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CHARACTERIZATION OF SOILS DEVELOPED ON NUPE SANDSTONE AND THEIR SUITABILITY FOR SUGARCANE (*Saccharum officinarum* L.) IN SOUTHERN GUINEA SAVANNA, NIGERIA

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ABSTRACT

Soils developed from Cretaceous Nupe Sandstones parent materials were surveyed to characterise and assess their suitability for sugarcane production on a 35.7 ha land area. The study area was surveyed at detailed scale of 1:4,000 using rigid grid method. Three soil mapping units were delineated namely: BKG I (10.40 ha; 29.70 %), BKG II (20.90 ha; 59.50 %) and BKG III (3.80 ha; 10.80 %). Morphologically, the soils were very deep (177 - 220 cm) on level to nearly level topography dominated by loamy sand over sandy loam and sandy clay loam textures. Drainage varied between very poorly drained (BKG I), moderately drained (BKG III) and well drained (BKG II). Physical properties indicate sand fraction dominated the particle size, while available water capacity was low and ranged between 3.30 and 7.51 cm/120 cm soil depth. Chemical properties showed that, soil reaction (pH) varied between 5.65 and 6.80, and rated moderately acid to neutral. Electrical conductivity, ESP and SAR were low, and therefore considered as non-saline and non-sodic. Cation exchange capacity was low to medium and was attributed to Nupe sandstone parent material. However base saturation varied between medium and high (59.91 - 84.88 %). Organic carbon and total nitrogen were generally low, while available micronutrient Fe was generally high across the soil units. The soils were classified as Typic endoaqualfs, Arenic Hapludalfs and Arenic endoaqualfs for soils of units BKG I, BKG II and BKG III respectively, and correlated with Gleyic Luvisols (BKG I and BKG III) and Haplic Luvisols in WRB Soil Resource 2014. Actual suitability based on parametric evaluation for sugarcane showed that the soils were classified as moderately suitable (S2csf) for BKG II and marginally suitable (S3cswf) for BKG I and BKG III. Sustainable management practices like incorporation of crop residue, application of organic and inorganic fertilizers was suggested to reduce the limitations and upgrade the land suitability for sugarcane production in the study area.

Keywords: Sugarcane; Suitability; Nupe Sandstone; Parametric evaluation

INTRODUCTION

Agriculture is a major source of livelihood and contributes in accelerating economic growth of most developing countries (Sajjad *et al*., 2014). It does not only provide food for man but also raw material to the manufacturing industries (Sajjad *et al*., 2014). Agriculture and its allied sectors contribute greatly to the Gross Domestic Product of developing countries like Nigeria.

Sugarcane as an agricultural produce is the most important sugar crop contributing more than 62 % of the world sugar production (Naidu *et al*., 2006). For countries like Brazil, India and Thailand, sugarcane is considered as one of their most important crops produce beyond subsistence level to meet the need of large and complex industrial system for its processing and marketing (Jamil *et al*., 2017). Therefore, to increase the productivity of sugarcane, the cultivation should be based on the suitability of land. Sugarcane is a tropical plant that thrives well in long summer growing season with adequate rainfall, though water logging conditions are serious problem at early stages of cane but less severe at older stages of growth (Naidu *et al*., 2006). Nigeria relies on other nations for sugar and other agricultural products, thus contributing to food insecurity within the challenges of her fast growing population, hence intensification of agriculture is critical. This calls for judicious planning of land resources to sustain agricultural production to meet the ever increasing demand for food, while achieving environmental protection (Sekar and Palanichamy, 2016). The concept of sustainable agriculture involves producing quality crops in an environmentally friendly, socially acceptable and economically feasible manner (Addeo *et al.*, 2001). This implies optimum utilization of the available natural resources for efficient agricultural production, which could be achieved through land evaluation.

Land evaluation process deals with the identification and measuring land qualities and their assessment for land utilization type. Land evaluation is usually carried out in a way that the land resources are utilized in a sustainable manner. Knowledge of the natural environment and kinds of land utilization is necessary for optimum land use planning (FAO, 1983). Land suitability classification quantifies in broad terms is the extent to which land qualities match crop requirements under a defined input and management, and it is based on understanding crop requirements, prevailing conditions and applied soil management approaches (Ande, 2011; FAO, 1983). Therefore, evaluation of land suitability is prerequisite to utilization of available land resources for specific land use in sustainable manner. Several researches on land suitability have been carried out related to maize (Adesemuyi, 2014; Udoh and Ogunkunle, 2012), rice (Isitekhale *et al*., 2014; Olaleye *et al*., 2008; Olaleye *et al*., 2002), cassava (Raji, 2016; Ande, 2011; Fasina and Adeyanju, 2006) and some tree crops (Udoh *et al*., 2011), with little or no attention to sugarcane within the zone. This survey is carried out to establish baseline soil information by characterizing the soils, assessing their suitability for sugarcane and identify limitations to production as well as suggest reasonable management options for their use.

MATERIALS AND METHODS

Description of the Study Areas

The study was carried out within Sub-Humid Niger Trough Agro-ecological zone of Nigeria (Ojanuga, 2006) characterised by Southern Guinea Savanna. The study site is situated between latitude 08º 51’ 59.0” to 08º 52’ 516.3” N and longitude 006º 10’15.7” and 006º 10’ 25.9” E which lies within the floodplain of River Niger at Bakogi, Katcha Local Government Area in Niger State. The soils were formed from alluvial deposits and Cretaceous Nupe Sandstone (feldspatic sandstone and siltstone) parent materials (Ojanuga, 2006). The geomorphology of the study areas showed a topography that is generally nearly flat to flat plains with gently sloping surface. The area had low relative relief.

