76	10YR 4/4	-	SAB	Hard	D
	Bt$_3$	76-108	7.5YR 2/3	-	SAB	Hard	D
	BCg$_1$	108-128	7.5YR 4/7	2.5YR 5/6	SAB	Hard	D
	BCg$_2$	128-167	10YR 5/2	2.5YR 5/6	Loose	Friable	D

SCL= Sandy clay loam, S$_i$L= silt loam, S$_i$C= silt clay, SL= sandy loam, SC= sandy clay, S= sand, LS= loamy sand ABK=Angular blocky, SG=Single grain, SAB= Sub-Angular blocky, D=Diffuse, G=Gradual.

Morphological Characteristics

The morphological properties of the soils are presented in Table 1 of TGA1 moderately deep with a depth by nearly 100cm. The Ap horizon had greyish dark colour (10YR 4/6). Mottles ranges from greyish brown (10YR 5/3) to brownish (7.5YR 4/4) dark yellowish-brown mottles (10YR 4/6). The presence of mottles in these horizons is an indication of prolonged poor drainage in the soil. The soil ranges from sand to loamy sand, sandy loamy, sandy clay loam for surface horizon and in the subsoils the soils are clayey loam and silty clay. The surface horizon is plate-like and subangular blocky while the subsoil had platy, angular and subangular blocky structure.

In TGA2, the soils were deep nearly 200cm. The soil has distinctive colour patterns, bearing light brownish gray (10YR 6/2) in the surface horizon, dark brown (10YR 3/3) with sudden change to gray colour (7.5YR 5/1) in the sub-surface horizon. The soil has may roots, there were presence of mottles in the subsurface horizons which varies in colour from yellowish (10YR 8/8) to strong brown colours (7.5YR 5/8 and 7.5YR 5/6), the soil is poorly drained because of the redoximorphic characteristics of the soil. The texture varies from sand to sandy loam on the surface to silty clay to sandy clay at the subsoil. The soils have angular blocky structure at the surface and changes to angular blocky to platy structure at the subsurface and changes to angular blocky at the sub-horizon, however, the soils were very hard at the surface and hard in consistency at the sub-surface.

In the soil profile TGA3 is moderately deep with a depth of 112cm, the soils in this mapping unit are lightly brownish gray in colour (10YR 6/2) in the surface and changed to dark brown (10YR 3/3 and 10YR 3/3) at a depth of 21-112cm. The presence of mottles was observed at the surface soils with yellowish brown colour (10YR 5/8). The textures of the soil were sandy clay at the surface, and this resulted with the firmness of the soil. The soils were sub-angular blocky in structure within the depth of 0-60cm and angular blocky at the subsoil level. The soils were firm at the surface and very firm in at the subsurface soils, this will affect water infiltration and because of poor pore spaces in the soil.

The soils in TGA4 have a depth of 137cm, they are very dark grayish brown in colour (10YR 3/2) at the depth of 0-21cm, grayish brown colour (10YR 5/2) at the second horizon of 21-31cm, the subsequent horizons the soils were having features of brownish colours ranging from light brownish gray (10YR 6/2) pale brown (10YR 6/3) and gray colour (10YR 5/1). In this profile it was observed that there were mottles at the subsoils ranging from yellowish brown (10YR 5/6) strong brown colours (7.5YR 5/8 and 7.5YR/5/6) the soil has redoximorphic features which is an indication of poor drainage. Averagely, the texture of the soil in this mapping unit was observed to be loamy sand at the surface level and clayey at the subsoil. The structural features of the soil at the surface and subsoil was observed to be sub-angular blocky, and platy at the sub surface. Thus, the soils were hard in consistency only friable at the subsoil.

The soils in TGA5 are deep having up to 168cm in depth, the colour at the surface is dark greyish brown (10YR 4/2) this indicates the presence of reduced (ferrous) iron oxide (Brady *et al.*, 2006), yellowish brown (10YR 5/6), very dark brown (10YR 2/2) this indicates relatively moderate content of organic matter in the soil (Brady *et al.,* 2006), dark brown (10YR 3/3) and in the subsoil it was observed that the soils are brown in colour (10YR 4/3). The soil has low aeration because of the presence of mottles observed to be light reddish brown (2.5YR 7/4) and light red coloured mottles (2.5YR 7/6) this is because of ferric oxide present in the soil. The textural class of the soil is mostly loamy sand to sandy loam. The structural nature of the soil is sub-angular blocky except at the depth of 20-27cm which was single grained structure.

Soil mapping unit TGA6 is very deep with 182cm in depth, the soil in this mapping unit showed distinctive characteristics in terms of colour, structure, and textural class. The colour ranges from dark yellowish brown colour (10YR 4/4) at the surface, dark brown (10YR 3/3) in the subsurface between the depth of 14-42cm with presence of mottles of dark red (2.5YR 3/6), this is an indication of the presence of ion oxide in the soil, which is an indication of poor aeration and drainage, the subsequent sub-horizons shows light yellowish brown colour (10YR 6/4) with the mottles of strong brown colour (7.5YR 5/8), yellowish red colour (5YR 5/8) and red coloured mottles (2.5YR 4/8) hence, the subsoil horizon was strong brown colour (7.5YR 4/6). The soil in this category has loam and sand in their textural class. Structurally, the epipedons are sub-angular blocky, and the sub horizon were single grained in structure and loose; this is because of the high proportion of sand. This soil unit exhibits the characteristics of poor drainage and aeration because of the available reddish mottles in soil unit and relatively moderate organic matter content because of the presence brownish colour in some horizons.

The soil mapping unit TGA7 has a depth of 167cm, the colour in this mapping unit showed that the surface horizons were light yellowish brown (10YR 6/4), dark yellowish brown (10YR 3/4 and 10YR 4/4) very dark brown (7.5YR 2/3) strong brown (7.5YR 4/2) with mottling of red colour (2.5YR 5/6) the subsoil horizon was greyish brown (10YR 5/2) this indicates ferric reactions. The average proportion of silt, sand, clay was present in this mapping unit. The mapping unit tends to have deep rooting and water infiltration attributes. The structural classification of the soil in this mapping unit are mostly sub angular blocky and angular block.

Table 2: Physical Characteristics of the Soils

Pedon	Horizon	Depth (cm)	Particle Size Distribution (%)			Textural Class	Bulk Density	Particle Density	Porosity (%)
			Sand	Silt	Clay		(gcm^{-3})		
					TGA 1 (Haplustepts)				
1	Ap	0-22	52.4	24.9	22.7	SL	1.43	2.33	39
	ABg	22-34	77.8	11.2	11.0	LS	1.44	2.28	37
	BCg_1	34-57	83.7	7.2	9.0	LS	1.83	2.33	21
	BCg_2	57-71+	87.6	3.2	9.0	LS	-	-	-
		Mean	**75.4**	**11.6**	**12.9**		**1.57**	**2.31**	**32.33**
					TGA 2 (Haplusstalfs)				
2	Ap	0-29	91.6	3.4	5.0	S	1.82	2.18	17
	Bt_1	29-61	54.3	13.2	32.5	SL	1.85	1.81	2
	Btg_1	61-112	32.7	19.1	48.2	SL	-	-	-
	Btg_2	112-156	48.4	9.3	42.3	S_1L	-	-	-

