Land Capability Classification of Soils Developed from Limestone Geological Formations in Cross River State, Nigeria

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Abstract

Soils developed from limestone formations in the humid tropics differ from similar soils in areas with limited rainfall. This research was carried out to investigate soils developed from limestone formations in the three agricultural zones (North, central and south) ofCross River State with respect to their capability classifications. Google satellite imageries of the areas underlain by limestone were obtained. The slope map generated from the digital elevation models (DEMs) of the area was used to stratify the study area into eight mapping units (IH1, IH2, AI1, AI2, AI3, MF1, MF2, MF3) with two profile pits excavated in each of the units.Results revealed thatIH1, AI1, AI2, MF1, MF2 soils were placed in class II. On the other hand, soils in the poorly drained IH2, AI3 and MF3 were classified as class III or IV and variously limited by wetness, soil physical properties and fertility characteristics. In northern Cross River, 37.2 % were class II soils, while 61.7 % were class III and only 1.1 % qualified as class IV. For soils in Central Cross River, 49 % were class II soils, 35.3 % class III and 15.7 % were classified as class IV soils, while in southern Cross River, 71.8 % of the soils qualified as class II, while 28.2 % qualified as class III soils. For a possible upgrade to class 1 soils, an intensive fertility evaluation of the soils is recommended for a site-specific nutrient recommendation.

Keywords: Land capability classification, limestone formation, Cross River

Introduction

State factors, pedogenic processes and their interaction over time co-relate with landscape segments to facilitate land use planning and improve soil mapping. Detailed soil surveys are helpful in soil genesis and extrapolation of information and solve problems related to the distribution of soils (Ezeaku, 2011). New trends in soil survey facilitate soil mapping through technologies such as remote sensing and geographic information system (GIS) to extrapolate points and provide approaches to meet the demand of resource-related modeling (Mermut and Eswaran, 2001; Salehi*et al.*, 2003). The use of digital elevation models (DEM), satellite data and digital geological data to improve map quality has been investigated (Bayramin, 2001). In an earlier study, Vink (1970) opined that remote sensing techniques facilitate the process of soil surveys, but the technology should not replace but complement field surveys (Ezeaku, 2011).

Through soil mapping, analysis and categorization put data obtained from resource inventory into a form that is useful to farmers by evaluating the mapping units for diverse land use types. Land use planning seeks to evaluate and assess land as a basis for decisions involving land use to reconcile competing demands for land and reduce incidences of soil degradation (Ameztegui*et al.*, 2016). Among the many technical systems of classification, the FAO land suitability and USDA land capability classification systems have been designed to evaluate land for specified and general land uses, respectively and are most widely used (Esu, 2010).

Land capability classification is used to evaluate the capability of land to support a range of land uses, on a long term sustainable basis and considers the physical nature of the land including; geology, soils and slope as well as climate and erosion hazard which may influence the long term sustainable use of the land for agriculture (Odoemena and Uchua, 2014). It takes into account limitations due to salinity, stoniness, drainage and flooding but does not take into account the economics of agriculture and sociopolitical factors. In the case of permanent limitation or where it is technically not feasible for an individual farmer, the land is classified according to the nature of its present limitation. As an alternative and improved soil mapping technique, Aksoy*et al.* (2009) successfully used DEM and Landsat TM imagery to survey the soils in a hilly terrain, in order to develop a land capability as well as irrigation suitability maps of Northwest province, Turkey. Digital elevation model is therefore well established in solving soil survey related issues globally. Land capability classification grades land for broad scale agricultural uses, while land suitability classification is applied to clearly defined land uses (Idoga *et al.*, 1995).

Except for a study by Ofem *et al.* (2020), there is a dearth of information regarding recent published soil surveys in Cross River State, especially in the use of remote sensing techniques such as satellite imageries and DEM for soil resources inventory in the limestone areas of the state. Also, despite the importance of limestone to the state's agricultural sector, there have been no identified published studies on the land capability classification of limestone geological formations of the state. The current study is aimed at establishing the land capability classifications of major limestone geological formations in Cross River Sate, Nigeria.