The study area has long time mean annual rainfall of 1240.7 mm/annum. The rainy season normally starts around March/April and ends in October. The rainfall pattern is uni-modal tending towards bi-modal. The period of the rainy season is between 120 – 240 days. The mean daily sunshine hours on monthly basis ranged between 6 hours in the month of August and 11 hours November to March. The mean minimum and maximum temperatures varied between 16ºC and 42ºC.

The dominant land uses are for rice, cassava, melon (egusi) and sesame at commercial level, while millet and cowpea production are at subsistence level.

Field Study

The study area covering 35.7 ha was surveyed at detailed level using rigid grid method at a scale of 1:2,000 on the field. Traverses were made at 100 m interval and auger observations were taken along each transect with the aid of base map and hand held GPS Garmin *Etrex 10* model and final soil map was produced at a scale of 1:4,000. Observations were made on the physiographic information and soil descriptions were done following field guidelines for soil survey (Soil Science Division Staff, 2017; FAO, 2006). Auger points with similar soils were delineated and three soil mapping units were identified within the entire study area. A total of six soil profile pits were dug across the study area with two representatives in each unit (Figure 1).

Morphological properties including colour, texture, structure, consistence, clay films, concretions, boundary, pores and roots occurrence were described according to the USDA Soil Survey Manual (Soil Survey Division Staff, 1993). Soil samples (disturbed and undisturbed) were collected within genetic horizons for laboratory analyses.

Laboratory Analysis

Particle size distribution of the less than 2 mm soil samples was carried out using the method described in IITA (1979). Bulk density was determined by oven drying the undisturbed soil samples (Blake and Hartge, 1986) and available water capacity (AWC) was obtained from equation 1 after moisture determination at various retention heads:

$$AWC = \frac{(FC\,\% - PWP\,\%)}{100}\left(\frac{\rho b}{\rho w}\right)D \quad \text{---------------- } \textit{equation 1}$$

Where FC = field capacity
PWP = permanent wilting point
ρ_b = bulk density of soil
ρ_w = density of water
D = depth of soil horizon in cm.

Soil pH was determined in a 1:1 soil/water ratio and the saturation extract was also used to obtain electrical conductivity (Udo *et al*., 2009). Exchangeable bases (Ca, Mg, K and Na) were determined using ammonium acetate (NH_4OAc) saturation method and exchange acidity was obtained by the method described by Thomas (1982).

Cation exchange capacity (CEC) was determined by neutral (pH 7.0) NH_4OAc saturation method (Rhoades, 1982). Base saturation percentage was calculated as the proportion of exchangeable bases to CEC. Organic carbon was determined by Walkley-Black dichromate wet oxidation method (Nelson and Sommers, 1982), total nitrogen (TN) was by micro-Kjeldahl technique as described by Bremner and Mulvaney (1982) and available phosphorus (AP) by method described in IITA (1979) laboratory manual. Available copper, iron, manganese and zinc were extracted with 0.1M HCl solution by shaking soil paste for 4 hours and centrifuged. The contents of Cu, Fe, Mn and Zn in the respective extracts were determined with atomic absorption spectrophotometer (AA500 spectrophotometer PG Instrument model).

Soil Classification

Soil classification for the surveyed area was according to USDA Soil Taxonomy (Soil Survey Staff, 2014) and World Reference Base for Soil Resource 2014 (IUSS Working Group WRB., 2015).

Land Suitability Evaluation

Multiplication approach of the parametric method was adopted to assess the suitability of soils for sugarcane production. Suitability classification was arrived at by matching the land qualities with the sugarcane requirements (Table 1) (Naidu *et al*., 2006; Sys *et al*., 1991) to obtain crop suitability rating (index of productivity; Table 2) for each quality assessed (FAO, 1983). Equation 2 was used to obtain the overall suitability index from the multiplication approach of the parametric system which is presented as:

$$\mathrm{IP} = A\left(\sqrt[2]{\frac{B}{100} x \frac{C}{100} x \frac{D}{100} x \frac{E}{100} x \frac{F}{100} x \frac{G}{100}}\right) \text{ --------------- } \textit{equation 2}$$

IP	=	Crop Suitability Index (Index of Productivity)
A	=	Climate (c)
B	=	Erosion hazard (e)
C	=	Wetness (w)
D	=	Rooting condition (r)
E	=	Soil physical characteristics (s)
F	=	Chemical fertility (f)
G	=	Salinity hazard (n)

A, B, C, D, E, F and G = lowest characteristic rating for their respective land qualities groups.