	BCg	156-170	30.7	19.2	50.1	SC	-	-	-
		Mean	**51.5**	**12.8**	**35.6**		**1.84**	**1.99**	**9.5**
TGA 3 (Torriorthents)									
3	Ap	0-21	38.6	19.1	42.3	SC	1.99	1.88	6
	AC_1	21-60	48.4	19.1	32.5	S_iL	1.85	2.00	7
	AC_2	60-112	44.5	28.9	26.6	S_iL	-	-	-
		Mean	**43.4**	**22.4**	**33.8**		**1.92**	**1.94**	**6.5**
TGA 4 (Haplustepts)									
4	Ap	0-21	72	9.2	18.8	LS	2.23	2.39	7
	AB	21-31	68.0	21.0	11.0	LS	2.09	2.39	13
	ABg	31-77	87.6	5.3	7.1	LS	-	-	-
	BCg	77-103	91.6	5.3	3.1	S	-	-	-
		Mean	**79.8**	**10.2**	**10.0**		**2.16**	**2.39**	**10**
TGA 5 (Haplustepts)									
5	Ap	0-20	70.0	19.0	11.0	LS	1.80	2.28	21
	AB	20-27	87.6	9.3	3.1	LS	2.04	2.51	19
	Btg_1	27-69	68.0	15.1	16.9	SL	2.05	2.39	14
	Btg_2	69-120	62.2	11.2	26.6	SL	-	-	-
	BC	120-168	68.0	9.3	22.7	SL	-	-	-
		Mean	**71.1**	**12.8**	**16.1**		**1.96**	**2.39**	**18**
TGA 6 (Haplustepts)									
6	Ap	0-14	83.7	13.2	3.1	LS	1.83	2.04	11
	ABg_1	14-42	83.7	7.3	9.0	LS	1.95	2.97	33
	ABg_2	42-86	81.8	9.2	9.0	LS	1.99	2.65	25
	BCg_1	86-149	81.5	8.9	9.2	S	-	-	-
	BCg_2	149-182	80.4	8.6	9.3	S	-	-	-
		Mean	**83.1**	**9.9**	**7.0**		**1.92**	**2.55**	**23**
TGA 7 (Haplustalfs)									
7	Ap	0-33	48.4	32.8	18.8	S_iL	1.37	2.23	39
	Bt_1	33-51	24.9	40.6	34.5	S_iC	1.57	2.58	15
	Bt_2	51-76	32.7	42.6	24.7	S_iC	2.08	2.45	39
	Bt_3	76-108	28.8	34.7	36.5	SCL	-	-	-
	BCg_1	108-128	42.5	28.9	28.6	S_iL	-	-	-
	BCg_2	128-167	77.8	13.2	9.0	LS	-	-	-
		Mean	**42.5**	**32.1**	**25.3**		**1.67**	**2.42**	**31**

SCL= Sandy clay loam, S_iL= silt loam, S_iC= silt clay, SL= sandy loam, SC= sandy clay, S= sand, LS= loamy sand

Physical Characteristics of the Soils

The soils of the study area have is dominated with high proportion of sand content at all the soil mapping unit with higher sand content of 83.1% at TGA6 (Table 2) and lowest sand content of 42.5% (Table 2). These soils are formed on alluvial soil deposit processes (Bullinger-Weber and Gobat, 2005).

The silt distribution was irregular within soil depth irrespective of landscape positions, probably because these soils were developed *in situ* (eluvial deposits) and partly to geological processes involving sorting of soil materials by biological or agricultural activities, clay migration through eluviation and illuviation, or surface erosion by runoff or their combinations (Malgwi and Abu, 2011 and Saikh *et al.*, 1998). It was also observed that TGA7 had the highest amount of silt with an average value of 32.1% with the lowest value at TGA4 (10.2%) Table 2

The soils of the study area are found to contain substantial clay fraction, clay was lest to sand and silt in dominance in all the pedons. Clay was higher in the TGA2 with an average value of 35.6% and lowest mean value at TGA6 7.0% (Table 2). Its distribution within the subsoil of all the pedons was irregular, this is an attribute of a cambic horizon (Buol *et al.,* 2003; Chadwick and Grahm, 2000).

Consequently, the textural soil forms varied from loamy sand, sandy loam to silty loam overlying sandy, sandy clay and silty clay soils respectively in the overall soils of the study area.

The results showed relatively high bulk density values was recorded in TGA2, TGA3, TGA4, TGA5, TGA6 and TGA7 of 1.84, 1.92, 2.16. 1.96, 1.92 and 1.67g/cm^3 is attributed to compaction caused by low or zero tillage operation in the study area. Plant performs best in bulk densities below 1.6g/cm^3 and 1.1g/cm^3 for clayey and sandy soils respectively (Donahue *et al.,* 1990). Root growth could also be inhibited due to high bulk density because of soil resistance to root perpetration, poor aeration, slow movement of nutrients and water and build-up of toxic gases and root exudates (Tarawali *et al.,* 2001; Brady and Weil, 2002; Odunze, 2006). Consequently, the bulk density value of TGA1 is more favourable for crop production, while that of TGA2, TGA3, TGA4, TGA5, TGA6 and TGA7 may impair proper root penetration. Brady (1987) reported that particle density values increase with soil depth. Similar results were also reported by Idoga *et al*. (2006) in soils of Samaru area, Nigeria, this contradicts the findings in the study area, which shows inconsistent values from the mapping unit

Highest porosity value was recorded in TGA1 with 32.33% followed by TGA7 with 31.0%, the lowest value was seen in TGA3 with mean value of 6.5%. Generally, the porosity of the soils in the mapping unit was poor owning to poor structural development in the subsurface horizons, but this can be improved by working on the soils. Fetter (1998) and Rieu and Sposito (1991) recommended that soils having porosity of over 50 and 45-50% of volume are good agricultural soils. The values of porosity recorded for soils in this study shows that they the porosity is not good for agricultural soils but can be improved by working on the soil. The porosity values in the study area are poor owing to poor structural development in the sub-surface horizons.