Materials and methods

Description of the Study Area

Cross River State in which the study is located is found within latitudes 5°32′ and 4°27′ N, and longitudes 7°50′ and 9°28′ E and bordered by Benue, Ebonyi, Abia and AkwaIbom States, and the Atlantic Ocean and the Cameroons in the South and East, respectively. Ishibori, AgoiIbami and Mfamosing in Ogoja, Yakurr and Akamkpa Local Government Areas found in the northern, central, and southern agricultural zones, respectively were selected for the study due to the prevalence of the geologic material in the areas.

The Oban-Obudu hills form the basement complex of Cross River State and are made up of Precambrian Schist and Gneiss with intrusives of igneous rocks (Ekwueme, 1987). The sedimentary limestone of Cretaceous and Tertiary ages in Cross River State is common in the Ikom depression (Mamfe rift) and Calabar flank, and intercalated with shale, siltstone, and fine-grained sandstone (Fatoye and Gideon, 2013; Ofem *et al.*, 2020).

Humid tropical climate defines Cross River State with distinct wet and dry seasons which vary slightly in duration and location. In the Koppen climate classification system, the areas qualify as a tropical moist climate with an average temperature that exceeds 18 ^{o}C in all months and precipitation of over 1,500.00 mm per year. Rainfall varies from 1,251 to 3,348 mm per year in Ishibori and 1760-3,771 mm per year in the AgoiIbami and Mfamosing areas. Temperature is less than 34 ^{o}C in all the locations (Sambo *et al.*, 2016). The state's vegetation ranges from the mangrove swamps in the Southern coastal areas through the tropical rainforests in the southern uplands (Eni *et al.*, 2011) and central areas of the State to the southern guinea savannahs in the northern parts of the

State (Fon *et al.*, 2014). Montane parkland dominates the Obudu-Obanlikuplateaux.

Field studies

Google satellite imageries were obtained and used as base maps and later, for the selection of sampling areas. Sample areas were selected in each of Ishibori, AgoiIbami and Mfamosing to represent the northern, central and southern agricultural zones, respectively. This was done according to the criteria set by Esu (2010) and Ezeaku (2011) for selecting sampling areas during soil surveys. Field reconnaissance visits were then carried out in the selected sample areas. Digital elevation models (DEMs) of the study locations were obtained from USGS Explorer SRTM 1 arc-second Global at a resolution of 30 m. Using ArcGIS (ESRI, US) software, the DEMs were used to generate the slope maps of the study areas (Aksoy *et al.*, 2009) and presented as Figures 1, 2 and 3.

The slope map generated from the digital elevation models was used to stratify and delineate the area into eight mapping units (IH1, IH2, AI1, AI2, AI3, MF1, MF2, MF3). Ground truthing of the delineated mapping units and profile sampling were thereafter carried out using Global Positioning System (GPS) receiver.IH1 and IH2 were located in the northern agricultural zone, AI1, AI2 and AI3 were found in the central agricultural zone, while MF1, MF2 and MF3 were in the southern agricultural zone.

Two representative profile pits were excavated in each of the mapping units delineated and described for their morphological attributes. The morphological properties were basically employed in field studies, while horizons samples collected from bottom-up were taken to the laboratory for the determination of physical and chemical properties. These properties were used for land capability classification. Fifty-three (53) soil samples were collected from 16 soil profile pits and used for the analyses.

Laboratory Studies

Particle size distribution was determined on the fine-earth fraction by the Bouyoucos hydrometer method using sodium hexametaphosphate as the dispersant. Soil texture was thereafter determined by tracing the percent textural sizes on the USDA soil textural triangle. Soil pH was determined in a soil to water ratio of 1:2.5 using a glass electrode pH meter. The soils were leached with 1 *N* NH_4OAc (pH 7) in a 1:1 soil-solution ratio and exchangeable K and Na in the extract determined with the aid of a flame photometer, while Ca and Mg were determined by the versenate EDTA titration procedure. Furthermore, cation exchange capacity by NH_4OAc at pH 7.0 was obtained by saturating the soil exchange sites with NH_4^+ at pH of 7.0 by treating the soil with 1 *M* NH_4OAc at pH 7.0 and the concentration of NH_4^+ in the extract was determined by distillation and titration. Base saturation was then calculated by expressing the sum of exchangeable bases as a percentage of CEC. All laboratory analyses were carried out as outlined in the Soil Survey Staff (2014).