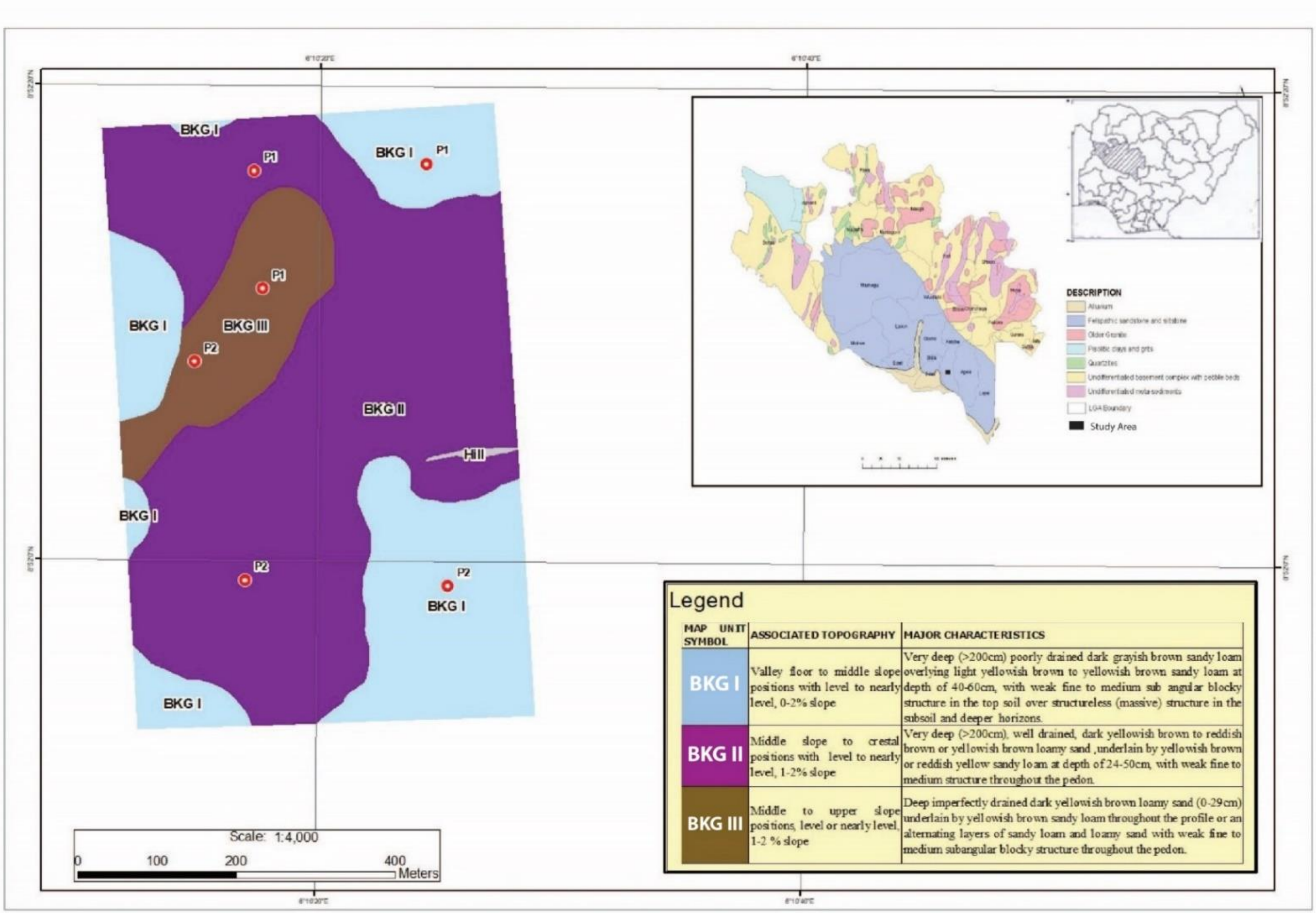

Figure 1: Map of Nigeria showing study site within Niger state and the delineated soil mapping units

Table 1: Factor Ratings of Land Use Requirements for Sugarcane

Factor	Land qualities/ Characteristics	S1 (100 %)	S2 (85 %)	S3 (60 %)	N (40 %)
A			Climate (c)		
	Annual rainfall (mm)	>1400	1200-1400	900-1200	<900
	Mean Temperature (^{0}C)	30-34	26-29, 35-38	20-25, 39 - 40	15–19, 41 - 45
B	Rooting conditions (r)				
	Effective soil depth (cm)	>100	75 – 100	50 - 75	< 50
	Stoniness (gravels) (%)	<15	15 -35	35 - 50	50 -75
C			Soil Physical Characteristics (s)		
	Texture	L, CL, SC, SiL	SCL, SiCL, SL	C, LS	heavy/ crack C, S
D	Wetness (w)				
	Drainage	Well	Moderate	poorly	v. poorly Excessive
	Depth of water table (cm)	>100	75- 100	50 - 75	<50
E			Toxicity (t)		
	Salinity (ECe) (dS/m)	<2	2 – 4	4 - 9	>9
F	Erosion hazard (e) (%) Slope	<3	3 – 5	5 - 8	>8
G			Chemical Fertility (f)		
	pH	6.1-7.3	7.4 – 8.0, 5.1 – 6.0	8.1– 8.9, 4.5 – 5.0	>9, < 4.4
	CEC (cmol kg^{-1})	>20	10-20	5 - 10	<5

Sources: FAO (1983), Sys *et al*., (1991), Naidu (2006).