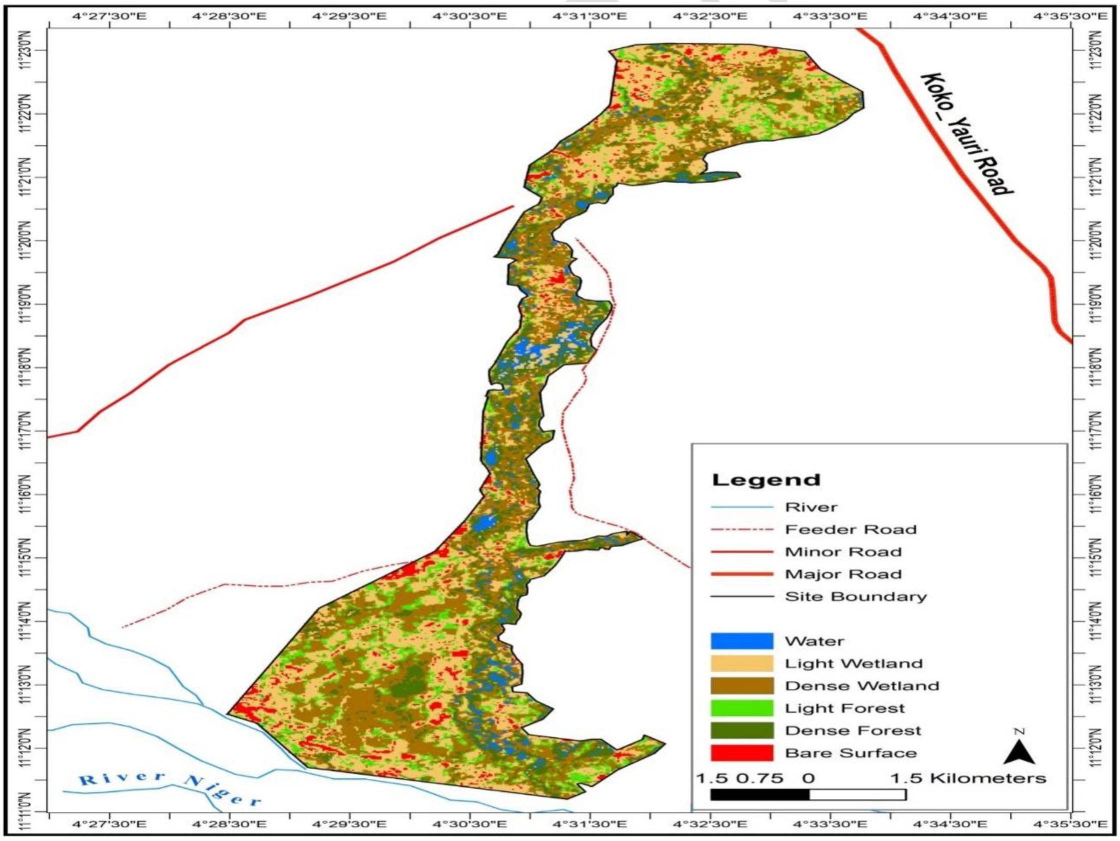

Figure 2: Land Use Cover

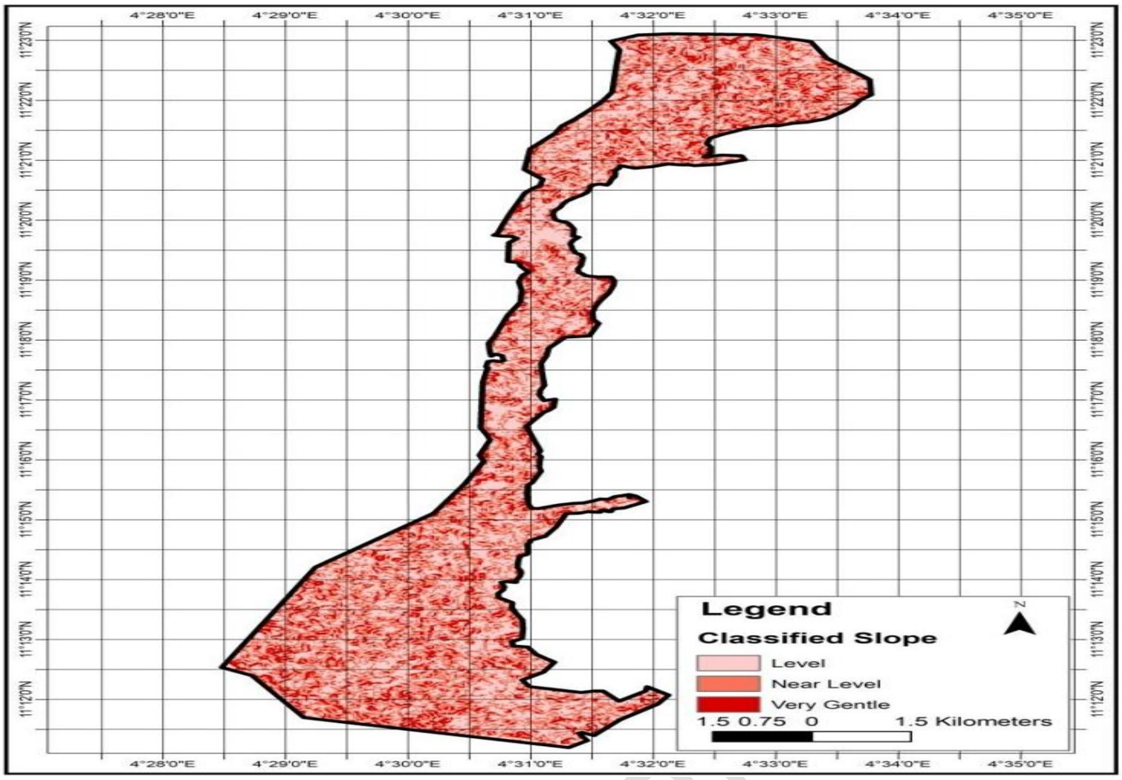

Fig. 3: Slope Map

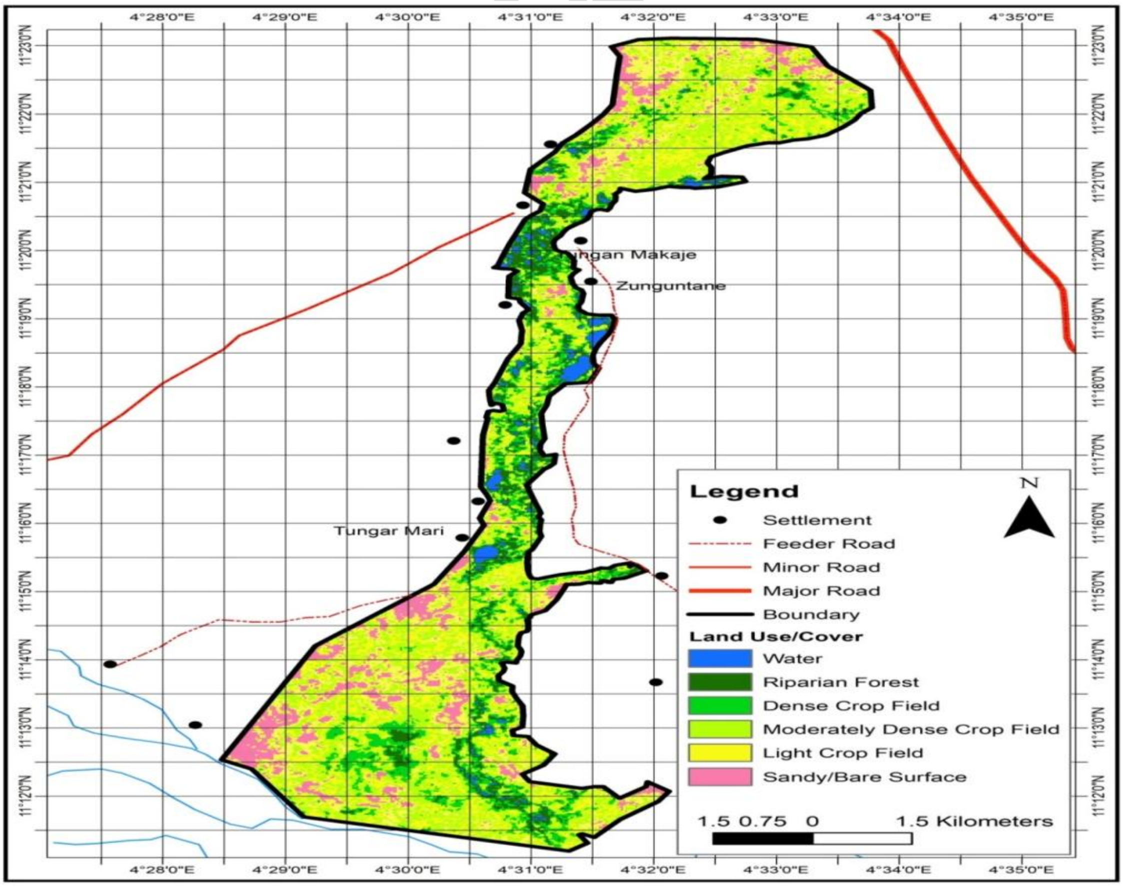

Fig. 4 : Land Use Cover types

Table 3: Chemical Properties of the Soils.

