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 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 Luvisols, Arenosols, and Fluvisols respectively. Analyses on climate, topography, physical soil properties, wetness and fertility suitability at the research site returned results of TGA2, TGA3, TGA4, TGA5 and TGA6, moderately suitable (S2) while TGA1 and TGA7 are marginally suitable (S3) with limited factors of physical and chemical properties.

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 (Buol *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. There is an increasing demand for information on soils to produce food (Fasina and Adeyanju, 2007). Agriculture is the predominant economic activity in Nigeria hence there is need for appropriate and timely scientific information about the soils of Nigeria as well as site specific soil information.

Kebbi State virtually has available arable land for agricultural purposes to sustain its rapidly increasing population. This will however require proper land use planning and management to ensure the soils are put to optimal use. To provide a sound basis for this, reliable information on various soils of the state is needed.

Soil characterization provides the information needed for understanding of the physical, chemical, mineralogical, and microbiological properties of the soils used to grow crops, sustain forests and grasslands as well as support homes and societal structures (Ogunkunle, 2005). Soil classification, on the other hand, helps to organize our knowledge, facilitates the transfer of experience and technology from one place to another and helps to compare soil properties. According to Eswaran (1977), some different uses of soil characterization data include to aid in the correct classification of the soil and enable other scientists place the soils in their taxonomies or classification systems and to serve as a basis for more detailed evaluation of the soil as well as gather preliminary information on nutrient, physical or other limitations needed to produce a capability class. A soil characterization study, therefore, is a major building block for understanding the soil, classifying it and getting the best understanding of the environment (Esu, 2005).

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 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. The climate of the area is typical of tropical climate; characterized by wet and dry seasons. The dry season is usually 7 months in most cases from November to May while the rainy season last for 4-5 months usually from June to October (Usman *et al.,* 2016).

Field study

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 (Shepherd, 2000).

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 based on morphological characteristics according to established standard procedure (FAO, 2006). The characteristics described 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 pH was determined in both water (H20) and in CaCl2 solution at 1:1 soil/water or solution ratio using a pye Unicam Model 290Mk pH meter. Electrical conductivity was determined in 1:2.5 soil/water ratio using a Wheatstone bridge at 25^{O}C. The organic carbon was determined by Walkey-Black dichromate wet oxidation method as described by Nelson and Sommers (1986). The organic matter was determined by colorimetric method (Datta *et al.,* 1962). Organic matter is oxidized with the chromic acid. Total nitrogen content of the soils was determined using the micro-Kjeldahl technique as describe by Bremner and Mulvaney (1982). Available phosphorus was determined following the procedure described by IITA (1979) using Bray-1 extraction method (Bray and Kurtz, 1945). 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) was determined by the neutral (pH 7.0) NH_4OAC saturation method (Rhoades, 1982). $CEC_{clay} = \frac{CEC_{soil}-(3.5\%C)}{\%Clay} \times 100$. Undisturbed core samples were used for bulk density determination in the laboratory by oven drying as described by Blake and Hartge (1986).

Particle density was determined using this formula: $PD = \frac{Weight\ of\ oven\ dry\ soil\ (g)}{volume\ of\ soil\ particles\ (cm^3)}$

Total porosity was calculated mathematically using the formula below: $F = 1 - \left(\frac{bd}{pd}\right) \times 100$; where *bd=Bulk Density* and *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_iL= silt loam, S_iC= 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. The soil of all the pedons are generally deep with depth of >50cm. The colour of the soil varied from dark grey (10YR 4/2) at the surface horizon changing to yellowish brown (10YR 4/4) in the subsurface horizon. The texture of the soil varied from loamy sand to sandy loam in the surface horizon changing to loamy sand in the subsurface horizon with distinctive structures ranging from platy, sub-angular blocky and angular blocky. The consistence of the soil varied from hard to very hard; firm, loose and sticky-plastic. The clay content increased with depth which indicates the presence of argillic horizon. The root of the soils varied from many roots changing to medium roots in the surface horizon and very few roots in the subsurface horizons.