Table 2: Suitability index for Suitability Indices (CI) Classes

Class	Suitability Index	Definition
S1	>75	Highly suitable
S2	50 – 74	Moderately suitable
S3	25 – 49	Marginally suitable
N1	15 – 24	Currently not suitable
N2	<15	Permanently not suitable

The land evaluation was carried out for both actual and potential sugarcane cultivation, in which chemical fertility properties such as pH, CEC which are easily altered, were not considered in calculating index of productivity for potential land use. In calculating index of productivity for current sugarcane cultivation, all characteristics were grouped to form land qualities.

RESULTS AND DISCUSSION

Morphological Properties

The study area was delineated into three soil mapping units namely: BKG I (10.40 ha; 29.70 %), BKG II (20.90 ha; 59.50 %) and BKG III (3.80 ha; 10.80 %). Morphological properties of the soils of the different mapping units are presented in Table 3. Soils of the study areas were generally very deep (177 - 220 cm), and are situated on level to nearly level plain topography (0 – 2 %) within the landscape. The soils were coarse to medium texture, dominated by loamy sand in the surface horizon. The subsoils were characterised by sandy loam and sandy clay loam materials. The soil materials originated from Nupe Sandstone thereby influencing the present texture (Ojanuga, 2006).

The soils were very poorly drained in BKG I resulting in gleization influencing the soil colour as dark greyish brown (10YR 5/2) in the surface horizons over yellowish brown subsoil horizons. The resultant redoximorphic feature of these soils had few fine faint mottles of dark brown or brown colours across the entire pedons. Soil mapping unit BKG I was notable with presence of soft black Fe and Mn concretions. Soils of units BKG II and BKG III were well drained and imperfectly drained respectively, and were characterised by dark yellowish brown (10YR 4/4, moist) colour in the surface horizons and yellowish-brown subsoil horizons. The soil structure was dominated by weak fine or medium subangular blocky structure, however structureless massive materials were found in the subsoils of BKG I, and was associated with poor drainage and eventual aquic moisture regime. Soil consistence varied mostly between non sticky and non-plastic and slightly sticky and slightly plastic which was influenced by dominance of sand particle in the soils.

Table 3: Morphological properties of the pedons of study area

Hor.	Basal Depth (cm)	Colour (Moist)	Texture	Structure	Consistence (Moist)	Boundary	Other features
Pedon BKG I P 1				Soil Mapping Unit BKG I			
Apg	15	10YR ¾	SL	1mg	Sopo	Cs	many fine roots, common fine tubular pores
BEg	60	10YR 4/6	SL	1msbk	Sssp	As	many fine roots, common fine tubular pores
Btg1	112	10YR 6/4	SCL	0m	Sp	As	many tubular and few vesicular pores, soft black Mn concretions
Btg2	200	10YR 6/4	SCL	0m	Sp	-	soft red Fe concretions
Pedon BKG I P2							
Apg	19	10YR 5/2	LS	1fsbk	Sopo	Cs	many fine roots, many fine tubular pores
BEtg	40	10YR 5/4	SL	1msbk	Sopo	As	few fine roots, many fine tubular pores
Btg1	116	10YR 5/4	SCL	0m	Sssp	Cs	many vesicular pores, many fine soft black Fe – Mn concretions
Btg2	200	10YR 5/4	SCL	0m	Vsvp	-	many medium to coarse red Fe concretions
Pedon BKG II P1				Soil Mapping Unit BKG II			
Ap	24	10YR 4/3	LS	1fg	Sopo	As	many fine roots, common medium tubular pores
Bt	97	5YR 5/4	SL	1fmsbk	Sopo	Gs	few fine roots, common medium tubular pores
BCt	113	5YR 5/6	SL	1msbk	Sspo	Gs	many fine tubular pores
Ct1	173	5YR 5/8	SL	1fmsbk	Sspo	Gs	few fine soft black Fe – Mn concretions
Ct2	220	7.5YR 6/8	SL	1fmsbk	Sspo	-	-
Pedon BKG II P2							
A	16	10YR 4/4	LS	1fsbk	sopo	Gs	common fine roots, common fine to medium tubular pores

ABt	58	10YR 5/6	LS	1fsbk	sssp	Ds	many fine roots, common fine tubular pores
Bt1	117	10YR 5/6	SL	1fsbk	sssp	Ds	many fine roots, very few fine tubular pores
Bt2	183	10YR 5/8	SL	1fsbk	sp	-	very few fine roots, very few coarse vesicular pores
Pedon BKG III P1				Soil Mapping Unit BKG III			
Ap	29	10YR 4/4	LS	1msbk	sssp	Gs	few fine to medium roots, common fine to medium tubular pores
Bt1	71	10YR 5/6	SL	1fsbk	sopo	Cs	few fine roots, common fine tubular pores
Bt2	124	10YR 5/6	SL	1fmsbk	sssp	Gs	common medium soft black Mn concretions
Bt3	184	7.5YR 6/4	SL	1msbk	Sp	-	common coarse vesicular pores, common fine red Fe concretions
Pedon BKG III P2							
Ap	28	10YR 4/6	LS	1fmsbk	Sopo	Cs	few fine to medium roots, common fine tubular pores
Bt1	65	10YR 5/8	SL	1fsbk	Sssp	Gs	few fine and coarse roots, few fine tubular pores
Bt2	132	10YR 6/4	LS	1fsbk	Sssp	Ds	common medium vesicular pores
BCtg	177	10YR 6/3	SL	1fsbk	Sp	-	common medium vesicular pores

Keys: Texture: SL, Sandyloam, LS = Loamy Sand, SCL= sandy clay loam.
Structure: 1fsbk: Weakfine subangular blocky, Om: structurelss, massive, 1 msbk: weak medium subangular block.
Soil consistence: wet: Sopo, Non-sticky non-plastic, sssp, slightly sticky slightly plastic, vsvp, very sticky very plastic, Sp slightly plastic.
Boundary: CS – clear, smooth, Gs – gradual smooth, CW – clear, wavy, Dw – diffuse, wavy, Ds – diffuse, smooth, Gw - gradual wavy.

