Characterization and land capability evaluation of selected soil units in northern Cross River State, Nigeria

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Abstract
Some selected soils of Northern Cross River State within the guinea savanna zone of Nigeria, were surveyed, characterized and evaluated for its capability. The free soil survey method was used for this study. The study area was delineated into three (3) soil units based on soil homogeneity. The land capability evaluation for the study area placed the soils of mapping unit 1 under capability class III, sub class IIIw, unit 2 under capability class II, sub class IIf while soils of unit 3 were placed under capability class IV, sub-class IVrtg based on degree and severity of land limitations. The study recommended that productivity of soils of unit I, can be enhanced through drainage and good water control mechanisms. Soils of unit 2 can be managed through appropriate application of lime, NPK fertilizers and manures. The soils of unit 3, adjudged incapable for a wide range of agronomic uses can be restricted to pasture, ranching and forestry to reduce risk of deterioration due to erosion.

Keywords: Survey, Characterization, Evaluation, Capability

Introduction

Soil survey and Land evaluation are expedient in sustainable agricultural land utilization. Soil survey is paramount in agriculture as it provides a background for the evaluation of soils for general or specified land use type. Idoga and Azagaku (2015) remarked that characterization and land evaluation are essentially basic requirements for any land utilization type. They further added that soil information acquired through survey and characterization of soils can be widely applied in land use planning and management for sustainability. Esu (2004) stated that one of the strategies for achieving food security and a sustainable environment is by soil characterization and land evaluation for various land utilization types (LUT).

Land evaluation is the assessment of land quality for the various land utilization requirements. It provides a good link between the basic resource survey and land use decisions and management. Land evaluation also provides relevant information for planning, development and land resource conservation (FAO, 2014). Elealem *et al.* (2010) noted that if self sufficiency in agricultural production is desired to be achieved in developing and transitional countries, land evaluation techniques will be required to develop models for predicting the land's capability for different types of agricultural land use. Adeboye (1994) stated that specific management patterns are required for delineated homogenous sites, hence the need for land to be put to use according to its capability for optimization and sustainability.

Agricultural productivity in Northern Cross River State, Nigeria is on the decline in recent time due principally to inadequate soil information (Afu *et al.*, 2015). This according to the findings of Nsor and Udofia (2019), results in land misuse, high cost of production and poor land management. In view of the significance of soil as a critical component in agricultural production, it has become pertinent to pay special attention to the capability of each soil unit / type under general land use and management consideration. Knowledge of spatial distribution of soil types within and across landscapes are important in refining agricultural land use and management practices as this will enable users to minimize cost, enhance productivity and reduce environment degradation. This then underscores the need for a study on survey, characterization and land capability evaluation of selected soils of the study area. The objective of this study is to survey, characterize, classify and evaluate the soils of Northern Cross River State, Nigeria.

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). The climate of the study area is humid tropical, characterized by distinct wet and dry seasons. The annual rainfall in the study area is between 2000-3000 mm. The study area experiences great uniformity of temperature throughout the year with mean monthly temperature always around 27 °C, with peak of about 35 °C during February- April. The relative humidity varies from 60-70 % in January to 70-80 % in July (NIMET, 2020)

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 and on previous works of Ekwueme *et al.* (1995) on the geology of Eastern Nigeria and geomorphology of Cross River State. The sampling locations are shown on Figure 1.

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 visit 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 hand held GPS. 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 soil unit were dug and described according to the procedure specified in the field book for describing and sampling soils (Schoenberger *et al.,* 2012). A total of eight (8) profile pits, one each were located in Bansaral, Bansara 2 and Idum Mbube (Ogoja LGA), Imajie and Adagum (Bekwara LGA), Bebi (Obanliku LGA), Otugwang and Otukpuru (Obudu LGA) respectively. Thirty (30) soil samples were collected for laboratory analysis from each genetic horizon.

Sample Preparation and Analysis

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 the hydrometer method as outlined in Gee and Or(2002).Bulk density was measured by the cylindrical core method (Anderson and Ingram 1996). Porosity was evaluated using the relationship.

Porosity = (1-Bd/Pd) 100 % .... Equation 1.

Where Bd=bulk density, Pd = particle density ($2.65Mgm^{-3}$).

