

Land Suitability Evaluation for Cotton Production in the Guinea Savanna Zone of Nigeria

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Abstract

Some soils of the guinea savanna zone of Nigeria, were surveyed, characterized and evaluated for cotton production. The free soil survey method delineated the entire study area into three mapping units based on soil homogeneity. The results indicate that land suitability of soils in the study area for cotton, evaluated by the soils of unit 1 as currently not suitable (NI) on account of poor drainage. The soils of unit 2 were assessed marginally suitable (S3) on fertility grounds while soils of unit 3 were rated permanently unsuitable (N2) for cotton production due to permanent limitations of stoniness, steep slope and rooting zone limitations. The study recommended that soils of mapping unit 1, currently not suitable (NI) for cotton production on grounds of wetness limitation can be made suitable through installation of surface trenches and sub-surface tile and drain pipes to remove excess water. The suitability of land unit 2 can be enhanced through liming, manuring and NPK fertilization. The soils of unit 3 can be restricted to pasture, ranching and forestry to reduce its degradation.

Key words: Survey, Evaluation, Suitability, Cotton, Savanna

Introduction

Soil survey and land evaluation are two basic important requirements for sustainable land use planning. They provide information that is useful for predicting the potentials and limitations of the soil under a defined land use. Lekwa *et al.* (2002) remarked that soil survey is a tool used to generate information for land use planning, Nwaoba and Lekwa, (2016) also stated that soil survey provides an accurate and scientific inventory of different soils, their kinds, nature, and extent of distribution so that one can make predictions about their characters and potentialities whereas FAO (2000) described land evaluation as the interpretation of soil survey data in order that every hectare of land in use should be used in accordance with its suitability, capability and limitation. The basic feature of land evaluation is the comparison of the requirements of land use with the resources offered by the land. Elaalem (2010) noted that if self-sufficiency in agricultural production is to be achieved in developing and transitional countries, land evaluation techniques will be required to develop

models for predicting the land's suitability for different types of Agriculture.

Land suitability evaluation is the fitness of a given tract of land for a specified kind of use (FAO, 2000), which is a function of matching the land characteristics of that particular land with the crop requirements (Nwaoba *et al.*, 2024), thus land suitability is assessed, classified and presented separately for each kind of use. This implies that land suitability evaluation is necessary as a first step to land use planning. This will enhance judicious and maximum utilization of any available piece of land, without jeopardizing the prospect of future generation (Nsor & Udofia, 2019).

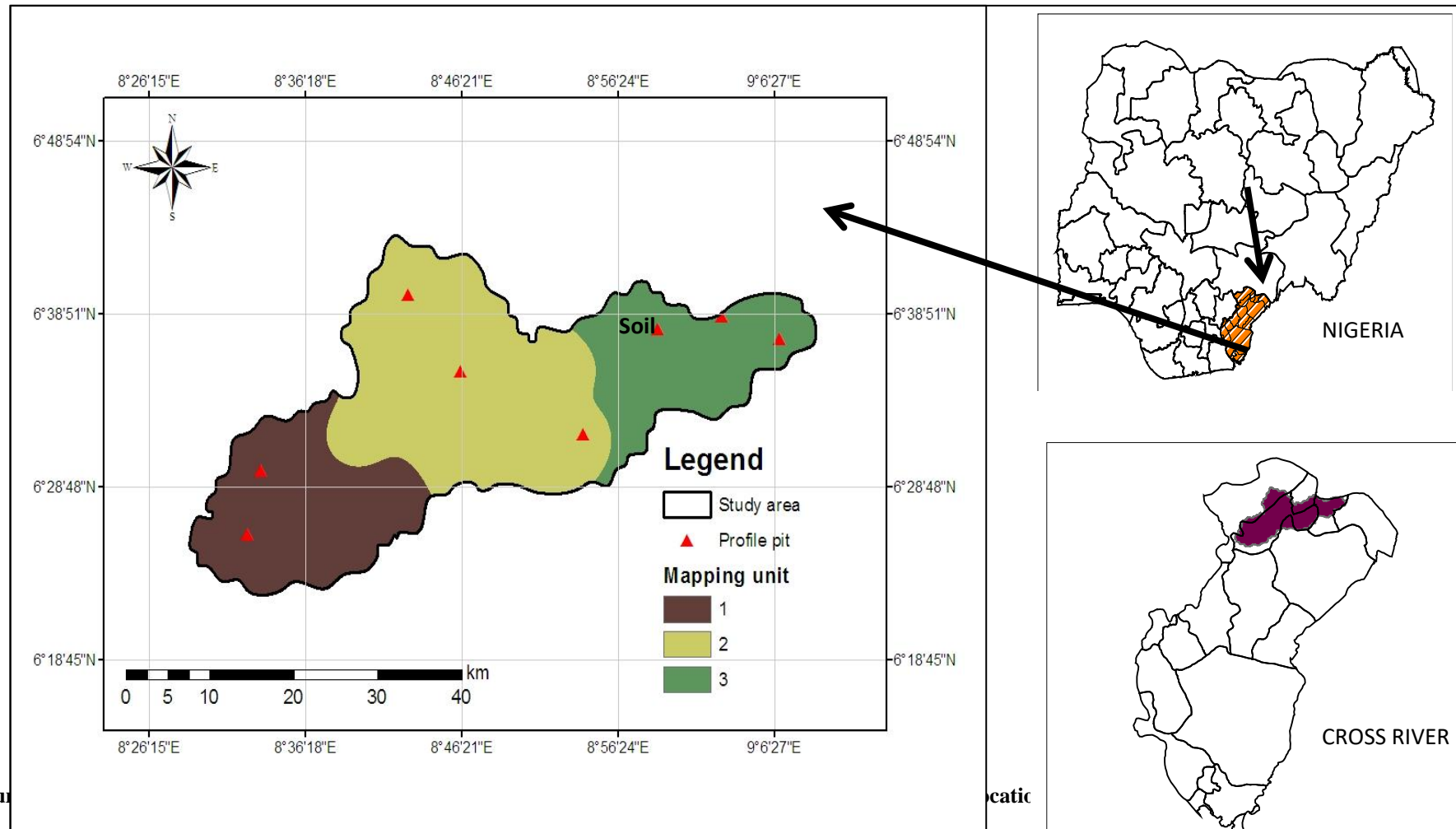
Cotton is world's most important oil seed crop. In many countries, cotton is one of the primary economic base which provide employment and income for millions of people involved in its production, processing and marketing. Prentice (1992) observed that cotton production depends on various factors ranging from weather, cotton price, soil and nutrient availability, pest and disease. However, the increase in the prices of farm inputs especially fertilizer and poor pricing of cotton units is the reason for the collapse of textile industries in Nigeria. Due to the enormous gains cotton offers to the economy, the production of cotton in the guinea savanna zone of Nigeria becomes pertinent. Cotton provides employment opportunities, generates income, foreign exchange and raw materials for textile industries, particularly the Cross River State Garment Factory. This later concern however necessitated the present study on the suitability evaluation of selected soils of Northern Cross River State within the guinea savanna zone of Nigeria for cotton production. The objectives of this study were to characterize, classify and evaluate some selected soils derived from diverse lithological formations in the derived guinea savanna zone of Nigeria for cotton production.