Physical Properties

Sand fraction dominated the particle size and was attributed to the soil development from Nupe Sandstone parent material. Sand content of soils of units BKG II and BKG III were greater than 720 gkg^{-1} (Table 4), but varied between 590 gkg^{-1} and 770 gkg^{-1} in BKG I. Silt and clay particles were generally less than 300 gkg^{-1} in the soils. The values of bulk density varied between 1.28 gcm^{-3} and 1.55 gcm^{-3} across the soils and rated as low to medium (FAO, 2006) with their reciprocating total porosity values between 41.51 % and 51.70 % and considered as moderate to high. Saturated hydraulic conductivity ranged between 0.47 $cmhr^{-1}$ and 5.09 $cmhr^{-1}$, and was rated as moderately high to high (Soil Science Division Staff, 2017). Available water capacity of the soils ranged between 3.30 and 7.51 cm/120 cm soil depth, and rated low, as the values were less than 10cm/ 120 cm soil depth (Soil Science Division Staff, 2017). This implies that moisture deficit will be supplemented through irrigation management.

Chemical Properties

Soil reaction (pH) values varied between 5.65 and 6.80and rated moderately acid to neutral. The current range of soil reaction indicates more nutrients will be readily available for crop uptake. Electrical conductivity values were rated low (< 0.02 dSm^{-1}), ESP and SAR values were also low compared to the critical limit values (Soil Science Division Staff, 2017) required to define saline and sodic soils. Therefore, salinity and sodicity are not presently anticipated in these soils. However, the current ESP values up to 7.81 indicate the need to monitor sodium level to avert sodicity threat within the study area.

Exchangeable bases across the soil mapping units indicate calcium dominated the exchange sites followed by magnesium and least were K and Na (Table 5), although exchangeable Na was rated as medium to high and hence requires monitoring to avoid sodicity development. Cation exchange capacity was rated low to medium (3.20 – 7.80 cmol(+) kg^{-1}), which was attributed to dominance of sand particles (Kparmwang *et al*., 2001) originating from Nupe sandstone parent material. Percentage base saturation varied between medium and high with values ranging from 59.91 % to 84.88 %.

Table 4: Physical properties of the study area

Horizon	Basal Depth (cm)	Gravel %	Sand	Silt g kg^{-1}	Clay	Textural class	Bulk density g/cm^3	Porosity %	Sat. HC cm/hr	Moisture 0.33 g g^{-1}	Bar Suctions 15 g g^{-1}	Available moisture g g^{-1}
Pedon BKG I P1				Location 08º 52'16.3" N 006º 10'24.6 E Alt. 67m asl								
Apg	15		650	180	170	SL	1.35	49.06	0.91	0.061	0.034	0.027
Beg	60		690	180	130	SL	1.33	49.81	0.47	0.096	0.052	0.044
Btg1	112		630	160	210	SCL	1.46	44.91	0.52	0.123	0.066	0.057
Btg2	200		550	220	230	SCL	1.38	47.92	0.81	0.122	0.076	0.046
Pedon BKG I P2						Location 08º 5'59.0" N and 006 º10'25.9" E , Alt 66m asl						
Apg	19		770	180	50	LS	1.38	47.92	1.47	0.069	0.029	0.040
BEtg	40		710	200	90	SL	1.43	46.04	1.59	0.069	0.033	0.046
Btg1	116		590	160	250	SCL	1.46	44.91	1.50	0.105	0.098	0.007
Btg2	200		630	120	250	SCL	1.55	41.51	1.66	0.116	0.112	0.004
Pedon BKG II P1						Location 08º52'16.3" N 006º 10'18.4" E Alt. 68m asl						
Ap	24		870	80	50	LS	1.28	51.7	4.80	0.051	0.034	0.017
Bt	97		790	80	130	SL	1.32	50.19	0.66	0.073	0.043	0.030
BCt	113		790	60	150	SL	1.34	49.43	4.77	0.078	0.053	0.025
Ct1	173	16.80	770	80	150	SL	1.43	46.04	2.01	0.097	0.056	0.041
Ct2	220		790	80	130	SL	1.32	50.18	5.09	0.082	0.055	0.027
Pedon BKG II P2						Location 08º52' N 006º 10'17.5" E Alt.70m asl						
A	16		830	80	90	LS	1.35	49.06	1.48	0.064	0.032	0.032
ABt	58		830	60	110	LS	1.38	47.92	1.64	0.071	0.036	0.035
Bt1	117		730	100	170	SL	1.42	46.42	3.28	0.096	0.068	0.028
Bt2	183		770	80	150	SL	1.38	47.92	2.22	0.102	0.065	0.037
Pedon BKG III P1				Location 08º 52'11.9 N and 006º 10'18.4" E Alt 67m asl								
Ap	29		790	140	70	LS	1.38	47.92	1.34	0.066	0.039	0.027
Bt1	71		790	100	110	SL	1.44	45.66	1.27	0.063	0.043	0.020
Bt2	124		750	80	170	SL	1.47	44.53	2.12	0.098	0.068	0.030
Bt3	184		790	60	150	SL	1.43	46.04	4.24	0.110	0.080	0.030
Pedon BKG III P2				Location 08º 5'08.4" N and 006º 10'15.7" E Alt 66 asl								
Ap	28		810	120	70	LS	1.39	47.54	4.24	0.064	0.042	0.022
Bt1	65		790	100	110	SL	1.41	46.79	1.27	0.064	0.049	0.015
Bt2	132		810	80	110	LS	1.38	47.92	4.77	0.076	0.046	0.030
BCtg	177		790	100	110	SL	1.38	47.92	2.00	0.070	0.048	0.022