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 >2 mm in diameter sieve regarded as gravels were weighed and expressed as a percentage of the whole soil sample weight. Soil pH in H_2O was determined by using a pH meter in 1:2.5, soil: water ratio respectively, according to the method of Thomas (1996). Available phosphorus was determined by Bray and Kurtz as modified by Oslen and Sommers (1982). Organic carbon was determined by using Walkley and Black (1934) wet oxidation method as outlined by Nelson and Sommer (1996). Total nitrogen was determined by the Kjeldahl method as modified by Bremner (1996). Exchangeable bases were extracted with neutral NH_4OAc solution; exchangeable Ca and Mg were be determined by the use of an Atomic Absorption Spectrometer (AAS) while exchangeable K and Na were determined by flame photometry (Grant,1982).Cation exchange capacity (CEC) was measured using ammonium acetate leaching at pH 7.0 (Rhodes,1982). Base saturation percentage was calculated as follows

$$BS\ (\%) = \frac{\text{Total Exchangeable Bases}}{\text{Cation Exchange Capacity}} \times \frac{100}{1} \quad .... \text{Equation 3}$$

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 Capability Evaluation Procedure

The capabilities of soils in the study area were evolved based on limitation of soil properties and terrain features. The land evaluation procedure used was the simplified from of the USDA system of land capability classification modified by Sys *et al.* (1991) and Oluwatosin *et al.* (2006). The land limitation places the soils into different classes, I – IV (arable) and V – Viii (non-arable). The classification thus depended more on the severity of the limitation than the number of limitations (FAO, 1983).

Results and discussion

The data on morphology, physical and chemical properties of selected soils of Northern Cross River State, Nigeria is presented, discussed and evaluated for its capability.

Morphological Characteristics

The morphological characteristics of selected soils of Northern Cross River State within the Guinea Savanna zone of Nigeria are presented in Table 1. The results are presented for the various soil units identified as 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 to water table and seasonally water logged with hydromorphic features. The extent of soil unit 1 is vast and occupies an approximate area of about 264.6 ha. This soil 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 colluvial and alluvial deposits with alluvial materials dominating the area. Under moist conditions the soils of unit 1 were characterized by very dark greyish brown (10YR 3/2) to dark grey (5YR 4/1) to grey (7.5YR 5/1) surface soils over reddish grey (5YR 5/1) to grey (7.5YR 5/1) sub surface soils (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 and 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 and Akamigbo (2009), Fasina *et al.* (2015) and Sahu *et al.* (2001). 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 geometry. 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.

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 soil unit is vast and occupies an approximate land area of about 296.3 ha. This soil unit dominates farm lands around Imajie and Mbube communities in Ogoja and Adagom in Bekwara Local Government Areas.

Under moist conditions the soils of unit 2 were characterized by dark reddish brown (5YR 3/3) to dark brown (10YR 3/3) surface horizons over dark yellowish brown (10YR4/4) to yellowish brown (10YR5/6) sub surface horizons (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 is similar to Mbagwu (1997) work, who reported that water infiltration into soil depend on texture and profile pore geometry in his study on Quasi-steady infiltration rates of highly permeable tropical savannah soils in relation to land use and poor size distribution.

Soils of unit 3 consist 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 that is dominated by granites. This unit consists of about 145 ha of land, and occurs extensively around Bebi, Utugwang and Utukpuru axis of Obudu LGA of Cross River State, Nigeria. Under moist condition the soils of this soil unit consist of dark reddish brown (7.5YR 3/2) to dark brown (7.5YR 3/4) surface horizons over reddish brown (5YR 4/5) to orange (5YR 7/6) sub surface horizons (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 nonsticky, 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 finding is similar to the work by Nsor (2017) who studied "similar soils in the Guinea Savanna zone of Nigeria. The soil's pore geometry indicated that the soils had many medium pores over few fine to few very fine sub soil pore (Table 1).