Materials and Methods

Study Area

The northern part of Cross River State lies between latitude 5°20' and 6°20' N and longitude 8°00' and 9°20' E. Northern Cross River State has a total land area of about 7556.69sq km, consisting of five (5) Local Government Areas: Obudu, Obanliku,

Bekwara, Ogoja, and Yala (NPC, 2006). This study was carried out in representative soils derived from diverse lithological formation in the guinea savanna zone of Nigeria. The sampling locations were selected based on information contained in the map of Cross River State (2005) and on previous works of Ekwueme (2003) on the geology of Eastern Nigeria and geomorphology of Cross River State. The sampling locations are shown on Figure 1.



Figure

Location

Field Work/Sampling Technique

A reconnaissance visit was made to the study area to familiarize with the environment and the various community leaders. An advocacy visits to stake holders to obtain permission to work in the area was made as an aid to proper planning and design of the field work. The free soil survey method was adopted in mapping the entire area using a scale of 1:500,000. Auger points were made across the field to delineate the study area into mapping units. Profile pits were dug based on the sampling units, two (2) to (3) profile pits per mapping unit were dug and described according to the procedure specified in the field book for describing and sampling soils (Schoenberger, 2012). Soil samples were collected for laboratory analysis from each genetic horizon.

Sample Preparation

Soil samples for routine analysis were air dried, crushed gently with a wooden roller and sieved through a 2mm diameter mesh sized sieves and laboratory analysis. Particle size distribution was done by hydrometer method (Gee & Or, 2002). Bulk density was measured by the cylindrical core method (Brady and Weil, 2005). Porosity was evaluated using the relationship. Porosity = $(1 - \text{Bd}/\text{Pd}) \times 100\%$

... Equation 1 Where Bd=bulk density, Pd = particle density (2.65cm^{-3}). Soil erodibility index was determined using the relationship. Soil Erodibility index = % sand + % silt / % clay... Equation 2

Electrical Conductivity was determined in 1:2.5 soil: water extract using conductivity bridge and expressed as dSm^{-1} (Jackson, 1962). The percentage gravel content which were the materials collected on the sieve (>2mm in diameter), regarded as gravels were weighed and its percentage to whole soil sample weight calculated. Soil pH values in H_2O was determined by using a pH meter in 1:2.5, soil/water ratios respectively, according to the method of (Thomas, 1996). Available phosphorus was determined by Bray-2 and Kurtz as modified by Oslen & Sommers (1982). Organic Carbon was determined by using wet oxidation method as outlined by Nelson & Sommer (1996). Total nitrogen was determined by the Kjeldahl method as modified by Bremner McLean (1996). Exchangeable acidity was determined by KCl extraction using Mclean's method (1965). Exchangeable bases were extracted with neutral NH_4OAc solution; Ca and Mg were determined by Atomic Absorption Spectrometer (ASS) while K and Na were determined by flame photometry (Thomas, 1996). Cation exchange capacity (CEC) was measured using ammonium acetate leaching at pH 7.0 (Brady and Weil, 2005)). Base saturation percentage was calculated as follows: % BS = $\frac{\text{Total Exchangeable Bases}}{\text{CEC}} \times 100$

... Equation 3 Available Micro nutrients (Fe, Zn, Mn and Cu) were extracted with 1N Hcl and determined by atomic Absorption Spectrophotometry (AAS)

using Association of Analytical chemist (AOAC) 1990 methodology.

Land Suitability Evaluation Procedure

The simple limitation method is the conventional non parametric method in which suitability classes attributed to matching the crops requirements with the land qualities using the framework for land evaluation (FAO, 2000) and the guidelines by Sys *et al.*, (1991).

Morphological Characteristics

The morphological characteristics of selected soils of Guinea Savanna zone of Nigeria are presented in Table 1. The results are presented for the various mapping units identified and delineated in the field. The soils of mapping unit 1 consists of flood plain and inland valley soils occurring on flat or nearly flat terrains of 0-2 % slopes. The soils are shallow to moderately deep and seasonally water logged with hydromorphic features. The extent of wetland soils is vast and occupies an approximate area of about 264.6 ha. This mapping unit dominates Bansara axis of Ogoja and some parts of Yala Local Government Area. The parent material of this unit is an ad-mixture of colluvio-alluvial deposits however with a much higher percentage of alluvial materials. Under moist conditions the soils of mapping unit 1 were characterized by very dark greyish brown (10YR 3/2) to dark grey (5YR 4/1) to grey (7.5YR 5/1) epipedons over reddish grey (5YR 5/1) to grey (7.5YR 5/1) endopedons (Table 1). The grey sub soil colouration of this mapping unit might be due to gleization arising from poor drainage condition of the soils. This observation corroborates Akpan-Idiok & Ogbaji (2013) who attributed gleying of fadama or inland valleys (flood plains) of River Onwu to gleization. The soils of this unit were redoximorphically mottled with few fine faint to common medium distinct to prominent strong brown (7.5YR 5/6) and reddish yellow (7.5YR 6/6) mottles. The mottling was attributed to episaturation of flood water, seasonal water table fluctuation and reduction- oxidation cycles taking place in these soils. Mottling of wetland soils had been reported by many scholars including Nsor & Akamigbo (2009) and Fasina *et al.*, (2015). Structurally, the soils of this unit consist of weak to moderate medium crumb and granular top soils over moderate to strong, medium prismatic sub soils structure (Table 1). The consistence of this unit indicate soft surface soils over slightly hard to hard sub surface soils (dry), loose to friable top soils over firm to very firm sub soils (moist), and slightly sticky, slightly plastic top soils over sticky plastic to sticky very plastic sub soils (wet). The soils had common medium top soil pores over common fine to many fine sub soil pore geometries. The occurrence of meso pores over fine pores in the profile of this unit might be the reason for the poor drainage condition of the soils.

Table 1: Morphological Characteristics of Selected Soils of Guinea Savanna zone of Nigeria.