Guide for Classifying the Soils into Land Capability Classes and subclasses

Land capability classification is assessed by comparing the characteristics of soil mapping units with critical limits set for each capability class (Ezeaku, 2011). Critical limits as reported by Sys *et al.* (1991), Sinclair and Dobos (2006),Dobos (2006) and Lynch (2009) were used in the land capability class category and presented in Table 1.

According to Lynch (2009),subclass allocation priority when more than one kind of limitation is considered indicates that erodibility is given a preferential consideration as compared to wetness, soil and climate limitations such that erodibilty (e), wetness (w), rooting limitations (s), climate (c) preferentially occur in that order.

Results and Discussion

Land Capability Classification of the Soils

Land characteristics used in classifying the soils into USDA Land Capability Classes are presented in Table 2.

a. **Northern Agricultural Zone**

In the northern agricultural zone, soils in mapping unit IH1 were deep (> 100 cm) with sandy clay loam and sandy loam textural classes but with gravel content that exceeded 15 %. They were moderately well-drained and were not susceptible to flooding. Rainfall amount in the area exceeded 1500 mm/annum resulting in the low base saturation of less than 40 %. However, the soil reaction of IH1P2 exceeded 6.5 required for crop production in the tropics (Udo e*t al.*, 2009). IH1P1 and IH1P2 therefore qualified in the subclass IIsf. The use of cover- and green manure crops as well as animal manure and a recommended dose of mineral fertilizer may increase the saturation of exchangeable bases in the soil exchange complex. The use of such soil amendment/combination is most likely to remove soil fertility related limitation in the soils.

Soils of mapping unit IH2 were

characterized by sandy loam textural class with soil reaction within the range of 5.2 and 6.7 as well as low base saturation. Climate in terms of effective precipitation and temperature regime was optimum for crop production. However, the soils were limited by gravel content that exceeded 20 %, poor drainage and flooding condition. Moderate depth in IH2P2 (87 cm) may have further created a limitation for the soils. Consequently, water tolerant crops like paddy rice and sugar cane may not be limited by the high water table. Soils in IH2P1 and IH2P2 therefore met the requirements for classification into land capability subclasses IVwcf and IIIwsf, respectively. The soils were down-graded to classes IV and III mainly by wetness limitation, base saturation and gravel content that exceeded 15 % in the surface soils. Such soils with moderate limitations may reduce the choice of crops. According to Sys *et al.* (1991) the soils require moderate conservation practices as well as careful management. Such conservation practices include; slight drainage to improve air and water relations. The distribution of capability classes of mapping units IH1 and IH2 is shown in Fig. 4, and indicates that the class II soils occupied 252.4 ha (37.2 %), class III occupied 418.9 ha (61.7 %) and class IV soils occupied the least expanse with only 7.8 ha (1.1 %) out of a total of 679.1 ha.

b. Central Agricultural Zone

In the central agricultural zone, soils in mapping unit AI1 were deep (> 100 cm) with negligible content of gravels in surface soils and favourable wetness and climatic characteristics. AI1P1 found in AI1 mapping unit and AI1P2 in AI2 mapping unit were, however limited by their loamy sand textures and low base saturation, while slope was a limiting factor in AI1P1 just as soil pH (H_2O) was relatively high in AI1P2 with values within 6.1-7.7. Soil pH values above 6.5 may be regarded as high for most crops (Sys *et al.*, 1991). AI1P1 and AI1P2 met the requirements for placement into land capability subclass IIIesf and IIsf, respectively (Fig. 5). The class II soil (AI1P2) may require careful to very careful soil management strategies. AI1P1 (class III) may therefore require terracing and surface mulching. These procedures will reduce the speed of running water down the slope as well as build up soil organic matter content. It may also require the application of mineral fertilizers so as to boast the saturation of exchangeable bases in the soil exchange complex.