Physical Properties

The data on physical properties of soils in the study area is presented in Table 2. The results indicate that soils of unit 1 had loamy top soils over silty loam to silty clay sub soils. Similarly the soils of unit 2 also had loam to silty loam top soils over silty clay loam sub soils. However soils of unit 3 contrasted the other 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 dorminated top soils of profiles of units 1 and 2, while sand dorminated the profile of soil 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 Ewulo *et al.* (2002) in their studies on soils with Kandic horizons in Southwestern Nigeria. The dorminance 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 and 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 Mgm^{-3}) and thus possess no serious limitation to agricultural productivity. Plants perform best in bulk densities between 1.4and 1.6 $Mgm^{-3}$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 and Weil, 2005; and 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 (Ayolagha and Opene, 2012).

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

The erodibility index of the studied soils was generally low to moderate (0.8 - 4.9) for the fine to medium textured soils of units 1 and 2 (0.8-4.9), but moderate to high (1.2-9.0) for the coarse textured soils of unit 3. This observation agrees with the work of Hudson (1995) 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 range of 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. The ranges of values on top soils are more vulnerable to sheet and gully erosion than the sub-soils with erodibilty index range of 1.2-2.6.

The soils of units 1 and 2 were relatively gravel free with percent gravel content < 11.1 % while the soils of 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 top soil: sub soil 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 5.35.8).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 coarsed texture of these soils which permits extensive leaching of basic cations by high rainfall of the Nigeria southern savanna region (Abagyeh and Idoga, 2013). 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 with range of 4.8-12.4 gkg^{-1} in soil unit 1 and 4.7-14.7 gkg^{-1} in soil unit 2 to low in soil unit 3 with range of 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 Ezenwa and Barrera (1985) who reported that differences in slope steepness contributed to variation in soil organic carbon in their soil survey of Ribako forest Reserve.

Total nitrogen was low to medium (0.1-1.4 gkg^{-1}) in unit 1, low (0.2-1.0 gkg^{-1}) in unit 2 and very low (0.01-0.07 kg^{-1}) in 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 Havlin *et al.* (2005) in their study of the soils in North- Eastern Victoria, Australla.

Amongst the exchangeable cations, sodium was generally low to medium (0.04-0.56 $cmolkg^{l}$) across the study area. Potassium was medium to high (0.24 -1.19 $cmolkg^{-1}$) in soil unit 1, medium (0.15-0.30 $cmolkg^{-1}$) in soil unit 2 and low (0.05-0.10 $cmolkg^{-1}$) in mapping unit 3. Calcium was medium (1.10-3.00 $cmolkg^{-1}$) in soil unit 1 and 2, but low (0.10-1.80 $cmolkg^{-1}$) in soil unit 3. Magnesium content was high in soil unit 1 (1.10-1.95 $cmolkg^{-1}$) and medium in soil unit 2 (0.30-1.00 $cmolkg^{-1}$) and soil unit 3 (0.10-0.50 $cmolkg^{-1}$) (Table 3). The medium to high contents of exchangeable Ca, Mg and K in soil unit 1 might be due to the flat terrain characteristic feature of the soils of this soil unit which favour deposition of erosional sediments. However the low to medium content of exchangeable bases in soil 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 Eswaran *et al.* (2001) and Odunze (2006).

Cation exchange capacity (CEC) was medium for soils of unit 1 (10.2-17.2 $cmolkg^{-1}$) and unit 2 (10.2-15.3 $cmolkg^{-1}$), but low (5.2-8.7 $cmolkg^{-1}$) in soils of 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 (Brady and Weil, 2005).

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 were in the range 0.80- 1.80 cmol/kg (mapping unit 1), 1.80-3.87 $cmolkg^{-1}$ (unit 2) and 3.60-9.40 $cmolkg^{-1}$ (unit 3). Indeed, the Ap horizons hard highest values among the horizons of all soil 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 and Markus *et al.* (2008) for Oxisols developed from three different parent materials. Exchangeable Al^{3+} concentration exceeded its H^{+} counterpart indicating that the soils have a high potential for acidification.

Available phosphorus values were medium for soils of mapping unit 1 (6.1-17.8 $mgkg^{-1}$) but low (3.0-9.2 $mgkg^{-1}$) 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 Igwe (2001) who attributed low available phosphorus observed in Niger flood plains to P-fixation and retention in soils. Electrical conductivity which is 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 soluble salt status of the soils in the study area (Plaster, 1992).