Pedon	Horizon	Depth (cm)	pH (H_2O)	EC dSm^{-1}	OC	TN gkg^{-1}	OM	AP $mgkg^{-1}$	Ca	Mg	K	Na	CEC
									cmolkg^{-1}				
						TGA 1 (Haplustepts)							
1	Ap	0-22	6.38	0.093	0.70	0.05	1.20	1.00	0.60	0.53	0.40	0.70	33
	ABg	22-34	6.36	0.031	0.80	0.05	1.43	1.00	0.60	0.41	0.33	0.53	33
	BCg_1	34-57	6.33	0.198	0.84	0.05	0.50	0.73	0.74	0.60	0.12	0.31	27
	BCg_2	57-71+	6.17	0.021	1.15	0.05	1.90	0.84	0.75	0.72	0.11	0.34	27
		Mean	**6.3**	**0.85**	**0.87**	**0.05**	**1.26**	**0.89**	**0.67**	**0.57**	**0.24**	**0.47**	**30**
						TGA 2 (Haplustalfs)							
2	Ap	0-29	6.14	0.022	0.51	0.04	0.90	1.10	0.84	0.50	0.15	0.20	20
	Bt_1	29-61	6.00	0.017	0.64	0.04	1.00	0.91	0.80	0.50	0.16	0.30	31
	Btg_1	61-112	6.03	0.015	0.90	0.04	1.61	0.90	0.92	0.52	0.50	0.30	27
	Btg_2	112-156	5.86	0.018	0.25	0.05	0.32	0.85	0.90	0.47	0.55	0.81	37
	BCg	156-170	5.69	0.0096	0.83	0.06	1.40	0.84	0.90	0.46	0.60	0.83	37
		Mean	**5.9**	**0.016**	**0.63**	**0.046**	**1.05**	**0.92**	**0.87**	**0.49**	**0.39**	**0.49**	**30**
						TGA 3 (Torriorthents)							
3	Ap	0-21	5.5	0.031	0.50	0.04	0.90	1.00	0.62	0.70	0.70	0.23	36
	AC_1	21-60	5.6	0.18	1.25	0.04	2.00	1.00	0.64	0.70	0.70	0.30	36
	AC_2	60-112	5.7	0.08	0.81	0.04	1.47	1.00	0.53	0.81	0.81	0.30	33
		Mean	**5.6**	**0.097**	**0.85**	**0.04**	**1.40**	**1.00**	**0.59**	**0.74**	**0.74**	**0.28**	**35**
						TGA 4 (Haplustepts)							
4	Ap	0-21	6.3	0.052	1.30	0.05	2.20	1.00	1.35	1.00	0.50	1.17	32

	AB	21-31	6.4	0.023	0.92	0.04	1.62	1.00	1.15	0.84	0.50	1.05	32
	ABg	31-77	6.0	0.014	0.36	0.04	0.58	1.00	1.15	0.72	0.16	0.48	31
	BCg	77-103	6.0	0.013	1.00	0.06	1.70	0.70	0.80	0.58	0.17	0.27	32
		Mean	**6.2**	**0.025**	**0.89**	**0.047**	**1.53**	**0.93**	**1.11**	**0.79**	**0.33**	**0.74**	**32**
TGA 5 (Haplustepts)													
5	Ap	0-20	6.3	0.012	0.90	0.06	1.60	1.05	1.20	0.82	0.60	0.72	20
	AB	20-27	5.9	0.028	0.85	0.05	1.41	1.05	0.95	0.50	0.60	0.71	20
	Btg_1	27-69	6.1	0.012	0.65	0.05	1.04	1.06	0.93	0.50	0.60	0.82	20
	Btg_2	69-120	6.2	0.014	0.08	0.4	0.19	0.80	0.75	0.50	0.30	0.40	22
	BC	120-168	6.1	0.087	0.48	0.04	0.70	0.80	0.60	0.45	0.32	0.40	27
		Mean	**6.1**	**0.031**	**0.59**	**0.12**	**0.99**	**0.95**	**0.88**	**0.55**	**0.48**	**0.61**	**36**
TGA 6 (Haplustepts)													
6	Ap	0-14	6.6	0.010	0.28	0.05	0.30	0.80	1.01	1.00	0.20	0.32	30
	ABg_1	14-42	6.4	0.0082	0.35	0.05	0.50	1.00	1.02	0.95	0.22	0.32	36
	ABg_2	42-86	6.3	0.0071	0.74	0.06	1.20	0.75	0.90	0.70	0.10	0.23	22
	BCg_1	86-149	5.9	0.0075	0.49	0.06	0.70	0.75	0.90	1.00	0.10	0.21	22
	BCg_2	149-182	5.9	0.0063	0.50	0.06	0.90	0.75	0.90	0.25	0.10	0.20	22
		Mean	**6.2**	**0.0078**	**0.47**	**0.056**	**0.72**	**0.81**	**0.95**	**0.78**	**0.14**	**0.26**	**44**
TGA 7 (Haplustalfs)													
7	Ap	0-33	6.3	0.0705	0.37	0.04	0.50	0.71	0.90	0.75	0.20	0.74	25
	Bt_1	33-51	6.2	0.0074	0.72	0.04	1.25	1.00	0.90	0.76	0.20	0.73	33
	Bt_2	51-76	5.7	0.0076	1.00	0.04	1.70	0.90	0.93	0.70	0.22	0.70	33
	Bt_3	76-108	6.2	0.0075	0.35	0.04	0.50	0.87	0.92	0.60	0.22	0.70	39
	BCg_1	108-128	6.2	0.013	0.27	0.05	0.38	0.70	0.80	0.48	0.10	0.70	36

BCg_2	128-167	6.6	0.0081	0.56	0.05	0.90	0.65	0.80	0.46	0.10	0.70	34
	Mean	**6.2**	**0.0190**	**0.55**	**0.043**	**0.87**	**0.81**	**0.88**	**0.63**	**0.17**	**0.71**	**33**

EC=Electrical conductivity, OC=Organic carbon, TN=Total nitrogen OM=Organic matter, AP=Available phosphorus Ca=Calcium, Mg=Magnesium K=Potassium, Na=Sodium, CEC=Cation exchange capacity.

Chemical Properties of the Soils.

The chemical characteristics of the soils are presented in Table 3 the pH value in TGA1 were slightly acidic, with a mean value of 6.3 (Table 3). The pH values range from 6.2-6.4 from the surface to the sub-surface horizon. The pH of the soil tends to increase with depth.

The electrical conductivity (EC) value was generally low in TGA1 with an average of 0.85 dSm^{-}1 and appears to be the highest value in all the mapping units. The soil in the mapping unit is not saline this is in accordance to the ratings of (Smith and Doran, 1996) salinity rate (0-1.4 dSm^{-1} non-saline, 1.2-2.8 dSm^{-1} slightly saline, 2.5-5.7dSm^{-1} moderately saline, 4.5-11.4dSm^{-1} strongly saline and 9.0-11.5+ dSm^{-1} very strongly saline). This is caused as result of the textural class of the pedon with low clay content in all the horizon as opined by USDA (2014), that soils that have higher content of smaller soil particles (clay) conduct more electrical current than those soils that have higher content of larger silt and sand particles.