Location	Horizon Designation	Horizon Thickness (cm)	Major Colour	Mottle Colour	Texture	Structure	Consistence			Roots	Pores	Horizon Boundary
							Dry	Moist	Wet			
Mapping Unit 1												
Bansara I	Ap	0-18	10YR 3/2; Vdgb		L	1 M Cr	S	l	ss-sp	cm	cm	cs
	Bgh ₁	18-38	7.5YR 4/1; Dg	7.5YR 5/6; fff, Sb	SiL	2 M Gr	Sh	fr	s-p	cf	cm	gw
	Bgh ₂	38-74	5YR 5/1; Rg	7.5YR 5/6; Cmd, Sb	SiC	2 M Pr	Sh	f	s-vp	ff	mf	gw
	Bg	74-118	5YR 5/1 Rg	7.5YR 5/6; Cmd, Sb		CL	3 C Pr	H	vf	s-vp	ff	mf
Bansara II	Ap	0-9	10YR 4/2; Vdgb		L	1 F Gr	S	l	ns-sp	mm	cm	cs
	Bh	9-32	7.5YR 3/1; Vdg		SiL	2 M Gr	S	fr	ss-sp	mm	cm	gw
	Bgh	32-49	7.5YR 4/1; Dg	7.5YR 6/6; Cmd, Ry	SiCL	2 M Gr	Sh	f	ss-sp	cf	mf	gw
	Bg	49-90	7.5YR 5/1; G	7.5YR 6/6; Cmp, Ry	SiC	2 M Pr	Sh	f	s-p	ff	mf	gw
Mapping Unit 2												
Imajie	Ap	0-11	5YR 3/3; Drb		SL	1 F Gr	S	l	ns-np	mm	cm	cs
	AB	11-36	5YR 4/4; Rb		SL	1 M Gr	S	vfr	ns-np	ff	fm	gw
	Bt ₁	36-74	5YR 4/8; Yr		SCL	2 M Sbk	Sh	fr	s-p	fm	mm	gw
	Bt ₂	74-115	10YR 5/6; Yb		CL	2 C Sbk	Sh	f	s-p	fvf	fmm	gw
Adagom	Ap	0-15	7.5YR 3/4; Db		LS	1 F Gr	S	l	ns-ns	cf	cm	cs
	AB	15-36	7.5YR 4/3; B		SiL	1 F Sbk	S	vfr	ss-p	fm	mm	gw
	Bt ₁	36-67	7.5YR 6/4; Lb		SiC	2 M Sbk	Sh	fr	ss-p	fvf	mm	gw
	Bt ₂	67-118	10YR 5/6; Yb		SCL	2 C Sbk	Sh	f	s-p	fvf	mc	gw
Idum Mbube	Ap	0-8	10YR 3/3; Db		LS	1 F Gr	S	l	ns-np	mf	cm	cs
	AB	8-27	10YR 4/4; Dyb		SL	2 M Sbk	Sh	fr	ss-sp	ff	mf	gw
	Bt ₁	27-55	7.5YR 6/4; Lb		SC	2 M Sbk	H	f	s-vp	mf	mc	gw
	Bt ₂	55-108	10YR 5/6; Yb		SC	2 M Sbk	H	vf	s-vp	fvf	mc	gw
Mapping Unit 3												
Bebi	Ap	0-9	7.5YR 3/2; Drb		SL	2 M Cr	L	fr	ns-ns	cf	mm	gw
	Btv ₁	9-27	5YR 7/6; O		LS	2 M Sbk	Sh	f	ss-sp	fm	fm	gw
	Btv ₂	27-61	5YR 4/8; Rb		SCL	3 C Sbk	Vh	vf	s-vp	mf	ff	gw
Utugwang	Ap	0-15	7.5YR 2/3; Vdb		SL	1 M Gr	S	fr	ns-np	mm	mm	gw
	Bt ₁	15-43	7.5YR 4/6; B		SL	2 M Sbk	Sh	f	ss-sp	fm	fm	gw
	Bt ₂	43-77	5YR 4/8; Rb		CL	3 C Sbk	H	vf	s-sp	ff	mm	gw
Utukupuru	Ap	0-18	7.5YR 3/4; Db		LS	1 F Sbk	S	fr	ns-np	mf	mc	gw
	Bt ₁	18-32	7.5YR 4/3; B		SL	1 M Sbk	Sh	f	ss-np	fm	fm	gw
	Bt ₂	32-63	5YR 4/8; Rb		CL	2 M Sbk	Sh	vf	s-p	ff	fvf	gw
	BC	63-98	5YR 4/8; Rb		SC	3 M Sbk	H	vf	s-p	fm	fm	gw

Keys:

- Colour:** Vdgh = Very dark greyish brown, Dg = dark grey, Rg = Reddish grey, Vdg = Very dark grey, G = grey, Drb = Dark reddish brown, Rb = Reddish brown, Yr = Yellowish red, Yb = Yellowish brown, Db = Dark brown, B = Brown, Lb = Light brown, Dyb = Dark yellowish brown, O = Orange, Vdb = Verb dark brown, Sb = Strong brown, Ry = Reddish yellow.
- Mottles:** fff = Few fine faint, Cmd = Common medium distinct, Cmp = Common medium prominent
- Texture:** L = Loam, SiL = Silty loam, SiC = Silty clay, CL = Clay loam, SiCL = Silky clay loam, SI = Sandy loam, SCL = Sandy clay loam, LS = Loamy sand, SC = Sandy clay
- Structure:** 1 = weak, 2 = moderate, 3 = strong, F = fine, M = Medium, C = Coarse, Sbk = Sub angular blocky, Cr = Crumb, Gr = Granular, Pr = Prismatic
- Consistence:** S = soft, Sh = slightly hard, h = hard, f = firm, vh = very hard, l = loose, fr = friable, f = firm, vf = very firm, Vfr = very friable, ss-sp = slightly sticky-slightly plastic, s-p = sticky-plastics, s-vp=sticky-very plastic, ns-sp=non sticky-slightly plastic, ss-sp = slightly sticky-slightly plastic, ns-np = non sticky-non plastic, ss-np = slightly sticky-non plastic, ns-ns = non sticky-non sticky, s-sp=sticky-slightly plastic
- Horizon Boundary:** Cs= clear smooth, gw = gradual wavy, cw = clear wavy

Soil mapping unit 2 consists of soils that are moderately deep to deep found on nearly flat to undulating plains of 3-5% slopes, developed on sedimentary siltstone parent materials. The soils are fine to medium textured and gravel free. This mapping unit is vast and occupies an approximate land area of about 296.3 ha. This mapping unit dominates farm lands around Imajie, Mbube and Adagom communities in Ogoja, Yala and Bekwara Local Government Area in Guinea Savanna zone of Nigeria. Under moist conditions the soils of mapping unit 2 were characterized by dark reddish brown (5YR 3/3) to dark brown (10YR 3/3) epipedons over dark yellowish brown (10YR4/4) to yellowish brown (10YR5/6) endopedons (Table 1). Structurally, the soils of this unit had weak fine to medium granular top soils over moderate medium to coarse sub angular blocky sub soil structural aggregates. Investigations on the consistence of mapping unit 2 revealed a soft surface soil over slightly hard to hard sub surface soils (dry); loose to very friable top soils over friable to firm sub soils (moist) and non-sticky, non-plastic top soil over slightly sticky-plastic to sticky-plastic sub soils (wet), Table 1.