Amongst the available micronutrients, iron (Fe) was deficient in mapping unit 1 (1.2-1.9 gkg^{l}) and in mapping unit 2 (1.0-1.8 gkg^{-1}) and adequate (4.4-5.8 gkg^{-1}) in mapping unit 3. Zinc was marginal (0.5-0.7 gkg^{-1}) in mapping unit 1 and 2, but adequate (1.0-1.7 gkg^{-1}) in mapping unit 3 (Table 3). Copper was generally adequate (0.6-1.6 gkg^{-1}) in soils of the study area. Manganese was deficient to marginal (0.06-0.7 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.

Land Capability Evaluation

A summary of land qualities (characteristics of the study sites are shown in Tables 1, 2 and 3 and the land capability ratings obtained by matching the land characteristics values of the three mapping units with the land requirements for optima productivity is shown in Tables 4 and 5. The soils of unit 1 consisting of flood plains and inland valley occurring on flat or nearly flat terrains of less than 2 % slopes (class 1) and occurring around Bansara I and II. These soils are stoneless and gravel free, except for the presence of soft iron-oxide concretions below 50 cm soil depths and mottling due to high fluctuating water table. The soils have somewhat imperfect internal drainage (class III) and are shallow to moderately deep in effective soil depth. They have moderate acid reaction (pH 5.0-5.9) and are in class III. In terms of texture the soils are loamy to clay loam (class I). Aggregate land capability placed the soils of mapping unit 1 under capability class III, sub class IIIw, due principally to their wetness limitation (Table 4). The soils of this unit will require moderate water control strategies such as drainage for enhanced agricultural productivity.

Soils of unit 2 are moderately deep to deep found on nearly flat to undulating plains on slopes less than 6 % (class II) developed on silt stones. The soils are stoneless and moderately drained (class II). Texturally, these soils are predominantly sandy loam to sandy clay loams (class II). They are moderately acid in reaction (pH 5.3 – 5.8) and quality as class III. Aggregate land capability classification placed the soils of unit 2 found around Imajie, Adagom and Idum Mbube under capability class II, and sub-class IIf due to moderate fertility limitation (Table 4). The soils of unit 2 will require moderate liming, NPK 15:15:15 fertilization and manuring for enhanced productivity.

The soils of unit 3 occur on undulating hilly terains with slope of 15-25 % and qualify as class III. These soils have moderate to good internal drainages (class II) but are rocky and gravelly and qualify as class IV. The soils are coarse textured (class III) and inherently low in fertility and qualify as class III – IV (Table 5). Soils of unit 3 were placed in capability class IV and sub class IVrtf due to its gravelly/nature (r) steep slope (t) and fertility (f) limitation. This land unit will require major conservation practices such as efficient erosion control measures and therefore should be restricted to pasture, grazing and forestry in farmstead planning.

Conclusion

Land characterization and evaluation indicates potentials, limitations and capability 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 enhanced agricultural utilization of soils in the study area as well as indicated its various limitations and management requirements. Aggregate land capability evaluation placed the soils of mapping unit 1 under capability class III, sub-class IIIw, due principally to wetness limitation. The soils of units 2 were placed under class II, sub-class IIf due to moderate fertility limitation, while the soils of unit 3 were placed under class IVrtf due to stoniness / rocky nature (r), steep slope (t), severe fertility (f) limitation and high risk of erosion hazard.

It is therefore necessary to use the soils of the study area conservatively for enhanced economic productivity and avoid risk of deterioration, so that the advantage derivable from them now can continue to be enjoyed by future generation. The land capability evaluation in the study area currently reveal that about 264.6 ha representing 37.5 % of unit 1 with wetness limitation can be adapted and used for agricultural activities that require wet soil conditions like swamp rice, sugarcane and fresh water fish farming or drained to accommodate a wider range of crops. The soils of unit 2 of about 296.3 ha representing 41.9 % of the study area placed under class II with mild or moderate fertility limitation is viable and economically capable of sustaining a wider range of agricultural production with minimal costs.

The soils of mapping unit 3 placed in class IV of about 145.5 ha representing 20.6 % of the entire study area, were adjudged incapable in sustaining any meaningful agricultural venture. This is due to their possession of permanent limitations of stoniness, high sand content, steep slope and high risk of erosion hazard.