Organic carbon content is very low in the pedon (TGA1) with a mean value of 0.87 %. the value decreased regularly with increase in depth. The total nitrogen (TN) is very low in this profile having mean values of 0.050 g/kg^{-1}. The low values of the total nitrogen reflect losses through leaching and crop removal. The farming system in the study area is such that crops like sugarcane are predominant with few farmers having nitrogen replenishing crops like cowpea and groundnuts as part of the crops on their farms. Similar result was obt ained by Sharu *et al.* (2013) in their findings in Dingyadi District of Sokoto State.
Organic matter in this profile (TGA1) was very low, with an average value of organic matter content of 1.26%, following Landon (1991) ratings of organic matter (>20% very high, 10-20% high, 4-10% medium, 2-4% low and <2% very low). The low organic matter content of the soil in this location can be attributed to factors such as continuous cultivation, frequent burning of farm residues carried out by farmers without replenishing them (organic residues like compost).

Available phosphorus (AP) content in the pedon (TGA1) is very low comparing it with the ratings of Koralage *et al.* (2015) rating of >10.7mgkg^{-1} extremely high, 6.6-10.7mgkg^{-1} high, 2.5-6.6mgkg^{-1} medium and low with value of 2.5mgkg^{-1}). The AP is relatively higher at the soil surface and decreases as increase in depth. The mean value of 0.89 $mgkg^{-1}$ was observed in this pedon.

The exchangeable bases, calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) were very low. This was also observed in the findings of Sharu *et al.* (2013) which also correspond with the findings of Noma *et al.* (2004), and Yakubu *et al.* (2011). The average values of calcium (0.67$cmolkg^{-1}$), magnesium (0.57$cmolkg^{-1}$), sodium (0.47$cmolkg^{-1}$) and with the least been potassium having an average value of (0.24$cmolkg^{-1}$). The cation exchange capacity (CEC) is very high with an average of 30$cmolkg^{-1}$ this is according to Esu rating (1991) rating of <6 low, 6-12 medium and >12 high

For TGA2 profile of the study area, the pH (H_2O) value was slightly acidic with an average pH value of 5.90. In this profile the electrical conductivity (EC) was very low which has 0.016 dSm^{-1}. This indicates no-salinity level of the soil mapping unit (Smith and Doran 1996)

The organic carbon was very low in the entire mapping unit (TGA2) and it increases as increase in depth across the horizons the average value of OC in this profile was 0.63%. Organic C content of less than 1.16% for tropical soils has been reported to be an indication of soil degradation and a high risk of soil erosion (Barrow, 1991). High intensity of agricultural activities depletes soil organic matter content (Greenland *et al.*, 1992)

Total nitrogen (TN) was very low and there was a gradual increase in TN as increase in depth, this may have resulted because of leaching down to the subsurface. The mean value was 0.046gkg^{1}.

In this soil profile, the organic matter (OM) was generally very low, with an average value of 1.05%. There was a gradual increase in organic matter content as increase in depth. Thus, to increase organic matter in the soil, organic residues should be applied in the soil and soil management practices that will increase organic residues in the soil like, groundnut, soybean, rotational and reduced burning of farm residues.

The available phosphorus (AP) content in this pedon (TGA2) was very low. AP was decreasing in value downward the subsurface of the profile this is because the phosphorus does not easily leach. Average value of available phosphorus in this profile was 0.92mgkg^{-1}

The chemical properties of TGA3 horizons are revealed in Table 3. The pH in this profile was strongly to slightly acidic, the pH increases down the profile. The mean value of the pH was 5.6 which is moderately acidic in nature. The electrical conductivity (EC) of this profile was very low which has an average value of 0.097 dSm^{-1} which is an indication of non-salinity nature of the soil of the profile.

The organic carbon (OC) content is very low in the entire profile and it increases irregularly as increase in depth whereas the mean value of OC in this profile is 0.85% which is very low comparing it with Landon (1991) organic carbon ratings.

Total nitrogen (TN) was very low, and the values were uniform throughout the profile having a mean value of 0.04 gkg^{-1}

In this soil profile, the organic matter is very low, with an average value of organic matter content of 1.40% (very low). There was an abrupt increase in organic matter content as the depth increase, but it decreases at the subsoil (Bm horizon) with the value of 1.47%. Decrease in the organic matter downwardly in the profile may be as result of leaching due to irrigational activities going on in the location and removal by crops due to continuous cultivation of the land. Available phosphorus (AP) in this pedon (TGA3) was very low and the distribution in the profile was uniform with a mean value of 1.00mgkg^{-1}.

The exchangeable bases were very low in this profile, magnesium and potassium having uniform mean values of 0.74cmolkg^{-1} followed by calcium 0.59cmolkg^{-1} with the lowest value of sodium 0.28cmolkg^{-1}. Cation exchange capacity (CEC) was very high in comparison with the ratings of Esu (1991). Therefore, the cation exchange capacity (CEC) was very high with an average value of 35cmolkg^{-1}.

The chemical attributes of TGA4 are presented in Table 3. Generally, the soil in this profile was slightly acidic, with a mean value of 6.2 there was decrease in acidity as increase in depth of the profile. Electrical conductivity was generally low with an average EC value of 0.025dSm^{-1} which is an indication of non-saline status of the soil according to the limits set by Schoeneberger *et al.* (2002) the soil salinity rating according to him as partitioned into five levels: non-saline (0-2 dSm^{-1}), very slightly saline (2-4 dSm^{-1}), slightly saline (4-8 dSm^{-1}), moderately saline (8-16 dSm^{-1}), and strongly saline (>16 dSm^{-1}), this is an indication of low clay particles in the profile.

The organic carbon (OC) in this profile had an average value of 0.89%, it was highest at the surface horizon (Ap) with a value 1.30%, the values decrease abruptly downwardly and increased at the subsurface. Total nitrogen mean value was $0.047gkg^{-1}$. Low total nitrogen values were also observed by Sharu *et al.* (2013) in Dingyadi District of Sokoto State.

Organic matter (OM) is very low, in this profile with the mean value of 1.53% (very low) according to Landon (1991) ratings. There was an abrupt increase in organic matter content as the depth increase, but it decreases at the subsurface. Decrease in the organic matter downward the profile may be as result of leaching due to continuous cultivation of the land.

Available phosphorus (AP) content in this pedon is very low with an average value of 0.93 $mgkg^{-1}$ there was an increase value of AP in the downwards increase in depth of the profile. Thus, comparing with the ratings of Koralage *et al.* (2015). The AP is higher at the soil surface and decreases as increase in depth.

Total exchangeable bases were very low in this profile, calcium was dominant ($1.11cmolkg^{-1}$) with the lowest value been potassium $0.33cmolkg^{-1}$. Cation exchange capacity (CEC) ($32cmolkg^{-1}$) was very high in comparison with the ratings of Esu (1991).

pH values in this profile (TGA5) was generally slightly acidic with a mean value of 6.1. The average value of EC was generally low with a value of EC $0.031dSm^{-1}$ this shows that the soil of this profile to be non-saline in nature this is in accordance to the limits set by Schoeneberger *et al.* (2002).

The organic carbon (OC) in this profile was is largely very low with an average value of 0.59% there was decrease in the organic carbon rates as increase in depth. The mean value of total nitrogen ($0.12gkg^{-1}$) was very low. There is decrease in amount of TN in the profile as increase in depth.