The sticky-plastic sub soils of this unit present strong evidence of clay migration for the existence of sub soil argillic (Bt) horizon. The profile pore geometry revealed the existence of common medium pores over many medium to coarse pores. This profile pore size distribution might be the reason for the improved drainage condition of soils of this unit. This observation corroborates Nwaoba and Lewa (2016) who reported that water infiltration into soil depend on texture and profile pore geometry in their study of Characterization and Classification of soils of Ndegwu, Owerri west L.G.A, Imo State, Nigeria. Soils of mapping unit 3 consists of soils that are well drained, medium to coarse textured, shallow and gravelly with plinthites. The soils of this unit are found on moderate to strongly undulating plains of slopes of 7-12% surrounded by large hills with a few minor pockets of imperfectly drained soils. The soils are developed on basement complex rock parent materials dominated by granites. This unit consist of about 145 ha of land, and occur extensively around Bebi, Utugwang and Utukpuru axis of Obudu LGA of Cross River State, Nigeria. Under moist condition the soils of this mapping unit consist of dark reddish brown (7.5YR3/2) to dark brown (7.5YR3/4) epipedons over reddish brown (5YR4/5) to orange (5YR7/6) endopedons (Table 1). Structurally, soils of

this unit had weak to moderate medium crumb or granular top soil structures over moderate to strong medium to coarse sub angular blocky sub soil structural aggregates. The consistence revealed a loose to soft top soil over slightly hard to hard sub soils (dry), friable top soil over firm to very firm sub soils (moist), and non-sticky, non-plastic top soils over sticky-plastic sub soils (wet). The sticky-plastic sub soils might be due to clay illuviation suggestive of argillic Bt sub soil diagnostic horizon. This observation corroborates Nsor (2017).

Physical Properties

The data on physical properties of soils in the study area is presented in Table 2. The results indicate that soils of mapping unit 1 had loamy top soils over silty loam to silty clay sub soils. Similarly, the soils of mapping unit 2 also had loam to silty loam top soils over silty clay loam sub soils. However, soils of mapping unit 3 contrasted the other mapping units with medium to coarse textures of loamy sand to sandy loam textures over sandy clay loam to sandy clay sub soil texture. Silt fraction dominated top soils of profiles of mapping units 1 and 2, while sand dominated the profile of mapping unit 3. In all the pedons evaluated, clay separates were observed to increase with soil depth as a result of clay eluviations-illuviation in soils. This corroborated Nwaoba and Lekwa (2016) in their studies of Characterization and Classification of soils of Ndegwu, Owerri west L.G.A, Imo State, Nigeria. The dominance of sand fraction in pedons of mapping unit 3 might be due to their granitic parent materials. This observation agrees with the findings of Nsor & Adesemuyi (2018) who reported that granitic parent materials yields medium to coarse textured soils.

Bulk density values in the study area showed that the soils were non-compacted as they were generally moderate ($1.35-1.60 \text{ gcm}^{-3}$) and thus possess no serious limitation to agricultural productivity. Plants perform best in bulk densities below 1.4gcm^{-3} and 1.6 gcm^{-3} for fine and coarse textured soils respectively, because of soil resistance to root penetration, poor aeration, slow movement of nutrients or water and buildup of toxic gases and roots exudates (Brady & Weil, 2005; Odunze, 2006). The bulk density increased gradually downward (Table 2) from the top soils. This increase in bulk density with depth may be due to decreased organic matter content, less aggregation and compaction caused by overlying weights of soil layers (Nwaoba *et al.*, 2024).

Table 2: Physical Properties of Soils in the Study Area

Location	Horizon Designation	Horizon Thickness (cm)	Sand %	Silt %	Clay %	Textural Class	Silt: Clay Ratio	Bulk Density gcm ⁻³	Porosity %	Soil Erodibility Index	EC (dsm ⁻¹)	Gravel %	Illuvia: Eluvia Clay
Mapping Unit 1													
Bansara I	Ap	0-18	32	48	20	L	2.4	1.38	47.9	4.0	0.11	4.4	1.2
	Bgh ₁	18-38	24	52	24	SiL	2.2			3.2	0.10	4.8	1.5
	Bgh ₂	38-74	24	40	36	SiL	1.1	1.55	41.5	1.8	0.21	3.1	1.6
Bansara II	Bg	74-118	20	24	56	C	0.4			0.8	0.26	3.0	
	Ap	0-9	40	35	25	L	1.4	1.42	46.4	3.0	0.30	2.5	1.0
	Bh	9-32	30	46	24	SiL	1.9			3.2	0.35	2.2	1.5
	Bgh	32-49	15	50	35	SiCL	1.4	1.53	42.3	1.9	0.42	2.0	1.2
	Bg	49-90	13	44	43	SiC	1.0			1.3	0.51	2.3	
	Mean		24.8	42.4	32.9		1.5	1.47	44.5				
Mapping Unit 2													
Imajie	Ap	0-11	21	56	23	SiL	2.4	1.35	49.1	3.3	0.19	9.2	0.7
	AB	11-36	20	63	17	SiL	3.7			4.9	0.33	11.1	1.6
	Bt ₁	36-74	27	45	28	SiCL	2.5	1.45	45.3	2.3	0.44	14.3	1.4
	Bt ₂	74-115	06	54	40	SiC	1.4			1.5	0.50	16.5	
Adagom	Ap	0-15	32	44	24	L	1.8	1.41	46.8	3.2	0.24	6.6	0.8
	AB	15-36	32	48	20	L	2.4			4.0	0.36	7.1	0.7
	Bt ₁	36-67	30	56	14	SiL	4.0	1.51	43.0	6.1	0.50	7.8	2.1
	Bt ₂	67-118	40	30	30	CL	1.0			2.3	0.52	7.7	
Idum Mbube	Ap	0-8	30	44	26	L	1.7	1.40	47.2	2.8	0.26	4.4	1.2
	AB	8-27	24	44	32	CL	1.4			2.1	0.29	6.3	1.1
	Bt ₁	27-55	16	50	34	SiCL	1.5	1.46	44.9	1.9	0.30	6.9	0.9
	Bt ₂	55-108	17	51	32	SiCL	1.6			2.1	0.37	6.6	
	Mean		23.8	25.8	25.8		2.1	1.43	46.1				
Mapping Unit 3													
Bebi	Ap	0-9	76	12	12	LS	1.0	1.44	45.7	7.3	0.16	36.9	1.5
	Btv ₁	9-27	75	18	18	SL	0.4			4.6	0.19	58.1	1.6
	Btv ₂	27-61	60	28	28	SCL	0.4	1.60	39.6	2.6	0.22	71.2	
Utugwang	Ap	0-15	68	10	10	SL	2.2	1.45	45.3	9.0	0.30	42.0	1.2
	Bt ₁	15-43	68	12	12	SL	1.7			7.3	0.34	51.2	3.2
	Bt ₂	43-77	28	38	38	CL	0.9	1.53	42.3	1.6	0.39	63.5	
Utukpuru	Ap	0-18	84	10	10	LS	0.6	1.40	47.2	9.0	0.41	32.6	1.8
	Bt ₁	18-32	74	18	18	SL	0.4			4.6	0.46	54.4	1.9
	Bt ₂	32-63	57	34	34	CL	0.3	1.55	41.5	1.9	0.50	62.1	1.3
	BC	63-98	50	45	45	SC	0.1			1.2	0.55	70.2	
	Mean		64.0	22.5	22.5		0.8	1.50	43.6				

Key: L = Loam, Sil=Silty loam, C=clay,SiCl=silty clay loam, SiC=Silty clay, LS=loamy sand, SL=sandy loam, CL=Clay loam, SCL=sandy clay loam, SC=sandy clay

Soil porosity was adequate (39.6-49.1 %) for all the mapping units as the values were within the 40-50 % range, assumed optimal for any productive soil (Brady & Weil, 1999). The soils of mapping unit 1 and 2 with mean porosities of 44.5% - 46.1 % respectively were more porous than soils of mapping unit 3 with mean porosity of 43.6 % (Table 2). The implication here is that soils of mapping unit 1 and 2 will have higher water retention capacity and hence continuous nutrient supply and absorption into crop tissue and therefore will result in better crop performance than soils of mapping unit 3.