Recommendations

1. The soils of unit 1 currently under class IIIw can be made more capable for agricultural production, for ideal and other 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.

2. The capability of soils of unit 2 can be enhanced through appropriate application of lime, manures and NPK fertilizers.

The soils of unit 3 adjudged incapable for a wide range of agronomic use can be restricted to pasture, ranching and forestry to reduce its deterioration due to erosion.

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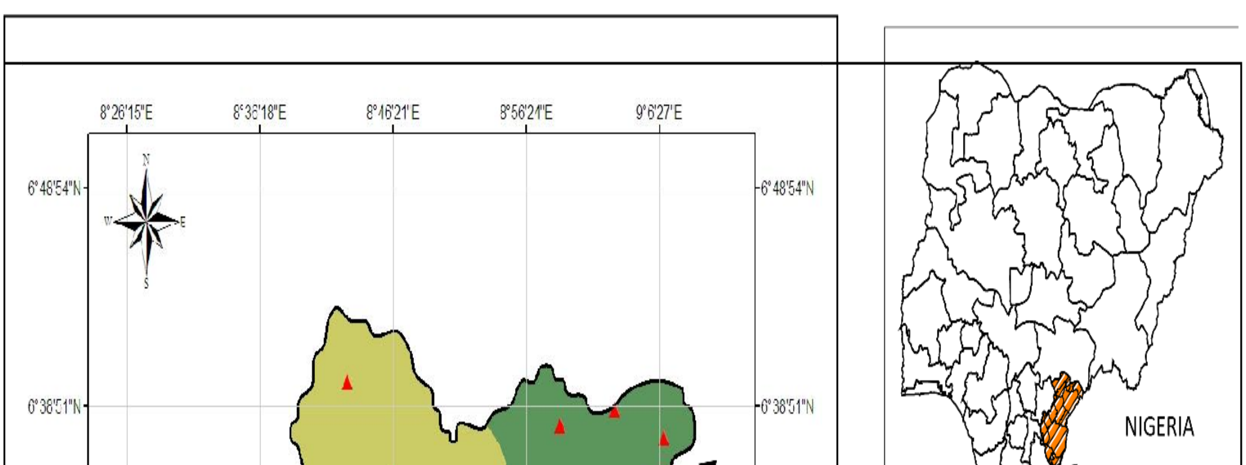

Table 1: Morphological Characteristics of Selected Soils of Northern Cross River State, Nigeria.

Location	Horizon Designation	Horizon Thickness (cm)	Major Colour	Mottle Colour	Texture	Structure	Consistence			Roots	Pores	Horizon Boundary
							Dry	Moist	Wet			
				Soil 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	
				Soil 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	
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	
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	
				Soil 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	
Utugwang	Ap	0-15	7.5YR 2/3; Vdb		SL	1 M Gr	S	fr	ns-np	mm	mm	cw
	Bt_1	15-4 3	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	
Utukpuru	Ap	0-18	7.5YR ¾; 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	

1. **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 3.4. **Texture:Structure:** L = Loam, SiL = Silty loam, SiC = Silty clay, CL = Clay loam, SiCL = Silky clay loam, Sl = Sandy loam, SCL = Sandy clay loam, 1 = weak, 2 = moderate, 3 = strong, F = fine, M = Medium, C = Coarse, Sbk = Sub angular blocky, Cr = Crumb, Gr = Granular, P LS = Loamy sand, SCr = Prismatic = Sandy clay 5.**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 6.**Horizon Boundary:** Cs= clear smooth, gw = gradual wavy, cw = clear wavy

Table 2a: Physical Properties of Soils of unit 1 in the Study Area

Location	Horizon Designation	Horizon Thickness (cm)	Sand %	Silt %	Clay %	Textural Class	Silt: Clay Ratio	Bulk Mgm^{-3} Density	Porosity %	Soil Erodibility Index	EC (dsm^{-1})	Gravel %	Illuvia: Eluvia Clay
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
	Bg	74-118	20	24	56	C	0.4			0.8	0.26	3.0	
Bansara II	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				