The average value of organic matter (OM) 0.99% is very low, according to Landon (1991) ratings. There was an inconsistent decrease in organic matter content as the depth increase. Using Koralage *et al.* (2015) rating limit of Available phosphorus

(AP) content in this profile was very low with a mean value of 0.95mgkg^{-1} there was gradual decrease value of AP in the downwards as increase in depth of the profile.
Exchangeable bases were very low in this profile, and there was downward decrease of exchangeable bases in all the horizons, calcium has the highest mean value of 0.88 cmolkg^{-1} with the lowest value of potassium (0.48cmolkg^{-1}). The cation exchange capacity (CEC) (36 cmolkg^{-1}) was very high in the mapping unit according to the ratings of Esu (1991).

The pH value in this profile (TGA6) was slightly acidic with average value of 6.2. The average electrical conductivity (EC) was 0.0078dSm^{-1} however; there was a decrease in EC as increase in depth of the profile.
The organic carbon (OC) was generally low with an average value of 0.47% there was an increase as increase in depth. Total nitrogen has mean value of 0.056 gkg^{-1}. The values tend to be uniform throughout the horizons.

The organic matter (OM) content increases as increase in depth of the profile, it was low at the surface and higher at the subsurface, with a mean value of 0.72%. The rate of Available Phosphorus (AP) was generally low with an average value of 0.81mgkg^{-1}; there is uniformity of AP in the subsurface horizons, the value reduces downwards.

Generally, the total exchangeable bases were low with a mean value of 0.53cmolkg^{-1}. There was decrease of the exchangeable bases (Ca, Mg, K and Na) as increase in depth. Calcium has the highest average value of 0.95cmolkg^{-1} while potassium with the lowest value of 0.14cmolkg^{1}. The CEC was very high having a value of 44cmolkg^{-1}; and this is the highest value recorded in all the mapping units.

From the table matrix (Table 3) pH values in the soil mapping unit TGA7 were slightly acidic having an average value of 6.2. Electrical conductivity (EC) was very low with a mean value of 0.0190dSm^{-1} this is indication of non-saline status of the soil in the profile according to Smith and Doran (1996) salinity rating.
Organic carbon content in this profile was very low with an average value of 0.55gkg^{-1} there was irregularity in the amount of OC across the profile. Average value of Total Nitrogen (TN) in this profile was generally low with a mean value of 0.043gkg^{-1}. The low value of total nitrogen reflects losses by the farming activities in the area like continuous cultivation with little or no replacement by the farmers in the study area.

The organic matter (OM) content was very low with a mean value of 0.87%, the values were relatively higher at the subsurface. There is irregular increase and decrease in the values of organic matter across the profile as increase in depth. Available phosphorus (AP) was very low with a mean value of 0.81mgkg^{-1}, according to Koralage *et al.* (2015) rating.

Exchangeable bases were low, calcium dominates with a mean value of 0.88cmolkg^{-1} while potassium has the lowest value of 0.17cmolkg^{-1}. There was decrease in number of exchangeable bases as increase in depth of the profile. Cation exchange capacity (CEC) was high with an average value of 33cmolkg^{-1}, and it increases as increase in depth.

Soil Classification

The soils were classified using USDA Soil Taxonomy (Soil Survey Staff, 2014) and the classifications were correlated with World Reference Base (WRB) system (FAO/ISSS, 2006). The seven soil mapping units that were identified in the study area and denoted by TGA1, TGA2, TGA3, TGA4, TGA5, TGA6 and TGA7 were classified as presented below:

The soils of TGA1, TGA4, TGA5 and TGA6 are classified as Inceptisols at the order level. At the suborder level the soils were classified as *Ustepts* because the soils have Ustic moisture regime similar soil type was observed by Sharu *el al.* (2013), in *Runjin Abdu* settlement of Dingyadi District area of Sokoto State. The soil was further classified into subgroup as Aquepts. The soil is classified into great group as *Haplustepts* the soils are dry for moderate periods in normal years.

Soil unit TGA2, and TGA7 are classified as Alfisols at order level because of the presence of an argillic horizon. It is Ustalfs at the suborder level. They are classified as *Haplustalfs* because they do not have a kandic or natric horizon, do not have a duripan that has its upper boundary within 100 cm of the surface, do not have a petrocalcic horizon within 150 cm of the surface, and do not have much plinthite and *Haplustalfs* (Soil Survey Staff, 1999 and 2014).

Soils of map unit TGA3 is classified as Entisols at the order level because the soils show no evidence of horizon development. At the suborder level they are classified as

Orthents. Few of these soils (*Orthents*) are recent loamy or fine eolian deposits or debris from recent landslides or mudflows. They occur in any climate and any vegetation. They are classified to great group as *Torriorthents* they occur in cool to hot arid regions. They have little organic carbon; the vegetation on *Torriorthents* is commonly sparse and consists mostly of xerophytic shrubs (Soil Survey Staff, 1999 and 2014).

Classification According to the World Reference Base (WRB)

TGA1, TGA4, TGA5 and TGA6 soil mapping unit was classified as *Arenosols* under the WRB grouping, they soil comprise deep sandy soils. This includes soils in residual sands after *in situ* weathering of usually quartz-rich sediments or rock, and soils in recently deposited sands such as dunes in deserts and beach lands. Corresponding soils in other classification systems include *Psamments* (United States of America).

TGA2 and TGA7 are classified as *Luvisols* at the reference soil groups (RSGs) for having an argic horizon overlain by loamy sand. At the lower level, is classified as *Haplic Luvisols* for having a texture of loamy sand.

Soils of map unit TGA3 is classified as *fluvisols*, the *fluvisols* accommodate genetically young soils in fluvial, lacustrine, or marine deposits. Despite their name, *Fluvisols* are not only restricted to *river* sediments they also they also occur in lacustrine and marine deposits. Many Fluvisols correlate with Alluvial soils (Russia)

Table 4 Suitability levels of the soil mapping units

Criteria for suitability	Rainfall	Drainage	Soil texture	Soil depth	Slope	pH	Erosion hazard	Risk of flooding	Distance to road	Distance to sugar mill	Remark	Longitude	Latitude
Mapping unit													
TGA1	N	S3	S2	S3	S1	S1	S2	S3	S3	N	S3	4.55016	11.3663
TGA2	N	S2	S3	S1	S1	S1	S2	S3	S3	N	S2	4.53436	11.3581
TGA3	N	S3	S1	S1	S1	S1	S2	S3	S3	N	S2	4.51719	11.3017

TGA4	N	S1	S3	S1	S1	S1	S2	S3	S3	N	S2	4.50826	11.2413
TGA5	N	S2	S2	S1	S1	S1	S2	S3	S3	N	S2	4.53642	11.3749
TGA6	N	S2	S2	S1	S1	S1	S2	S3	S3	N	S2	4.49968	11.2001
TGA7	N	S2	S2	S1	S1	S1	S2	S3	S3	N	S3	4.53402	11.2015

S1=Suitable, S2=Moderately Suitable, S3= Marginally Suitable and N=Currently Not Suitable. TGA=Tungan Ahmadu

Land Suitability Evaluation

Climate and soil are very important environmental factors that influences the growth and yield of sugarcane. Sugarcane can grow and reach optimal crop production in various types of soils if the soil has good structure, aeration and solum which allows the root to grow to depth of at least 60cm (Sys *et al.*, 1993). Most external natural factors are solar radiation, temperature, evapotranspiration, and precipitation. (Mueller *et al.* 2010; FAO 2007). In addition to climate, soil characteristics also greatly affect the productivity of the plant. There are basically five land quality groups in suitability determination of soil for sugarcane production which are climate, topography, soil physical properties, wetness, and fertility (Sys *et al.*, 1993).