The erodibility index of soils in the study area was generally low to moderate for the fine to medium textured soils of mapping unit 1 and 2 (0.8-4.9), but moderate to high for the coarse textured soils of mapping unit 3 (1.2-9.0). This observation corroborates Nsor and Akamigbo (2009) who reported that soil properties such as texture, structure, porosity directly affect erodibility of soils. The results also indicate that top soils with erodibility index in the range (3.0-9.0) were above the critical value of 1.0 and 3.0 suggested by Kinnell (1981) for coarse and fine textured soils respectively, are more vulnerable to sheet and gully erosion than the sub-soils with erodibility index range of (1.2-2.6).

Electrical conductivity, a measure of soil salinity was generally low (0.10-0.52 dSm⁻¹) in all the pedons studied. This low EC values may be due to the low cations status of the soils in the study area (Jackson, 1962). The root of mapping unit 1 and 2 were relatively gravel free with percent gravel content >11.1 % while the soils of mapping unit 3 were generally gravelly, having the highest gravel content (32.6-71.2 %). The high gravel content in this unit may be due to their granite parent material which yields large fragments on weathering. The sub soils of all the pedons studied had illuvia-eluvial clay ratios < 1.4, confirming evidence of argillic sub soil horizons (Table 2).

Chemical Properties

The data on chemical properties of soils in the study area as presented in Table 3 showed that the soils were moderately acid in mapping unit 1 (pH 5.0-5.9) and mapping unit 2 (pH 5.3-5.8). However, the soils of mapping unit 3 were strongly acid (pH 4.4-4.9). The strongly acid condition of soils of mapping unit 3 might be attributed to the medium to coarse texture of these soils which permits extensive leaching of basic cations by high rainfall of the Nigeria southern savanna region (Nsor, 2017). In all pedons studied epipedons had higher pH values than endopedons. This might be attributed to nutrient cycling through root absorption of bases from the subsoils to the top soils through litter fall.

Organic carbon in the study area ranged from medium in mapping unit 1 (4.8-12.4 gkg⁻¹) and mapping unit 2 (4.7-14.7 gkg⁻¹) to low in mapping unit 3 (1.2-5.2 gkg⁻¹). The low level of organic carbon content in soils of mapping unit 3 might be attributed to its slope

condition which favour rapid removal of leaf litter as well as high rate of organic matter turnover due to rapid mineralization as a result of the well-drained condition of this soil unit. This corroborates Nwaoba *et al.* (2024) who reported that differences in Morphology, Classification and Suitability Evaluation of soils for groundnut cultivation in Owerri south East Nigeria. Total nitrogen was low to medium (0.1-1.4 gkg⁻¹) in mapping unit 1, low (0.2-1.0 gkg⁻¹) in mapping unit 2 and very low (0.01-0.07 kg⁻¹) in mapping unit 3 (Table 3). The low content of total nitrogen across the study area might be due to continuous cultivation of the soils which rapidly increases the rate of organic matter decomposition due to increased aeration and crop uptake. This observation corroborates with Afu *et al.* (2015).