Soils in mapping unit AI2 were deep (> 100 cm) with gravel content less than 10 % as well as favourable wetness condition, climate, erosion and fertility characteristics except base saturation that had values less than 50 % especially in AI2P1. However, AI2P1 was limited by its loamy sand textural class, hence its qualification for placement into land capability subclass IIsf. AI2P1 (IIsf) will therefore require careful management *via* moderate conservation practices like crop rotations with concurrent application of animal manure for increased soil organic matter content. On the other hand, base saturation may be increased by the application of organic fertilizers and lime.

In mapping unit AI3, gravel was less than 10 % with favourable effective precipitation. The soils were limited by base saturation and wetness condition, while AI3P1 was in addition, limited by shallow depth, loamy sand textural class and soil reaction (5.2-5.3). According to the scale of Holland *et al.* (1989), the values of soil pH (H_2O) fall within the range of strongly acid reaction, and may bring about significant amount of exchangeable Al^{3+} on the soil exchange complex (Udo*et al.*, 2009). At such pH values, alumina is often soluble (Tan, 1998). AI3P1 and AI3P2 were therefore classified as class IVwscf and IIIwcf, respectively. AI3P1 (class IVwscf) closely suits the requirements of Sys *et al.* (1991) for class IV soils.

The soil will therefore require very careful management due mainly to its severe limitations of wetness, soil physical properties and base saturation. Special conservation procedures like drainage and flood protection are recommended. The use of soil organic amendments like animal manure as well as the careful use of lime will increase the base saturation per cent. On the other hand, AI3P2 (class IIIwcf) will require similar treatment however, the use of lime may not be necessary as soil pH was 5.7-7.5.

This range of values is within acceptable limits for arable soils in the tropics (Holland *et al.*, 1989). Adequate dosages of calcic and potash fertilizers can be used to step-up the base saturation of the soils. By this, the soils may be upgraded to class II.

The distribution of capability classes for soils in the central agricultural zone is shown in Fig. 5, and indicates that 137.2 ha (49.0 %) of the land qualified as class II, 98.7 ha (35.3 %) qualified as class III and only 44.0 ha (15.7 %) was classified as class IV land out of an overall hectarage of 279.79 ha. Classes II and III soils are suited for regular cultivation (Esu, 2010) and may require moderately intensive (class II) to intensive (class III) treatment to be safely cultivated. On the other hand, the class IV soils will be best suited for pasture. However, occasional protective cultivation to safeguard it against further deterioration is advocated.

c. Southern Agricultural Zone

In the soils of the southern agricultural zone, MF1 had favourable wetness conditions, soil reaction (5.4-6.6), as well as erosion and climatic properties(effective precipitation and temperature). Slope per cent was 4 % for soils in MF1 and so offered little or no limitation to agriculture; however, low base saturation was limiting as 12.7-48.8 % was obtained in MF1. Furthermore, loamy sand textural class and greater than 20 % gravels constituted the primary source of limitation for MF1P1. Sys *et al.* (1991) recommended <15 % of gravel per cent for arable lands (Classes I to IV). MF1P1, therefore, qualified as IIsf, while MF1P2 qualified as IIf in the land capability subclass (Fig. 6). Soils in mapping unit MF1 were good for farming and had very few limitations such as texture, gravels and base saturation. These limitations had down-graded the soils from class I to II. For safe cultivation, the soils need careful management or moderately intensive treatments such as cover cropping and fertilizer application to compensate crop output. The limitations are most likely to reduce the range of crops to be cultivated.

Soils in mapping unit MF2 were deep (> 100 cm) and optimal in terms of climate (precipitation and temperature) as well as slope and wetness condition but sub-optimal in its base saturation which constituted a basic soil fertility limitation. MF2P2 was, however, limited by loamy sand textural class and 15 % gravels, while MF2P1 was limited by low soil pH, which had values that ranged from 5.1 to 5.6. MF2P1 and MF2P2 were classified in the land capability subclass IIf and IIsf, respectively (Fig. 6).