Table 5: Chemical properties of the study area

Hor.	Basal Depth (cm)	pH H_2O	pH $CaCl_2$	ECe dSm^{-1}	Exchangeable Bases Ca	Mg	K	Na	TEB	Al +H	CEC	Base Sat. NH_4OA_c %	ESP %	SAR
					cmol(+)kg^{-1}									
Pedon BKG I P1							Soil mapping unit BKG I							
Apg	15	6.33	5.65	0.008	4.24	0.36	0.12	0.24	4.96	0.60	6.60	75.15	3.64	0.158
Beg	60	6.29	5.37	0.008	2.36	0.76	0.09	0.10	3.31	0.60	4.20	78.81	2.38	0.081
Btg1	112	5.92	4.39	0.003	2.78	0.74	0.15	0.17	3.84	1.20	5.60	68.57	3.04	0.128
Btg2	200	6.80	4.73	0.010	2.24	0.63	0.10	0.14	3.11	1.60	4.90	63.47	2.86	0.117
Pedon BKG I P2														
Apg	19	6.09	5.39	0.009	2.88	0.47	0.16	0.14	3.65	0.80	5.30	68.87	2.64	0.108
BEtg	40	5.65	4.58	0.009	2.12	1.208	0.06	0.25	3.638	0.80	4.80	75.79	5.21	0.194
Btg1	116	5.74	4.93	0.008	3.66	0.656	0.20	0.23	4.746	1.00	5.80	81.83	3.97	0.157
Btg2	200	6.00	5.16	0.008	2.40	0.57	0.16	0.21	3.34	0.60	4.20	79.52	5.00	0.172
Pedon BKG II P1							Soil mapping unit BKG II							
Ap	24	6.38	5.56	0.0075	3.48	0.43	0.18	0.26	4.35	0.60	5.40	80.55	4.81	0.186
Bt	97	6.50	5.75	0.008	4.08	1.102	0.14	0.15	5.47	0.60	6.70	81.67	2.24	0.093
BCt	113	6.16	5.55	0.008	3.96	0.450	0.15	0.19	4.75	0.80	5.80	81.90	3.28	0.128
Ct1	173	6.30	5.58	0.010	4.04	0.369	0.16	0.24	4.81	0.80	6.20	77.56	3.88	0.162
Ct2	220	6.42	5.69	0.013	3.92	0.854	0.11	0.35	5.23	0.80	6.40	81.78	5.47	0.226
Pedon BKG II P2														
A	16	6.41	5.54	0.008	3.08	0.356	0.08	0.20	3.72	1.00	4.90	75.84	4.08	0.153
ABt	58	6.37	5.48	0.011	3.84	1.04	0.10	0.23	5.21	0.80	6.40	81.41	3.59	0.147
Bt1	117	6.13	5.43	0.011	3.78	0.290	0.07	0.28	4.42	1.20	5.80	76.21	4.83	0.197
Bt2	183	6.18	5.12	0.008	3.97	1.136	0.05	0.28	5.44	1.00	6.70	81.13	4.181	0.175
Pedon BKG III P1							Soil mapping unit BKG III							
Ap	29	6.55	5.72	0.008	2.56	0.470	0.14	0.17	3.34	0.80	4.50	74.22	3.78	0.138
Bt1	71	6.72	5.93	0.0085	2.06	1.21	0.12	0.26	3.65	0.60	4.30	84.88	6.05	0.203
Bt2	124	6.10	5.41	0.013	2.00	0.44	0.17	0.21	2.82	0.80	3.80	74.21	5.53	0.190
Bt3	184	6.24	5.52	0.014	3.10	0.53	0.08	0.22	3.93	0.60	5.10	77.06	4.31	0.163
Pedon BKG III P2														
Ap	28	6.30	5.65	0.008	1.43	0.037	0.20	0.25	1.917	0.80	3.20	59.91	7.81	0.292
Bt1	65	6.02	5.30	0.0095	3.82	1.23	0.09	0.27	5.41	1.20	6.70	80.75	4.03	0.170
Bt2	132	5.66	4.64	0.0095	4.04	1.20	0.05	0.46	5.75	1.60	7.80	73.72	5.90	0.284
BCtg	177	6.00	4.90	0.0085	3.70	0.99	0.05	0.39	5.13	1.80	7.20	71.25	5.42	0.255