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, Mgm^{-3} = millgram per cubic meter, % = percentage, dsm^{-1} decisiemens per metre, cm = centimeter

Table 2b: Physical Properties of Soils of unit 2 in the Study Area

Location	Horizon Designation	Horizon Thickness (cm)	Sand %	Silt %	Clay %	Textural Class	Silt: Clay Ratio	Bulk Mgm^{-3} Density	Porosity %	Soil Erodibility Index	EC (dsm^{-1})	Gravel %	Illuvia: Eluvia Clay
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	0.22	6.3	1.1

Table 3b: Chemical Properties of Selected Soils of unit 2 in Northern Cross River State, Nigeria

Horizon Design	Horizon Thickn (cm)	pH (H_2O)	Org. C.	P. M. gkg^{-1}	T.N	Ca^{2+}	Mg^{2+}	K^+ cmol/kg	Na^+	CE C	Esp (%)	BS (%)	Al^{3+} cmol/kg	H^+ cmol/kg	EA $mgkg^{-1}$	ECEC $mgkg^{-1}$	AV.P gkg^{-1}	Fe	Zn	Cu	Mn
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	0.5	2.67	6.35	12.1	1.6	0.4	1.	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	1.3	3.73	7.48	11.2	1.8	0.2	1	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	1.0	3.68	7.58	10.1	1.0	0.4	1	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	1.1	3.87	7.53	6.5	1.6	0.4	1	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	0.3	2.38	5.24	13.2	1.1	0.3	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	0.8	2.73	5.86	13.1	1.1	0.3	1.	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	0.3	2.04	5.87	12.4	1.3	0.3	1.	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	0.5	2.41	5.91	8.3	1.4	0.3	1.	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	0.6	1.80	4.87	14.1	1.0	0.5	1.	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	1.4	4.00	6.74	14.0	1.8	0.6	1.	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	1.4	3.80	6.62	12.2	1.3	0.6	1	
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	3.0	5.20	8.18	10.3	1.6	0.7	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	1.0	3.19	6.52	11.5	1.1	1.3	1.	1.3

Key: pH = Hydrogen power, H_{20} = water, Org. C = Organic carbon, O.M = Organic matter, TN = Total Nitrogen, Ca^{2+} Exchangeable calcium, Mg^{2+} = Exchangeable Magnesium, K^+ = Exchangeable potassium, Na^+ = Exchangeable sodium, CEC = Cation exchange capacity, ESP = Exchangeable percentage, BS = Base saturation, % = Percentage, Al+ = Exchangeable aluminum, EA = Exchangeable

Table 3c: Chemical Properties of Selected Soils of unit 3 in Northern Cross River State, Nigeria

Horizon Design	Horizon Thickn (cm)	pH (H_2O)	Org. C.	O. M. gkg^{-1}	T.N	Ca^{2+}	Mg^{2+}	K^+ cmol/kg	Na^+	CE C	Esp (%)	BS (%)	Al^{3+} cmol/kg	H^+ cmol/kg	EA $mgkg^{-1}$	ECEC $mgkg^{-1}$	AV.P gkg^{-1}	Fe	Zn	Cu	Mn
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	0.6	3.60	4.26	9.2	5.8	1.7	1	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	2.2	6.40	7.96	7.1	5.4	1.7	1	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	4.0	9.40	10.6	6.5	5.2	1.6	1	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	3.4	8.00	9.89	8.8	5.6	1.8	1	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	3.2	7.60	9.40	8.6	5.5	1.7	1	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	2.8	6.20	7.92	5.2	4.7	1.7	1.	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	2.9	7.50	9.88	8.3	5.6	1.3	1	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	3.0	6.30	8.65	8.0	4.4	1.3	1	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	3.1	6.70	8.71	4.5	4.4	1.0	1	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	3.2	6.70	8.31	4.1	4.7	1.3	1.	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	2.8	6.84	8.56	7.0	5.5	1.6	1	0.4