The limitations which have reduced the capability of MF2 from class I to II were moderate, and the soil required moderate conservation practices with careful soil management procedures. Strip cropping, together with careful application of prescribed doses of mineral fertilizers and lime, will go a long way to address the limitations. This may raise the base saturation and pH to a more favourable level. The soils were suitable for regular cultivation of arable crops.

In mapping unit MF3, soil textural class (sandy loam to loamy sand), gravel percent (negligible in the surface soils), soil reaction (6.1-6.7), precipitation and slope per cent were optimal (Sys *et al.* 1991 and Esu, 2010), while base saturation values (12.1-49.4 %) were sub-optimal. Wetness condition as well as soil depth were however, the main limiting soil properties that qualified the soils for placement into land capability subclass IIIwsf. The limitations were severe and may reduce the choice of crops (Sys *et al.* 1991). Special conservation practices, as well as very careful management requirements, may increase the land use options. Properties such as frequent overflow accompanied by some crop damage, waterlogging, shallow depth and low fertility outlined by Sys *et al.* (1991) for class III soils fits the properties of MF3 most appropriately. Surface drainage will most likely improve air and water relations and increase the range of crops that can be cultivated.

The distribution of capability classes is shown in Fig. 6, indicating 1581.8 ha as class II, which represented 71.8 % of the entire area, while 619.85 ha (28.2 %) met the requirements of class III out of the entire area, which measured 2201.65 ha.

Summary and conclusion

Land capability classification of soils developed from various limestone formations indicate that the soils of IH1, AI2, AI1P2, MF1 and MF2 of all the limestone formations except AI1P1 were class II soils, and limited by gravels or soil texture (s) and/or base saturation; in combination or alone. On the other hand, soils in the IH2, AI3 and MF3 which were poorly drained were classified as class III or IV and variously limited by wetness, soil physical properties and fertility characteristics.

Land capability classes II, III and V were identified in the study areas. For the soils in northern agricultural zone, 37.2 % were class II soils, while 61.7 % were class III and only 1.1 % qualified as class IV. For soils in central agricultural zone, 49 % were class II soils, 35.3 % class III and 15.7 % were classified as class IV soils. In the soils of southern agricultural zone, 71.8 % of the soils qualified as class II, while 28.2 % qualified as class III soils.For a possible upgrade to class 1 soils particularly in areas with gravel content of less than 15 %, an intensive fertility evaluation study of the soils is recommended for a site specific nutrient recommendation for commonly grown crops.

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Table 1: Guide for Classifying Soils into Land Capability Classes

	Land capability class – Degree of limitations, restrictions or hazards							
Soil properties	I	II	III	IV	V	VI	VII	VIII
Physical soil conditions (s)								
**Soil depth (cm)	≥120	80-120	50-80	20-50	<20	-	-	-
Surface texture	Sl,fsl,vfsl,l, sil,scl,cl,sicl,(non arenic–ls,lfs, fs)	Ls,lfs,fs,sic,sc,c(<60%clay)muck,mucky peat	c (≥60% clay)	Cs	Same criteria as class I	As in class II	As in class III	Not class determining
Rock fragments (surface)	<15%	≥15-<35%	≥35-<60%	≥35-<60%	≥15%	Not class determining		
Wetness (w)								
**Drainage	Well or moderately well(5YR and redder)	Moderately well or somewhat poor(mottles between 80-100 cm)	Imperfectly drained(mottles between 40-80 cm)	Poorly drained (mottling between 0-40 cm)	Not class determining			
Flooding	None during growing season. Crop selection not restricted	Rare-Occassional. Slight crop damage. 0 to < 20% yield reduction or crop selection slightly affected	Occasional. Moderate crop damage. ≥20-<35% yield reduction or crop selection moderately affected	Frequent. Severe crop damage. ≥35-50% yield reduction or crop selection severely affected	Class I if overcome and protected from flooding	Class II and III if overcome	Class IV if overcome	Tidal flats
Fertility (f)								
Reaction (pH)	Favourable: easy to modify		Unfavourable: high lime or difficult to modify	Unfavourable: very difficult to modify	Not generally class – determining			Cat clays; unfavourable reaction; impractical to modify
***BS (%)	>80	60-80	40-60	20-40	<20	-	-	-
Climate								
Precipitation effectiveness (mm/annum)	≥1100	≥780-<1100	≥630-<780	≥480-<630	Not class determining	≥250-<480	<250	Not class determining
Cumulative days dry in moisture control section	<135 – Udic or UdicUstic	≥135-<180 – TypicUstic	≥180-<220 AridicUstic	≥180-<220 AridicUstic	Not class determining	≥220-<270 – UsticAridic	≥270 TypicAridic	≥270
Erosion (e)								
*slope(degrees)	0-<7	0-≤7	0-≤15	0-≤20	0-≤25	0-≤35	0->35	0->35
**Erosion	Low	Susceptible to erosion	Susceptible to erosion	Susceptible to erosion	-	Erosion	erosion	Erosion hazard