Table 6: Macro and Micro-nutrients status of the study area

Horizon	Basal depth (cm)	OC	TN	Avail. P	HCO_3	Cu	Mn	Zn	Fe
		g kg^{-1}					mg kg^{-1}		
Pedon BKG I P1									
Apg	15	2.80	0.83	9.69	1.60	0.02	0.24	1.82	6.40
Beg	60	2.70	0.24	7.00	1.20	0.10	0.84	2.30	4.84
Btg1	112	1.70	0.18	5.39	1.20	0.08	0.42	1.26	16.88
Btg2	200	1.50	0.32	3.77	0.80	0.08	0.12	1.77	8.05
Pedon BKG I P2									
Apg	19	4.00	0.38	15.09	0.80	0.06	0.32	1.08	6.02
BEtg	40	2.70	0.35	6.47	1.20	0.08	0.25	1.76	28.26
Btg1	116	2.70	0.24	5.93	1.20	0.06	0.04	1.12	7.04
Btg2	200	1.70	0.24	5.98	0.80	0.02	0.24	2.10	8.74
					Soil mapping unit BKG II				
Pedon BKG II P1									
Ap	24	4.20	0.35	15.09				0.18	
					1.20	0.18	0.22		6.87
Bt	97	1.10	0.29	5.98	0.80	0.16	0.12	1.64	5.40
BCt	113	3.20	0.21	7.54	1.20	2.40	0.22	1.64	9.67
Ct1	173	1.90	0.24	6.47	1.20	1.60	1.66	1.56	8.94
Ct2	220	0.80	0.32	7.00	1.20	2.00	1.20	0.96	13.67
Pedon BKG II P2									
A	16	3.00	0.27	8.62	1.20	0.18	0.32	1.04	7.18
ABt	58	2.30	0.27	42.56	1.20	0.32	1.92	0.76	26.32
Bt1	117	2.80	0.24	7.54	1.20	0.40	0.24	0.48	5.66
Bt2	183	1.30	0.32	10.78	1.20	5.60	0.46	1.20	4.57
					Soil mapping unit BKG III				
Pedon BKG III P1									
Ap	29	1.30	0.18	39.33	0.80	0.16	1.72	22.39	9.16
Bt1	71	3.20	0.21	14.55		19.20	3.76	1.40	13.54
					1.20				
Bt2	124	0.60	0.49	10.24	1.20	16.00	3.04	5.12	8.83
Bt3	184	2.70	0.38	6.47	2.00	1.20	0.56	0.24	15.86
Pedon BKG III P2									
Ap	28	4.40	0.47	8.08	1.20	1.54	3.64	1.30	6.77
Bt1	65	2.30	0.32	12.40	1.20	1.12	0.42	0.46	19.41
Bt2	132	1.30		77.04	1.20	1.20	2.52	0.64	15.99
			0.46						
BCtg	177	1.50	0.55	126.61	1.20	1.54	2.12	0.18	12.28

Organic carbon was generally low (< 4.50 gkg^{-1}) and decrease generally with increase in soil depth across the study area, thus indicating organic matter to be the main contributor of OC in these soils. Total nitrogen was very low and varied between 0.18 gkg^{-1} and 0.83 gkg^{-1} (Table 6) with similar distribution trend with OC, implying organic matter serves as sink for total nitrogen within the soils (Kparmwang *et al.* 2001). Therefore, addition of organic matter will enrich these soil nutrients and improve soil conditions for sugar cane production. Available phosphorus (<10 $mgkg^{-1}$) was considered as low to high in the soils, with values ranged between 3.77 gkg^{-1} and 126.61 gkg^{-1}.

Micronutrient Cu was generally low (0.02 – 0.10 $mgkg^{-1}$) for BKG I and mostly high for BKG III (Table 6), whereas low to high (0.18 – 5.60 $mgkg^{-1}$) for soils on BKG II. Available manganese varied between 0.04 $mgkg^{-1}$ and 3.76 $mgkg^{-1}$ and was rated as low to medium. Available Zn varied from medium to high (0.18 – 5.12 $mgkg^{-1}$), while Fe was generally high across the study area and ranged between 4.57 $mgkg^{-1}$ and 28.26 $mgkg^{-1}$.

Soil Classification

The summary of the soil classifications is presented in Table 7. All the pedons had argillic subsoil horizons and ochric surface horizons with base saturation exceeding 60 %. Therefore, the soils fit more into the order Alfisols. Soils of mapping units BKG II and BKG III were characterised by aquic moisture regime, therefore classified as Aqualfs at the Suborder level, and Endoaqualfs at the Great group level. The soils of BKG I were classified as Typic Endoaqualfs at Subgroup, whereas BKG III fitted into Arenic Endoaqualfs at Subgroup level and due to loamy sand texture within the upper < 50 to 100 cm surface horizons. Typic Endoaqualfs were noted by Maniyunda *et al*. (2015) in Floodplain soils of Northern Guinea Savanna zone. Soils of the two mapping units correlated with Gleyic Luvisols as characterised by high base saturation (> 50 %), high activity clay (> 24 cmol $(+)kg^{-1}$) and reducing conditions in some subsoil horizons. To further define the WRB Soil Resource 2014, supplementary qualifiers used include Loamic and Arenic features.