Key: pH = Hydrogen power, H_2O = water, Org. C = Organic carbon, O.M = Organic matter, TN = Total Nitrogen, Ca^{2+} Exchangeable calcium, Mg^{2+} = Exchangeable Magnesium, K^+ = **Key:** pH = Hydrogen power, H_2O = water, Org. C = Organic carbon, O.M = Organic matter, TN = Total Nitrogen, Ca^{2+} Exchangeable calcium, Mg^{2+} = Exchangeable Magnesium, K^+ = Exchangeable potassium, Na^+ = Exchangeable sodium, CEC = Cation exchange capacity, ESP = Exchangeable percentage, BS = Base saturation, % = Percentage, Al+ = Exchangeable aluminum, EA = Exchangeable

Key: pH = Hydrogen power, H_2O = water, Org. C = Organic carbon, O.M = Organic matter, TN = Total Nitrogen, Ca^{2+} Exchangeable calcium, Mg^{2+} = Exchangeable Magnesium, K^+ = Exchangeable potassium, Na^+ = Exchangeable sodium, CEC = Cation exchange capacity, ESP = Exchangeable percentage, BS = Base saturation, % = Percentage, Al+ = Exchangeable aluminum, EA = Exchangeable

Table 4: Simplified Conversion Table of USDA Land Capability Classification Differentia for Topical Soils

Land Characteristics	Class I	Class II	Class III	Class IV	Class V	Class VI	Class VII	Class VIII
Topography (t): Slope %	< 2	< 6	< 12	< 25	< 25	< 25	> 25	> 55
Wetness (w): Flooding	No flooding	No flooding	Slight	Slight	Severe	Severe	Severe	Very Severe
Drainage	Good	Moderate	Somewhat imperfect	Imperfect	Poor	Poor	Very poor	Very poor
Physical Soil Condition (s):								
Surface Texture	L – CL	SCL – SL	SL – LS	LS – C	LS – HC	LS – HC	Any	Any
Surf. Coarse Fragment (%)	None	< 15	< 35	< 55	< 55	< 55	< 75	< 75
Rockyness (%)	None	< 2	< 10	< 25	< 50	< 50	< 75	< 75
Soil Depth (m)	< 1.5	> 1.0	> 0.5	> 0.25	> 0.25	> 0.25	> 0.10	< / < 0.10
Fertility (f):								
Apparent CEC cmol/kg	> 16	16 – 12	12 – 10	10 – 6	Any	Any	Any	Any
Base Saturation (%)	> 80	> 50	> 35	> 15	> 15	Any	Any	Any
Org. Carbon (0-15cm)	> 1.5	> 1.0	> 0.6	> 0.4	> 0.4	Any	Any	Any
pH (H_2O)	6 – 8	6 – 8	5 – 6 /8-9	< 5 / >9	<5/>9	<5/>9	<5/>9	<5/>9

Key: L = loam, CL = clay loam, SCL = sandy clay loam, SL = sandy loam, LS = loamy sand, HC = heavy clay

Table 5: Land Capability Classification of the Study Area

Land Characteristics Limitations	Soil Unit 1	Soil Unit 2	Soil Unit 3
Slope (t)	I	II	IV
Wetness (w)	III	II	II
Drainage (d)	III	II	I

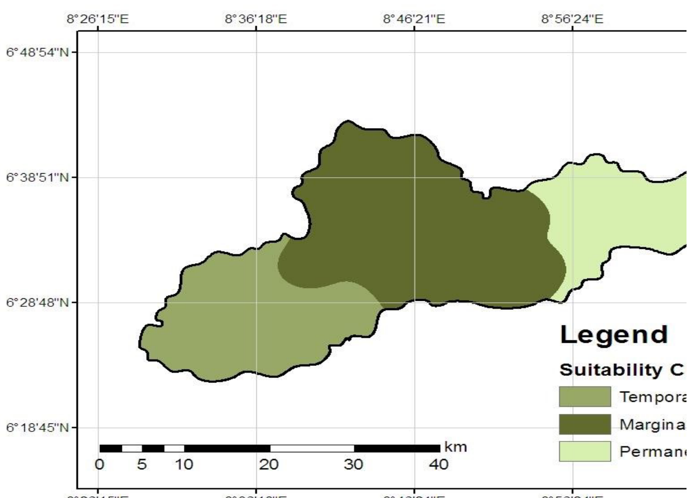

Figure 2: Land Capability Classification Map for Selected Soils of Northern Cross River State, Nigeria