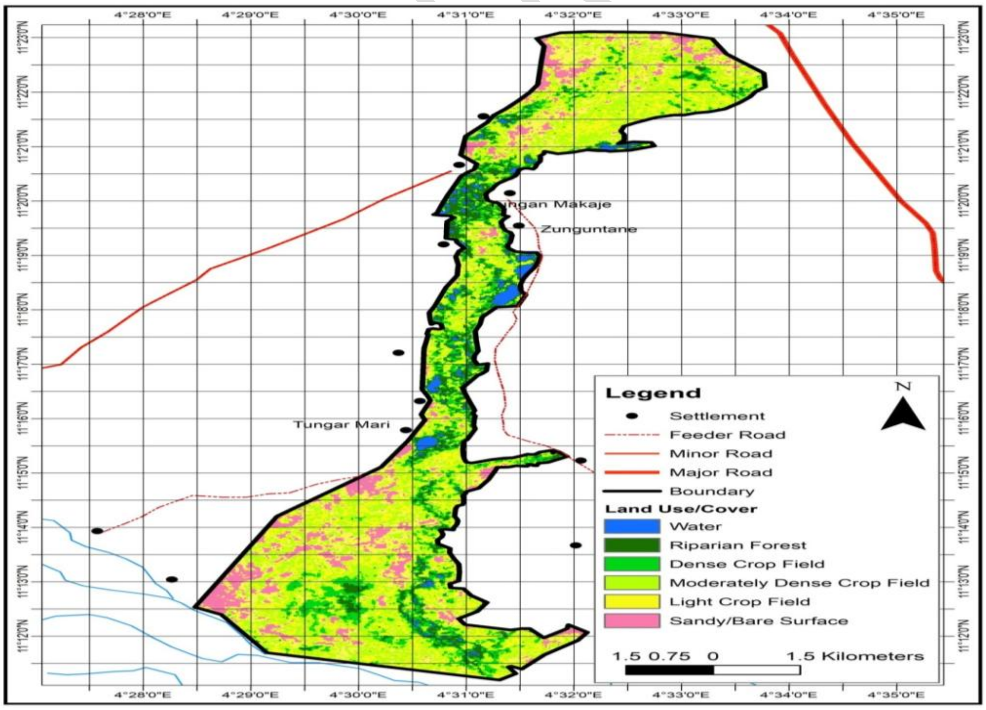

Fig. 1 : Land Use Cover types

Table 3: Chemical Properties of the Soils.

Pedon	Horizon	Depth (cm)	pH	EC	OC	TN	OM	AP	Ca	Mg	K	Na	CEC
			(H_2O)	dSm^{-1}		gkg^{-1}		$mgkg^{-1}$		$cmolkg^{-1}$			
						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 soil chemical properties are presented in Table 2. The pH values in all the pedon fall within slightly acidic range of 6.07. The moderately acidic pH values of the soils could be attributed to downward movement of the basic cation along the slope. The EC values in all the pedons fall within moderately low the soil in the mapping unit is not saline this is in accordance limits set by Smith and Doran (1996). The OC and OM values in all the pedons fall within very low range (0.693g/kg) and (1.117g/kg) respectively. The very low organic carbon values of the soils could be attributed to continuous cultivation and frequent burning of farm residues. The means value of TN; is very low in all the pedons having a value of 0.051g/kg ^{1}. The low values of TN reflect losses through leaching and crop removal. Similar result was obtained by Sharu *et al.* (2013) in their findings in Dingyadi Distrit of Soko to State, Nigeria. AvP; content in all the pedons was very low (0.901mgkg^{-1}) comparing it with limits set by Koralage *et al.* (2015). The exchangeable bases, $Ca, Mg, K\ and\ Na$ were very low having average values of; 0.85 cmolkg^{-1}; 0.65 cmolkg^{-1}; 0.36 cmolkg^{-1} and 0.59 cmolkg^{-1} respectively. 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 CEC is very high with an average value of 34.29cmolkg^{-1} this is according to Esu rating (1991).