Table 3: Chemical Properties of Selected Soils in Guinea Savanna zone of Nigeria

Horizon Designation	Horizon thickness (cm)	pH (H ₂ O)	Org. C. ←	O.M. gkg ⁻¹	T.N. →	Ca ²⁺ ←	Mg ²⁺	K ⁺ cmol / kg ⁻¹	Na ⁺ →	CEC	Esp (%)	BS (%)	Al ³⁺ cmol / kg ⁻¹	H ⁺ cmol /kg ⁻¹	EA cmol/kg	ECE C	AV.P mgkg ⁻¹	Fe ←	Zn gkg ⁻¹	Cu →	Mn
Mapping Unit 1																					
Ap	0-18	5.8	12.4	21.4	0.7	2.20	1.10	0.24	0.06	10.5	1.20	34.3	0.21	1.20	1.41	5.01	7.3	1.3	0.7	1.1	0.20
Bgh ₁	18-38	5.3	10.5	18.8	1.2	2.70	1.36	1.12	0.06	16.9	0.87	31.0	0.40	1.28	1.68	6.92	10.1	1.2	0.6	1.4	0.10
Bgh ₂	38-74	5.1	10.2	17.6	0.9	2.90	1.33	1.11	0.05	17.2	0.70	31.2	0.24	1.56	1.80	7.19	9.8	1.4	0.6	1.2	0.06
Bg	74-118	5.1	4.8	8.3	0.3	2.50	1.25	1.19	0.06	17.1	0.91	29.2	0.42	1.16	1.58	6.58	7.7	1.5	0.6	1.2	0.06
Ap	0-9	5.9	11.1	19.1	1.4	2.10	1.80	0.46	0.20	10.2	3.57	4.7	0.45	0.60	1.05	5.61	17.8	1.4	0.5	0.8	0.20
Bh	9-32	5.6	11.6	20.0	1.1	2.40	1.74	0.40	0.10	12.8	1.74	36.3	0.22	0.90	1.12	5.76	16.2	1.8	0.5	0.8	0.30
Bgh	32-49	5.4	6.6	11.4	0.3	2.60	1.95	0.47	0.15	15.2	2.51	34.1	0.10	0.70	0.80	5.97	8.0	1.9	0.6	1.0	0.10
Bg	49-90	5.0	5.1	3.6	0.1	1.10	1.21	0.30	0.10	15.0	2.93	18.1	0.10	0.60	0.70	3.41	6.1	1.2	0.7	1.1	0.10
X		5.4	10.1	15.0	0.8	2.31	1.47	0.66	0.10	14.4	1.80	32.4	0.27	1.00	1.27	5.81	10.4	1.5	0.6	1.1	0.14
Mapping Unit 2																					
Ap	0-11	5.8	6.3	11.0	0.8	2.80	0.60	0.23	0.05	11.1	0.79	33.2	2.10	0.57	2.67	6.35	12.1	1.6	0.4	1.2	0.1
AB	11-36	5.7	5.4	5.9	0.5	2.40	0.70	0.23	0.42	12.4	5.61	30.2	2.40	1.33	3.73	7.48	11.2	1.8	0.2	0.6	0.1
Bt ₁	36-74	5.5	5.0	3.4	0.2	2.20	0.90	0.24	0.56	14.2	7.39	27.5	2.60	1.08	3.68	7.58	10.1	1.0	0.4	0.8	0.0
Bt ₂	74-115	5.3	4.7	2.9	0.2	1.80	1.00	0.30	0.56	14.4	7.44	25.4	2.70	1.17	3.87	7.53	6.5	1.6	0.4	0.8	0.0
Ap	0-15	5.8	14.7	39.1	1.0	2.10	0.50	0.17	0.09	10.2	1.72	28.0	2.00	0.38	2.38	5.24	13.2	1.1	0.3	1.1	0.5
AB	15-36	5.5	11.2	19.3	0.6	2.50	0.40	0.15	0.08	12.0	1.37	26.1	1.90	0.83	2.73	5.86	13.1	1.1	0.3	1.2	0.6
Bt ₁	36-67	5.5	8.4	14.5	0.6	3.00	0.60	0.15	0.08	14.5	1.36	26.4	1.70	0.34	2.04	5.87	12.4	1.3	0.3	1.0	0.2
Bt ₂	67-118	5.6	6.8	11.7	0.5	2.60	0.60	0.17	0.13	15.3	2.20	22.9	1.90	0.51	2.41	5.91	8.3	1.4	0.3	1.0	0.2
Ap	0-8	5.7	13.2	22.8	0.5	2.50	0.30	0.20	0.07	11.7	1.44	26.2	1.20	0.60	1.80	4.87	14.1	1.0	0.5	1.3	0.7
AB	8-27	5.4	10.8	18.6	0.6	2.20	0.30	0.16	0.08	11.9	1.19	23.0	2.60	1.40	4.00	6.74	14.0	1.8	0.6	1.2	0.5
Bt ₁	27-55	5.5	5.6	9.6	0.4	2.20	0.40	0.15	0.07	12.2	1.06	23.1	2.40	1.40	3.80	6.62	12.2	1.3	0.6	1.0	0.3
Bt ₂	55-108	5.5	5.6	6.2	0.3	2.30	0.40	0.21	0.07	12.6	0.86	23.7	2.20	3.00	5.20	8.18	10.3	1.6	0.7	1.1	0.3
X		5.6	8.0	13.8	0.5	2.38	0.56	0.20	0.19	11.9	2.70	26.3	2.14	1.05	3.19	6.52	11.5	1.1	1.3	1.0	1.3
Mapping Unit 3																					
Ap	0-9	4.7	5.2	9.0	0.04	0.10	0.40	0.11	0.05	5.2	1.17	31.9	3.00	0.60	3.60	4.26	9.2	5.8	1.7	0.9	0.40
Btv ₁	9-27	4.6	4.4	7.6	0.03	1.12	0.30	0.09	0.05	5.5	0.63	28.4	4.20	2.20	6.40	7.96	7.1	5.4	1.7	0.8	0.20
Btv ₂	27-61	4.4	2.1	3.6	0.01	1.00	0.10	0.08	0.06	5.8	0.56	21.4	5.40	4.00	9.40	10.64	6.5	5.2	1.6	0.8	0.55
Ap	0-15	4.9	4.6	7.9	0.03	1.40	0.30	0.13	0.06	6.1	0.61	31.0	4.60	3.40	8.00	9.89	8.8	5.6	1.8	1.3	0.5
Bt ₁	15-43	4.8	4.1	7.1	0.03	1.20	0.40	0.10	0.10	6.4	1.06	28.1	4.40	3.20	7.60	9.40	8.6	5.5	1.7	1.5	0.40
Bt ₂	43-77	4.7	2.0	3.4	0.01	1.20	0.40	0.07	0.05	6.8	0.63	25.3	3.40	2.80	6.20	7.92	5.2	4.7	1.7	1.5	0.40
Ap	0-18	4.8	3.3	5.7	0.07	1.70	0.50	0.14	0.04	7.6	0.40	31.3	4.60	2.90	7.50	9.88	8.3	5.6	1.3	1.6	0.4
Bt ₁	18-32	4.6	3.0	5.2	0.04	1.80	0.40	0.11	0.04	8.2	0.46	28.7	3.30	3.00	6.30	8.65	8.0	4.4	1.3	1.4	0.33
Bt ₂	32-63	4.5	1.8	3.1	0.02	1.40	0.50	0.05	0.06	8.5	0.69	23.6	3.60	3.10	6.70	8.71	4.5	4.4	1.0	1.3	0.33
BC	63-98	4.5	1.2	2.1	0.02	1.00	0.50	0.05	0.06	8.7	0.72	18.6	3.50	3.20	6.70	8.31	4.1	4.7	1.3	1.3	0.4
X		4.7	3.2	5.5	0.03	1.19	0.38	0.09	0.06	6.9	0.69	26.8	4.00	2.84	6.84	8.56	7.0	5.5	1.6	1.2	0.4

Amongst the exchangeable cations, sodium was generally low to medium ($0.04\text{-}0.56\text{ cmolkg}^{-1}$) across the study area. Potassium was medium to high ($0.24\text{-}1.19\text{ cmolkg}^{-1}$) in mapping unit 1, medium ($0.15\text{-}0.30\text{ cmolkg}^{-1}$) in mapping unit 2 and low ($0.05\text{-}0.10\text{ cmolkg}^{-1}$) in mapping unit 3. Calcium was medium ($1.10\text{-}3.00\text{ cmolkg}^{-1}$) in mapping unit 1 and 2, but low ($0.10\text{-}1.80\text{ cmolkg}^{-1}$) in mapping unit 3. Magnesium content was high in mapping unit 1 ($1.10\text{-}1.95\text{ cmolkg}^{-1}$) and medium in mapping unit 2 ($0.30\text{-}1.00\text{ cmolkg}^{-1}$) and mapping unit 3 ($0.10\text{-}0.50\text{ cmolkg}^{-1}$) (Table 3). The medium to high contents of exchangeable bases in mapping unit 1 might be due to flat terrain characteristics feature of the soils of this mapping unit which favour deposition of erosional sediments. However, the low to medium content of exchangeable bases in mapping unit 2 and 3 may be attributed to intensive cropping of the soils, leaching, erosion losses and crop removal without replacement resulting in chemical deterioration as also reported by Esearam *et al.* (2001) and Odunze (2006).

Cation exchange capacity (CEC) values were medium for soils of mapping unit 1 ($10.2\text{-}17.2\text{ cmolkg}^{-1}$) and mapping unit 2 ($10.2\text{-}15.3\text{ cmolkg}^{-1}$), but low ($5.2\text{-}8.7\text{ cmolkg}^{-1}$) in soils of mapping unit 3. This observation corroborates Afu *et al.* (2015) who attributed low CEC observed in some selected soils of Northern Cross River State to the dominance of 1:1 non-expanding clay minerals in these soils. The low to moderate cation exchange capacity of the soils in the study area implies that with continuous cultivation, the soils would undergo rapid degradation physically and chemically. The incorporation of organic matter and addition of fertilizers would raise and stabilize cation exchange capacity in these soils (Brandy & Weil, 2000).