Based on the generally low fertility levels of the soils post-harvest incorporation of plant residue into the soil instead of the usual burning of crop residue can help to restore or stabilize the soil fertility level of the soil. To increase the moisture regime of the soil for sugarcane production, adequate and suitable water will be required for irrigation.

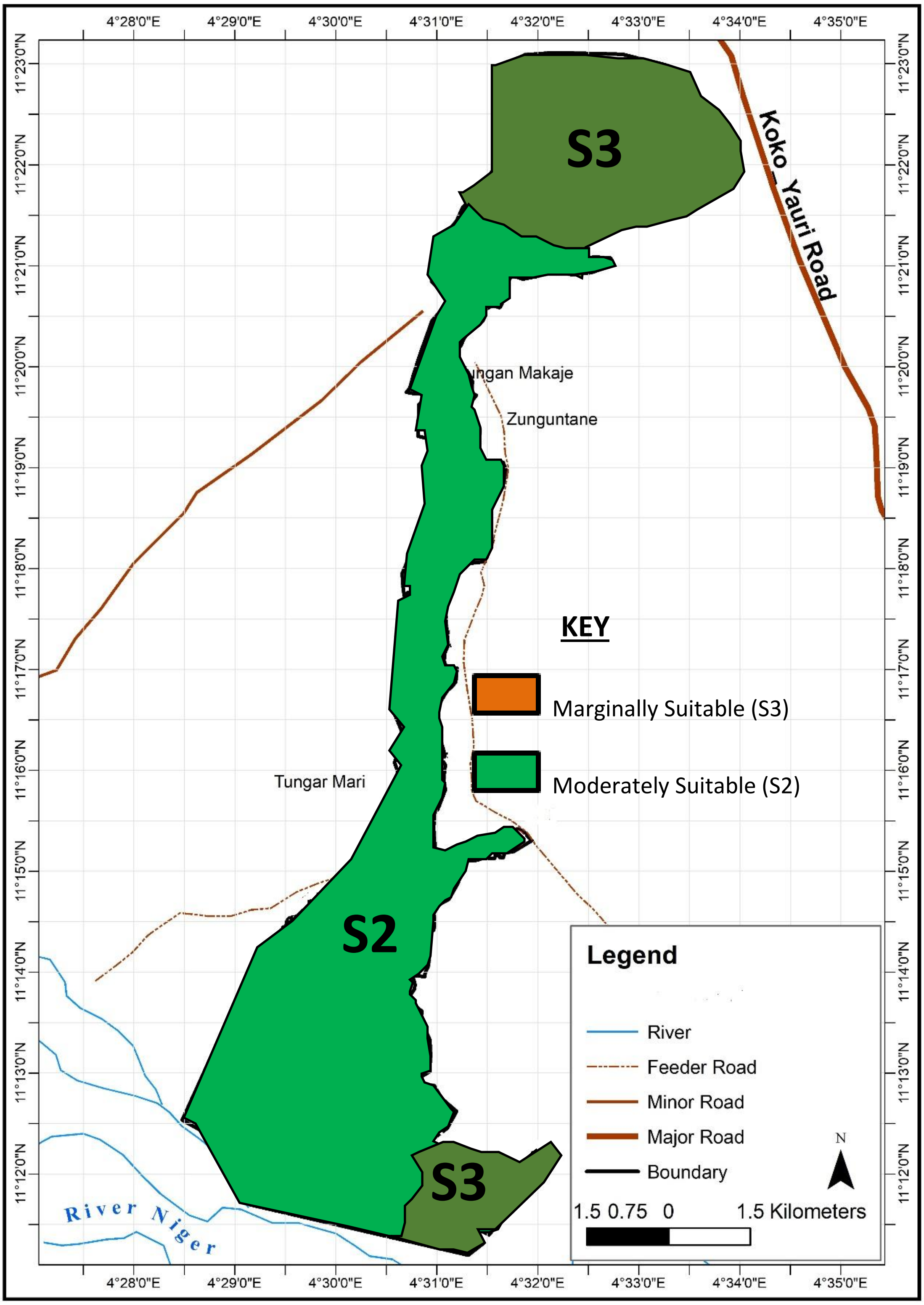

Fig. 5: Land suitability levels for sugarcane in Tungan Ahmadu District Area of Koko-Besse, Kebbi State Nigeria.

Conclusion

It is revealed that soils in the study area are moderately deep, moderately drained, and generally loamy sand to sandy in texture the soil ranges from block to sub-angular blocky in structure. From the findings, according to USDA soil taxonomy system, three soil units were identified as: TGA1, TGA4, TGA5 and TGA6 (Haplustepts), TGA2 and TGA7 (Haplustalfs) and TGA3 (Terriorthents) and correlate according to the World Reference Bases (WRB) as Arenosols, luvisols, and fluvisol respectively. Physical properties of the soils indicate a relative high bulk density and low porosity.
The soils have moderately low inherent natural fertility with low basic cations (Ca, Mg, K, Na), organic carbon, cation exchange capacity, total nitrogen. It is recommended that organic manures, fertilizer, and liming be carried out to supply deficient nutrients and enhance soil pH. Thus, the soil in the study needs to be well tilled to improve its structure.
From the results on chemical properties, it revealed that most of the nutrients were low in quantity and make not much suitable for sugarcane production.

REFERENCES

Barrow C.J. Wild. A, and Adams D. (1991). Organic matter dynamics in soils of the tropics from myth to complex reality. In "Myths and Science of Soils of the Tropics" (R. Lal and P. A. Sanchez, Eds.), pp. 17–33. SSSA-ASA, Madison, WI, 1992.

Blake, G.R. and Hartge. K.H. (1986) Bulk density. In: Klute, A., Ed., Methods of Soil Analysis, Part 1-Physical and Mineralogical Methods, 2nd Edition, Agronomy Monograph 9, American Society of Agronomy Soil Science Society of America, Madison, 363-382.

Boul, S. W., Southard, R.J Graham, R.C and McDaneil, P.A (2003). Soil Genesis and Classification, (5th ed.) State Avenue Ames, Lowa, lowa State Press.

Bray, N.C and Kurtz, L.T. (1945). Determination of Total Organic and Available forms of Phosphorus in soils. *Soil Science Journal* 59: 39-45.

Brady, N.C. (1987). *The nature and properties of Soils*, 8th edition, Macmillan, New York.

Brady, N., and Weil, R. (2002). *The Nature and Properties of Soils*, 13^{th} Edition. Prentice Hall. Upper Saddle River, New Jersey. 960 p.

Brady, Nyle C., and Ray R. Weil (2006) Elements of the Nature and Properties of soils, page 95. Prentice Hall. 2006.

Bremner, J.M. and Mulvaney, C.S. (1982) "Total nitrogen", In: A.L. Page, R.H. Miller and D.R. Keeny, (Eds.), *Methods of Soil Analysis,* American Society of Agronomy and Soil Science Society of America, Madison, pp. 1119-1123.

Bullinger-Weber G, J.M. (2005). Identification of facies models in alluvial soil formation: The case of a Swiss alpine floodplain. Gobat Laboratory Soil and Vegetation, University of Neuchatel, Emile-Argand 11, CH-2007

Chadwick O.A, and Grahm R.C. (2000) *Pedogenic processes M.E. Sumner* (Ed.), Handbook of Soil Science, CRC Press, Boca Raton, 2000; pp. 41–75.

Datta, N.P., Khera, M.S., Saini, T.R., (1962). A rapid colorimetric procedure for the determination of organic carbon in soils. *J. Indian Soc. Soil Sci.* 10 (1), 67–74.