Taxonomic Classification of the Soils

The soils were classified according to the USDA Soil Taxonomy System (Soil Survey Staff, 2014) and correlated with the FAO/UNESCO Legend of the World Reference Based (WRB) System (FAO/ISSS, 2006). These two systems are the most used ones in Nigeria for soil classification. The seven soils mapping units that were identified in the study area were designated TGAI; TGA2; TGA3; TGA4; TGA5; TGA6 and TGA7. The soils of TGA1; TGA4; TGA5; and TGA6 were classified as *Haplustepts* and corelate with WRB as Luvisols, these soils are dry for moderate periods in normal years, similar soil type was observed by Sharu *el al.* (2013), in *Runjin Abdu* settlement of Dingyadi District area of Sokoto State, Nigeria. Soil mapping units TGA2; and TGA7 are classified as *Haplustalfs* which correlate with WRB as *Arenosols,* they do not have a kandic or natric horizon (Soil Survey Staff, 1999); while Soil mapping unit TGA3 is classified to great group as *Torriorthents* they occur in cool to hot arid regions this also corelate with WRB as *Fluvisols*.

Table 3 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 Classes in the Study Area

Land suitability is usually evaluated using parameters, such as rainfall; texture; drainage; soil depth; slope; pH; erosion hazard; risk of flooding and accessibility. The basic land quality groups in suitability determination of soil for sugarcane production in the study area were climate; topography; soil physical and chemical properties (FAO, 2007). The land suitability levels of all the pedons are presented in Table 3 for sugarcane. The factors for suitability rating were based on the physical, chemicals and climatic attributes. The FAO Land suitability guidelines in which land has been classified as highly suitable (S1); moderately suitable (S2); marginally suitable (S3); currently unsuitable (N1); and permanently unsuitable (N2) has been adopted. Analyses on climate, topography, chemical and physical soil properties, wetness, and fertility suitability at the research site returned results of TGA2, TGA3, TGA4, TGA5 and TGA6, moderately suitable (S2) while TGA1 and TGA7 are marginally suitable (S3) with limited factors of physical and chemical properties.