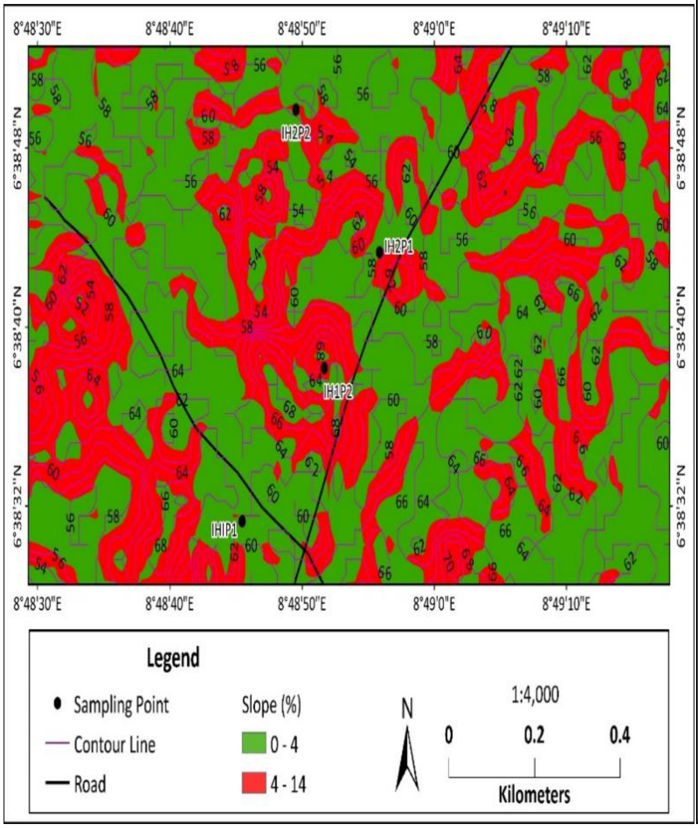
Foot note: Ls: loamy sand, lfs: loamy fine sand, fs: fine sand, Sic: silty clay, Sc: sandy clay, c: clay, Sl: sandy loam, fsl: fine sandy loam, vfsl: very fine sandy loam, l: loam, sil: silty loam, scl: sandy clay loam, cl: clay loam, sicl: silty clay loam

Source: Sinclair and Dobos (2006). *Lynch, 2009, **Sys *et al.*, 1991***Holland *et al.* (1989)

Table 2: Land characteristics at the study areas for classifying soils into USDA Land Capability Classes