Donahue, R.L, Raymond, M.W. and Schick Line, J.C. (1990). *Soils: An introduction to soils and plant growth*. Prentice hall of India. 667pp.

Esu, I.E. (1991). Detailed Soil Survey of NIHORT Farm at Bunkure, Kano State, Nigeria. Institute for Agricultural Research, Ahmadu Bello University, Zaria.

FAO (2006). Guidelines for Soil Descriptions 4^{th} Edition. Food and Agricultural Organization of United Nation FAO), Rome, Italy.

FAO [Foood and Agriculture Organization]. 2007. Land evaluation-Towards a revised framework. http://www.fao/ag/agl/public.stm. (Accessed on March 2012).

Fetter, C.W. (1998). *Applied Hydrogeology,* Macmillan publishing co. New York.

Gee, G.W. and Bauder, J.W. (1986). Particle–size analysis. In methods of soil analysis. A Klute (Ed). Part 1. 2^{nd} ed. Agron. ASA and SSSA, Madison WI.P383.

Gee, G.W., and Or, J.W. (2002). Particle-size analysis. p. 383–411. *In* A. Klute (ed.) Methods of soil analysis. Part 1. 2^{nd} ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Idoga, S., Ibanga, I.J., and Malgwi, W.B. (2006). Variation in Soil morphological and physical properties and their management implications on a toposequence in Samaru area, Nigeria. pp. 19–25. In Proceedings of the 31^{st} Annual Conference of Soil Science Society of Nigeria. Ahmadu Bello University, Zaria, Nigeria. November 13–17.

IITA (1979): Selected methods for soils and plant Analysis Manual series No. 1 IITA. International Institute for Tropical Agriculture.

Jagdish, P, Ray, S.K., Gajbhiye, K.S., and Singh, S. R (2009). Soil of Selsura Research farm in Wardha District, Maharashtra, and their suitability for crops. Agro- pedology 19:84-91.

Koralage S.A, Weerasinghe, P. Silva, N. R. N., and De Silva, C. S. (2015) The Determination of Available Phosphorus in Soil: A Quick and Simple Method.

Kufoniyi, O., (2000). Basic Concepts in Geographic Information Systems (GIS). In: Principles and Applications of GIS, Ezeigbo, C.U. (Ed.). Panaf Press, Lagos.

Landon, J.R. (1991). Booker Tropical soil manual. Longman Scientific and Technical Essex, UK. Pp 474.

Malgwi W.B, and Abu S.T. (2011) Variation in Some Physical Properties of Soils Formed on a Hilly Terrain under Different Land use Types in Nigerian Savanna. *Int J Soil Sci* 2011; 6: 150-63.

Mueller L, U Schindler, W Mirschel, TG Shepherd, BC Ball, K Helming, J Rogasik, F Eulenstein and H Wiggering. 2010. Assesing the Productivity Function of Soils. A Review. *Agron Sustain Dev* 30: 601-614. INRA.EDP Sciences.

Nelson, P.W., and Sommers, C.E. (1986). Total C, organic C and organic matter. In: PAGE, A.L. (Ed.). Methods of soil analysis. Part 2. Chemical methods. Madison: SSSA. p.539-579.

Noma, S.S., Ojanuga, A.G., Ibrahim, S.A. and Iliya, M.A. (2004). Detailed soil survey of the Sokoto- Rima flood plains at Sokoto, Nigeria. In Salako, F.K, Adetunji, M.T, Ojanuga, A.G, Arowolo T.A. and Ojeniyi, S.O. (Eds). *Managing Soil resources for food security and sustainable environment.* Proceedings of the 29th annual conf. of SSSN/University of Agriculture, Abeokuta, Nigeria Dec. 6-10, 2004.

Ray, S.K., Gajbhiye, K.S., Challa, O., Jagdish, S.N., Singh, S.R., Anantwar, G., Gaikawad, M.S., and Padihar, S.K (2000). Systematic soil survey to identify potential soil sodicity areas in parts of Tawa command, Madhya Pradesh. *J. Indian Soc. Soil Sci.* 48:346-351.

Reshmidevi, T.V., T.I Eldho, and R. Jana. (2009). A GIS-Integrated Fuzzy Rule Based Inference System for Land Suitability Evaluation in Agricultural Watersheds. Agr. Syst. 101(1–2):101– 109.

Rhoades, J.D. (1982). Cation exchange capacity. *In:* A.L. Page (ed.) Methods of soil analysis. Part 2: Chemical and microbiological properties (2nd ed.) Agronomy 9:149-157.

Rieu, S., and Sposito, T. (1991). Fractal Fragmentation, soil porosity and soil water properties. 1. Theory. *Soil Science. Society of American Journal,* **55:**1231-1238.

Rossiter, D.G., (1996). A Theoretical Framework for Land Evaluation (with discussion). Elsevier Scientific, Geoderma, 72(3-4): 165-202.

Saikh H, Varadachari C, and Ghosh K. (1998) Effect of deforestation and cultivation on soil CEC and contents of exchangeable bases: a case study in Simplipal National Park, India. Plant Soil 1998; 204: 175-81.

Schoeneberger, P.J., Wysocki, D.A., Benham, E.C. and Broderson, W.D. (Eds). (2002). Field book for describing and sampling soils, version 2.0 Nat. Soil survey center. NRCS, USDA, Lincolns, NE.

Sharu M. B, Yakubu, M., Noma, S.S., and Tsafe, A.I. (2013) Characterization and Classification of Soils on an Agricultural landscape in Dingyadi District, Sokoto State, Nigeria. *Nigerian Journal of Basic and Applied Science* (June 2013), 21(2): 137-147.

Smith, J.J and Doran, J.W. (1996). Measurement and use of pH and electrical conductivity for soil quality analysis. *In* Methods for assessing soil quality. J.W. Doran and A.J Jones (editors), Pages 169-185. Soil science society of America Special Publication 49. Madison, WI.

Soil Survey Staff. (1999). Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys, 2nd edition. Natural Resources Conservation Service. U.S. Department of Agriculture Handbook 436.

Soil Survey Staff (2014) Keys to Soil Taxonomy by Soil Survey Staff. United States Department of Agriculture Natural Resources Conservation Service Twelfth Edition, 2014.

Sys C., Van Ranst E., and Debaveye J. (1993): Land evaluation. Part 3: Crop requirements. Agricultural Publications 7, 3. General Administration of Development Cooperation of Belgium, Brussels, 199 p.

Usman S., Noma, S.S., and Kudiri, A.M. (2016). Dynamic Surface Soil Components of land and Vegetation types in Kebbi State Nigeria. *Eurasian J Soil Sci* 2016, 5 2) 113– 120.

Thomas, G.W. (1982). Exchangeable cations. *In:* A.L. Page (ed.). Methods of soil analysis. Part 2: Chemical and microbiological properties (2nd ed.) Agronomy 9:159-165.

Wilson, E., (2001). Applying Science to Sub-Saharan Africa`s Food Needs. In: The Unfinished Agenda: Perspectives on Overcoming Hunger, Poverty and

Environmental Degradation, Pinstrup-Andersen, P. and R. Pandya-Lorch (Eds.). Int. Food Policy Res. Nst., Washington DC., pp: 165-169.

Yakubu, M., Baraya, S., and Noma, S.S. (2011). Assessment of soil and water quality along river Kadarko in Sanyinna District, Sokoto State. In Hassan, W.A. Kyiogom, U.B. Tukur, H.M. Ipinjolu, J.K. Maigandi, S.A. Singh, A., Ibrahim, N.D., Dikko, A.U.