The base saturation values in the study area were generally low and less than 35% by ammonium acetate method. This is suggestive of an ultisol soil order. The exchangeable acidity values in the study area was in the range $0.80\text{-}1.80\text{ cmolkg}$ (mapping unit 1), $1.80\text{-}3.87\text{ cmolkg}^{-1}$ (mapping unit 2) and $3.60\text{-}9.40\text{ cmolkg}^{-1}$ (mapping unit 3). Indeed, the Ap horizons had highest values across the profiles (Table 3). This result is similar to the low exchangeable bases and high exchangeable acidity reported by Afu *et al.* (2015) for selected soils under different land use in Northern Cross River State. Exchangeable Al^{3+} dominated H^+ , indicating that the soils have a high potential for acidification.

Available phosphorus values were medium for soils of mapping unit 1 ($6.1\text{-}17.8\text{ mgkg}^{-1}$) but low ($3.0\text{-}9.2\text{ mgkg}^{-1}$) in soil of mapping unit 3. The low to medium level of available P might be due to fixation (Al-P) arising from the high Al^{3+} status of the soils and crop uptake. This observation corroborates Nwaoba *et al.* (2024), who attributed low available phosphorus observed in Niger flood plains to P-fixation and retention in soils.

Amongst the cationic available micronutrients iron (Fe) was deficient in mapping unit 1 ($1.2\text{-}1.9\text{ gkg}^{-1}$) and in mapping unit 2 ($1.0\text{-}1.8\text{ gkg}^{-1}$) and adequate ($4.4\text{-}5.8\text{ gkg}^{-1}$) in mapping unit 3. Zinc was marginal ($0.5\text{-}0.7\text{ gkg}^{-1}$) in mapping unit 1 and 2, but adequate ($1.0\text{-}1.7\text{ gkg}^{-1}$) in mapping unit 3 (Table 3). Copper was generally adequate ($0.6\text{-}1.6\text{ gkg}^{-1}$) in soils of the study area. Manganese was deficient to marginal ($0.06\text{-}0.7\text{ gkg}^{-1}$) in all the mapping units studied. The variation of micro nutrient content between the mapping units might be attributed to the contributing effect of parent material and rainfall. The fine to medium textured soils of mapping units 1 and 2 favoured the low level of Iron in these soils due to its resistance to leaching of basic cations unlike the coarse textural soils derived from granites of mapping unit 3 which accelerated leaching, hence enhanced or dominance of micro nutrient contents. This observation corroborated Kparmwang *et al.* (2000) on extractable micronutrients in some soils developed on sand stone and shale.

Suitability Evaluation

The soils of the study area were evaluated for cotton (*Gossypium spp*) production by matching the soils characteristics in Tables 1-3 with the land requirement of suitability classes of Cotton in Table 5. A summary of land qualities (characteristics of the study sites are shown in Tables 1, 2 and 3 and the land suitability ratings obtained by matching the land characteristics values of the three mapping units with the land requirements for cotton (Table 5) is shown in Table 6. In the study area, temperature range was 28-31% while rainfall was 1500-2000mm (NIMET, 2013) and were thus rated moderately (S2) and highly (S1) suitable (Sys *et al.*, 1993). Soil depth was considered moderately suitable (S2) for mapping unit 1, highly suitable (S1) for mapping unit 2 and marginally suitable (S3) for mapping unit 3. Clay content was rated moderately suitable (S2) for mapping unit 1 and 2, but marginally suitable (S3) for mapping unit 3. Sand content was rated marginally suitable (S3) for units 1 and 2, and unsuitable (N1) for mapping unit 3. Degree of stoniness was adjudged highly suitable (S1) for the gravel free soils of units 1 and 2, but unsuitable (N1) for soils of mapping unit 3. Topography was considered moderate (S2) for soils of units 1 and 2 and unsuitable for unit 3. According to Fasina and Adeyanju (2006), slope of <4% favours mechanical farm operations and is less prone to erosion deterioration. The soils of mapping units 1 and 2 occur in slopes less than 5% and thus were rated moderately to marginally suitable for cotton production. The occurrence of plinthic layers in the sub-soils of mapping unit 3 may predispose the soils of this unit to root penetration hindrance and are thus unsuitable. Depth to plinthic layers were 26 cm, 32 cm and 41 cm for the pedons at Bebi, Utugwang and Utukpuru respectively. Drainage was rated currently not suitable (N1) for soils of mapping unit 1, moderate (S2) for unit 2 and highly suitable (S1) for unit 3.

Table 5: Land Requirements for Suitability Classes of Cotton (*Gossypum spp*)

Land qualities	Factor suitability ratings				
	Highly suitable (Very good, S1)	Moderately suitable (Good, S2)	Marginally suitable (Fair, S3)	Less suitable (Poor, N1)	Unsuitable (Very poor, N2)
Climate (c)					
Rainfall (mm)	1000-1500	850-1000	700-550	>1500, <550	-
Temperature (°c)	22-28	28-32	>32	-	-
Soil physical characteristics (s)					
Depth (cm)	>100	80-100	50-80	25-50	<25
Clay (%)	35-40	25-35	<25, >60	-	-
Sand (%)	<5	5-15	15-40	>40	-
Stoniness (%)	<15	<15	15-40	>40	-
Topography (t)					
Slope (%)	<1	1-3	3-5	>5	
Wetness (w)					
Drainage	Good	Medium	Poor	Very poor	-
Fertility status of top soil (f)					
Exch. Ca (cmolkg ⁻¹)	>5	3-5	2-3	1-2	<1
CEC (cmolkg ⁻¹)	>12	8-12	6-8	<6	-
Base saturation (%)	>80	65-80	50-65	<50	-
Org. c (gkg ⁻¹)	>0.1	0.08-0.1	0.05-0.08	<0.05	-
EC dsm ⁻¹	<2	2-4	4-8	>8.0	-
ESP (%)	<5	5-10	10-15	15-25	>25
pH	5.5-6.5	6.5-7.2, 5.0-5.5	7.2-8.0, 4.5-5.0	<4.5, >8.0	-

Source: Sys *et al.* (1991).