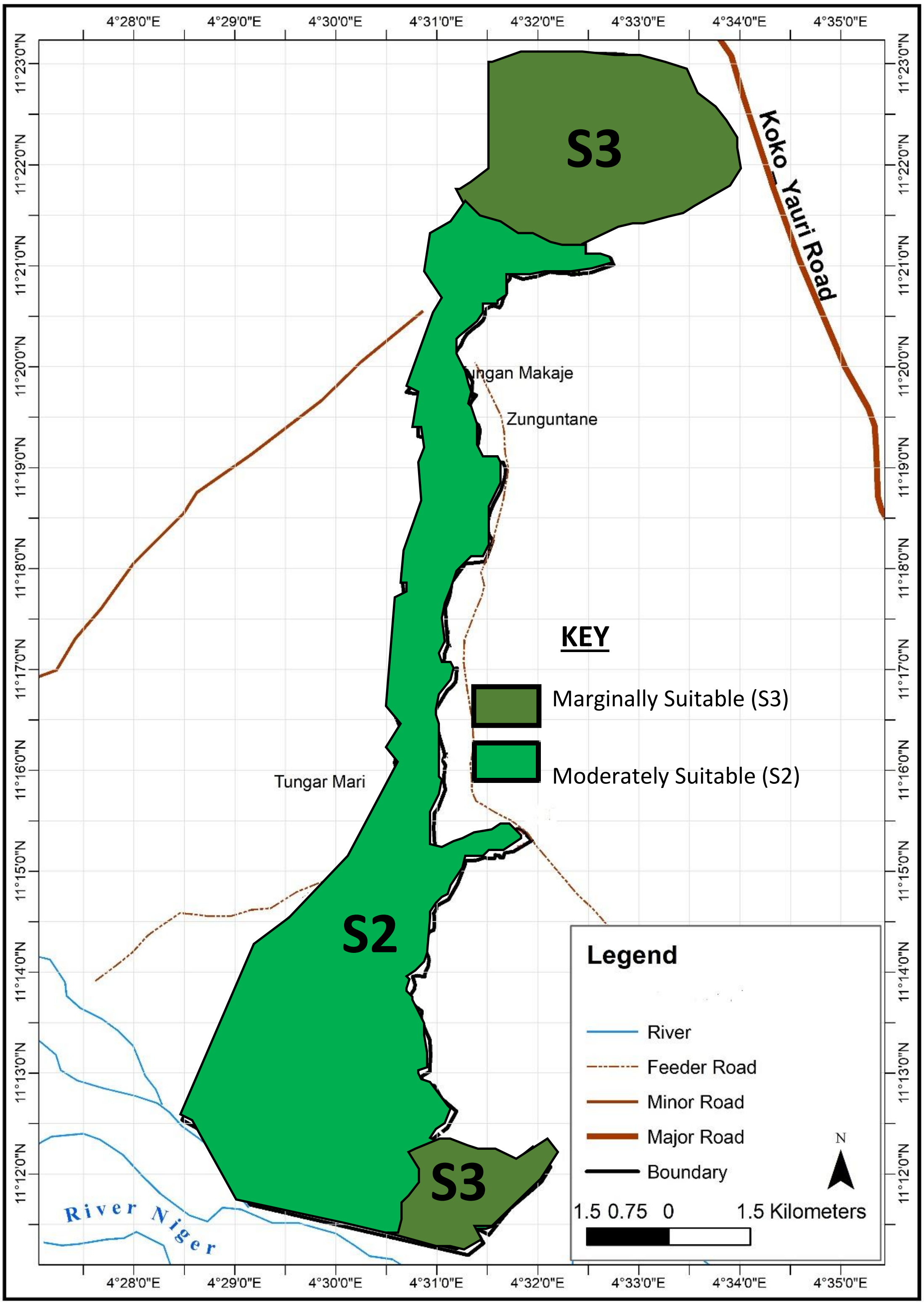

Fig. 5: Land suitability levels for sugarcane in Tungan Ahmadu District Area of Koko-Besse, Kebbi State Nigeria.

Conclusion

The result revealed that soils in the study area are moderately deep, moderately drained, and generally loamy sand to sandy in texture structurally 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 Luvisols, Arenosols, and Fluvisol respectively. 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

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.

Buol, 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.

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.

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.

Esu, I.E (2005). Soil characterization and mapping for food security. A Keynote Address at the 29th annual conf. of SSSN held at University of Nigeria, Abeokuta, from 6th to 10th Dec. 2004.

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

Eswaran, H. (1977). Soil Analysis for Soil Surveys. In: Soil Resource Inventories. A proceeding of a workshop held at Cornell University, Ithaca, USA, pp 315-324.

Fasina, A. S. and Adeyanju, A. (2007). Comparison of three Land Evaluation Systems in Evaluating the Predictive Value of some selected soils in Ado-Ekiti, Southwest Nigeria. *J. soil sci.* 17:113-119.

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

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

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

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.

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.

Ogunkunle, A.O. (2005). Soil Survey and Sustainable Land Management. Invited paper at the 29th annual conf. of SSSN held at University of Nigeria, Abeokuta, from 6th to 10th Dec. 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.

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

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.

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.

Shepherd, T.G. (2000): Visual Soil Assessment. Volume 1. Field guide for cropping and pastoral grazing on flat to rolling country. horizons.mw & Landcare Research, Palmerston North. 84p.

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, and N.D., Dikko, A.U.