Table 7: Soil classification of Niger state irrigation surveyed areas

Soil Mapping Unit	USDA Soil Taxonomy	WRB 2014 (FAO UNESCO)
BKG I	Typic Endoaqualfs	Gleyic Luvisols (Loamic)
BKG II	Arenic Hapludalfs	Haplic Luvisols (Arenic)
BKG III	Arenic Endoaqualfs	Gleyic Luvisols (Arenic)

Soils of mapping unit BKG II had base saturation greater than 70% with argillic subsurface horizon over ochric epipedon and classified at Order level as Alfisols. At the Suborder level, the soils were classified as Udalfs due to the Udic moisture regime. The soils were classified as Hapludalfs at the Great group level and as Arenic Hapludalfs at Subgroup level because it met sandy particle size criteria from the surface horizon to the argillic horizon. The soils correlated with Haplic Luvisols (Arenic) in WRB Soil Resource 2014 classification as were characterised by argic horizons, high base saturation greater than 50% and high activity clay (> 24 $cmolkg^{-1}$).

Land Suitability Evaluation for Sugarcane Cultivation

Land qualities and characteristics that were rated as highly suitable for sugarcane for the entire study area include mean temperature, effective soil depth, stoniness, depth of water table, salinity hazard (electrical conductivity) and erosion hazard (slope). Land qualities and characteristics that critically limit the suitability of the study area for sugarcane production included climate requirement in the form of amount of rainfall and was rated moderately suitable (S2), soil texture as moderately and marginally suitable, drainage as moderately suitable and not suitable (Table 8). Chemical fertility assessment through soil pH was moderately suitable for BKG III, while cation exchange capacity (CEC) was marginally suitable for BKG I and BKG II and not suitable for BKG III.

The parametric evaluation of the land suitability for sugarcane showed that the soils were classified based on actual suitability as moderately suitable (S2csf) for BKG II and marginally suitable (S3cswf) for BKG I and BKG III. To upgrade BKG II for sugarcane, organic matter sourced from crop residues and farmyard manure will be required to improve nutrient retention, water retention, increase CEC and aggregate stability (Odunze, 2017). Construction of drainage structure, ridges and incorporation of organic matter as management practices that will improve drainage (Odunze, 2017; Abagyeh *et al*., 2016) and upgrade BKG I and BKG III to moderately suitable (S2) class for sugarcane production. The potential suitability classes for BKG I and BKG II did not change from the actual suitability class as the soils were marginally and moderately suitable respectively, while BKG III significantly change from S3 to S2. This implied that management practices such as organic matter and fertilizer application along with ridging will reduce the limitations and upgrade the land suitability for sugarcane production in the study area (Abagyeh *et al.*, 2016).

Table 8: Suitability Index of Matching Land Qualities and Land use Requirements for Sugarcane

Factor	Land qualities/ Characteristics	Soil Mapping Units BKG I	BKG II	BKG III
A	Climate (c)			
	Annual rainfall	S2 (85 %)	S2 (85 %)	S2 (85 %)
	Mean Temperature	S1 (100 %)	S1 (100 %)	S1 (100 %)
B	Rooting conditions (r)			
	Effective soil depth	S1 (100 %)	S1 (100 %)	S1 (100 %)
	Stoniness (gravels)	S1 (100 %)	S1 (100 %)	S1 (100 %)
C	Soil Physical Characteristics (s)			
	Texture	S2 (85 %)	S3 (60 %)	S3 (60 %)
D	Wetness (w)			
	Drainage	N (40 %)	S1 (100 %)	S2 (85 %)
	Depth of water table	S1 (100 %)	S1 (100 %)	S1 (100 %)
E	Toxicity (t)			
	Salinity (ECe)	S1 (100 %)	S1 (100 %)	S1 (100 %)
F	Erosion hazard (e) Slope	S1 (100 %)	S1 (100 %)	S1 (100 %)
G	Chemical Fertility (f)			
	pH	S1 (100 %)	S1 (100 %)	S2 (85 %)
	CEC	S3 (60 %)	S3 (60 %)	N (40 %)
Parametric Evaluation				
Actual Suitability		S3cswf (38.39 %)	S2csf (51.00 %)	S3cswf (38.39 %)
Potential Suitability		S3csw (49.45 %)	S2cs (65.84 %)	S3csw (60.70 %)

CONCLUSION

Three soil mapping units were delineated within the study area as BKG I (10.40 ha; 29.70 %), BKG II (20.90 ha; 59.50 %) and BKG III (3.80 ha; 10.80 %). Nupe Sandstone parent material influenced the soil to be dominated by sand fractions for the particle sizes and were very deep with low available water capacity (3.30 and 7.51 cm/120 cm soil depth).

The soil units were moderately acid to neutral in reaction, and characterised by non-saline and non-sodic condition. Cation exchange capacity was low to medium with base saturation between medium and high (59.91 - 84.88 %). Organic carbon and total nitrogen were generally low while available micronutrients Cu, Mn and Zn varied between low to high, except Fe was generally high across the soil units.

The soils were classified as Alfisols and correlated with Luvisols in WRB Soil Resource 2014. Parametric evaluation based on actual suitability for sugarcane showed that the soils were classified as moderately suitable (S2csf) for BKG II and marginally suitable (S3cswf) for BKG I and BKG III. Construction of drainage structure, ridging, irrigation, incorporation of organic matter and fertilizer application are management practice suggested to reduce the limitations and upgrade the land suitability for sugarcane production in the study area.

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