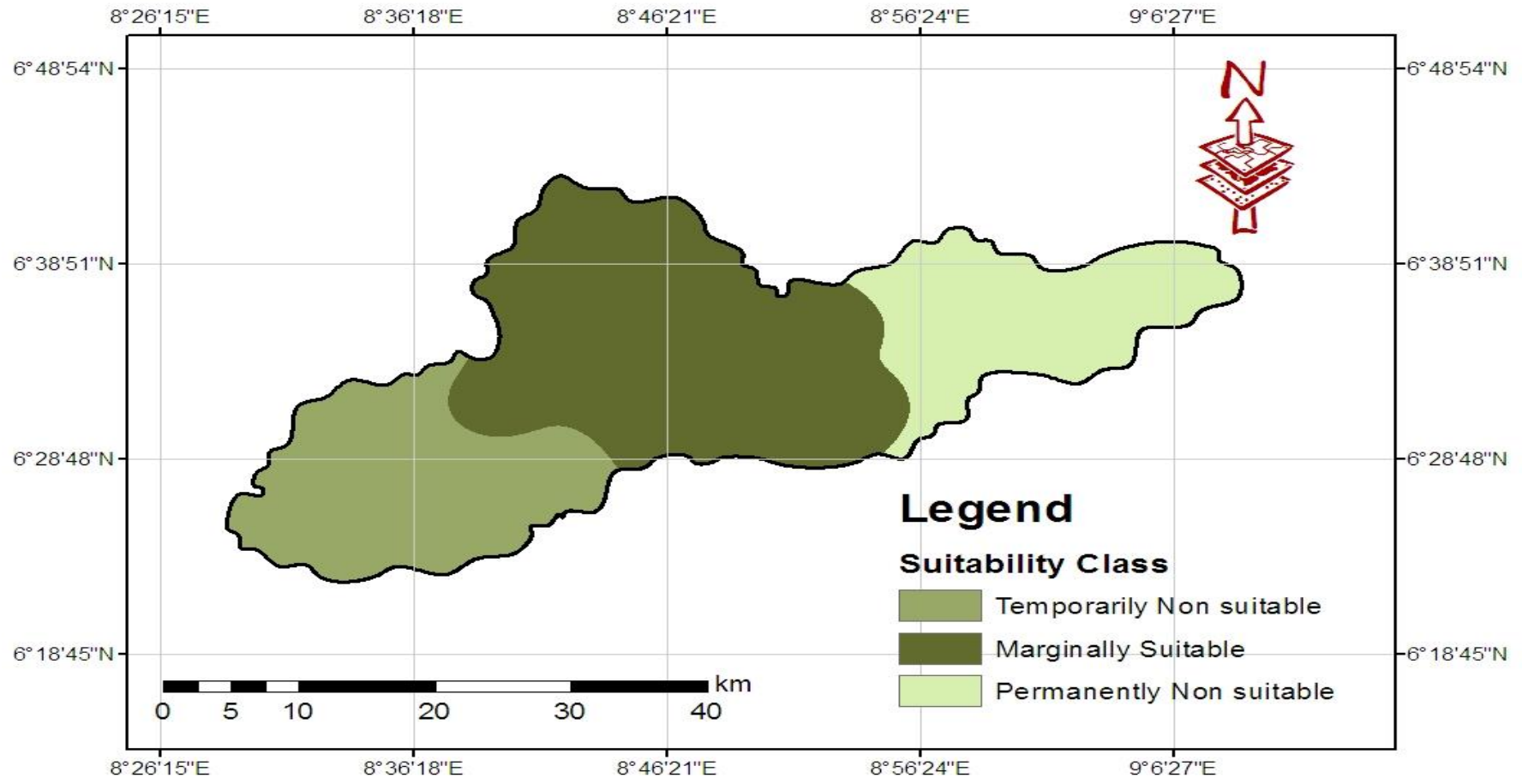
Table 6: Land Quality Ratings of Soils in the Study Area

Land quality	Mapping unit 1	Mapping unit 2	Mapping unit 3
Climate (c)			
Rainfall (mm)	95 (S1)	95 (S1)	95 (S1)
Temperature (°c)	85 (S2)	85 (S2)	85 (S2)
Soil physical characteristics (s)			
Depth (cm)	85 (S2)	95 (S1)	60 (S3)
Clay content	85 (S2)	85 (S2)	60 (S3)
Sand content	60 (S3)	60 (S3)	40 (N1)
Stoniness	95 (S1)	95 (S1)	40 (N2)
Topography (t)			
Slope	85 (S2)	85 (S2)	40 (N1)
Wetness (w)			
Drainage	40 (N1)	85 (S2)	95 (S1)
Fertility status of top soil (f)			
pH	85 (S2)	95 (S1)	60 (S3)
Exch. Ca (cmolk ⁻¹)	85 (S2)	85 (S2)	60 (S3)
CEC	85 (S2)	85 (S2)	60 (S3)
Base saturation	60 (S3)	60 (S3)	60 (S3)
Org. C	85 (S2)	85 (S2)	60 (S3)
EC	95 (S1)	95 (S1)	95 (S1)
ESP	95 (S1)	95 (S1)	95 (S1)
Aggregate suitability by limitation	N1	S3	N2

The fertility status of the top soil evaluated reveal that soil reaction was highly suitable (S1) for mapping unit 2, moderately suitable (S2) for unit 1 and marginally suitable (S3) for unit 3. The PH value in the range 5.0-5.8 may not pose a problem for the availability and uptake of essential plant nutrients (Mullen *et al.*, 2007). Exchangeable calcium was rated moderate (S2) for units 1 and 2, but marginal (S3) for land unit 3. Cation exchange capacity and organic carbon were rated same as calcium for the study area and are thus moderately suitable (S2) for land unit 1 and 2, but marginal (S3) for land unit 3. Electrical conductivity

and exchangeable sodium percentage were both rated highly suitable (S1) for all the mapping units as values obtained were far below their critical levels of < 2.0 dsm⁻¹ and < 5 % respectively.

Aggregate land suitability evaluation by limitation (non-parametric rated soils of mapping unit 1 as currently not suitable (N1), mapping unit 2 as marginally suitable (S3) and mapping unit 3 as being unsuitable (N2) for commercial cotton (*Gossypum* spp) production in selected soils of the Guinean Savanna Zone of Nigeria.



Conclusion

Land characterization and evaluation indicates potentials, limitations and suitability of various soils and provides valuable information to planners, engineers, developers, environmentalist, farmers and individual land owners for site utilization. The study under consideration highlighted all the potential land characteristics required for economic production of cotton (*Gossypium Spp*) in the study area as well as indicated its various limitations. The parametric and non-parametric suitability evaluation revealed that the soils of mapping unit 1 located in flood plains are limited by poor drainage and low sand content and thus rated currently unsuitable for commercial cotton production. The soils of mapping unit 2 were adjudged marginally suitable for cotton production due to fertility limitations. The soils of mapping unit 3 were adjudged unsuitable for cotton production due to possession of permanent limitations of stoniness, high sand content, steep slope and high risk of erosion hazard. It is therefore necessary to use the soils of the study area conservatively for economic production of cotton and avoid risk of deterioration, so that the advantage derivable from them now can continue to be enjoyed by future generation. The parametric and non-parametric approaches used in assessing the soils in the study area revealed that 264.6 ha representing 37.5% of the study area were currently not suitable (N1) for cotton production due to poor drainage, 296.3 ha representing 41.9 % of the study area were marginally suitable (S3) while 145.5 ha representing 20.6 % of the entire study area were unsuitable for cotton production.

Recommendations

- The soils of unit 1 currently not suitable (N1) for cotton production can be made suitable for the intended use through the removal of the temporal limitations of wetness through the installation of surface trenches and sub-surface tile and drain pipes to remove excess water.
- The suitability of soils of unit 2 can be enhanced through appropriate application of lime, manures and NPK fertilizers.
- The soils of unit 3 adjudged unsuitable for cotton production can be restricted to pasture, ranching and forestry to reduce its deterioration due to erosion.

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