Characteristics	IH1P1	IH1P2	IH2P1	IH2P2	AI1P1	AI1P2	AI2P1	AI2P2	AI3P1	AI3P2	MF1P1	MF1P2	MF2P1	MF2P2	MF3P1	MF3P2
Soil physical conditions. (s)																
Soil depth (cm)	195	150	145	87	200	180	120	132	80	124	121	153	161	200	48	49
Surf. Texture	SCL	SL	SL	SL	LS	LS	LS	SL	LS	SL	LS	SL	SL	LS	SL	SL
Gravels (%)	>30	>30	30	>20	0	0	<10	0	<10	0	>20	0	0	15	0	0
Wetness (w)																
Drainage	Mod.welldr	Mod.welldr	Poorly dr	V.poorly dr.	Well dr.	Mod.well .dr	Mod.well Dr	Well dr	Poorly dr	Poorly dr	Well dr	Well dr	Well dr	Well dr	v.poorly dr	v.poorlydr
Flooding	None	None	Rare-occasional	Frequent	None	None	None	None	occasional	occasional	None	None	none	none	Rare-occasional	Rare-occasional
Fertility (f)																
Reaction(pH)	5.5-6.7	6.4-7.3	5.8-6.7	5.2-6.1	5.3-7.2	6.1-7.7	6.3-6.4	5.7-6.7	5.2-5.3	5.7-7.5	5.6-6.6	5.4-5.8	5.1-5.6	5.3-6.4	6.5-6.7	6.1-6.3
BS %(AandB Horizon)	26.2	27.5	36.7	21.8	19.6	21.2	18.9	56.5	21.4	16.3	33.1	17.8	16.3	8.3	29.9	41.1
Climate (c)																
Eff.Ppt.	1983	1983	1983	1983	2258	2258	2258	2258	2258	2258	2894.1	2894.1	2894.1	2894.1	2894.1	2894.1
Days in MCS	Ustic, <135	Ustic, <135	Not class determining		Udic, <135	Udic, <135	Udic, <135	Udic, <135	Not class determining		Udic, <135	Udic, <135	Udic, <135	Udic, <135	Not class determining	
Erosion (e)																
Slope (%)	6.3	5	4	4	5.3	3.5	5.2	2.0	4.0	4.5	4	4	2.0	5.6	0.88	4
Erosion hazard	Slight sheet erosion	None	None	None	None	Slight sheet erosion	None	Slight sheet erosion	None	None	Slight sheet erosion	Slight sheet erosion	Slight sheet erosion	Slight sheet erosion	Slight sheet erosion	None

Foot note: MCS: moisture control section, SCL: sandy clay loam, SL: sandy loam, LS: loamy sand, dr.: drained, v: very, eff. Ppt.: effective precipitation



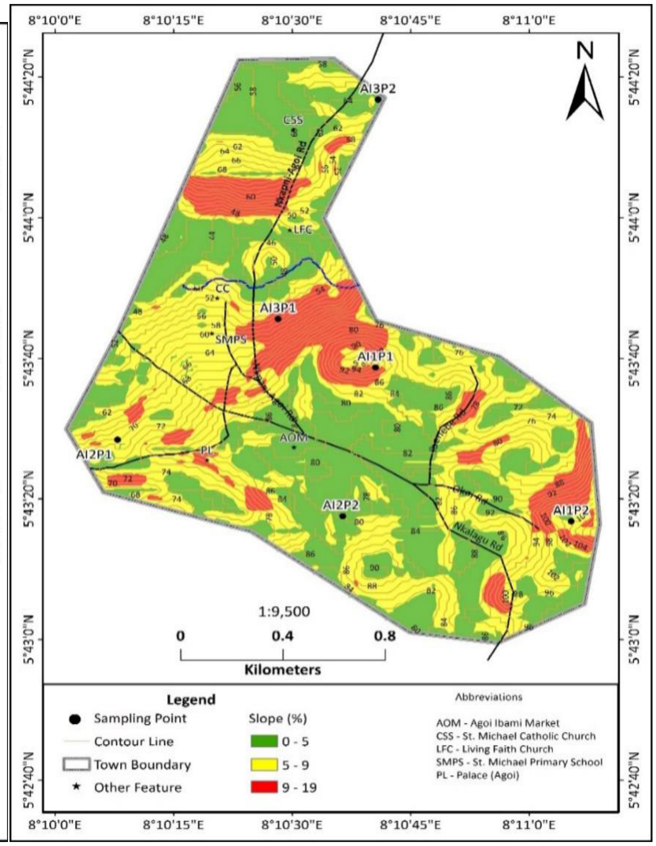


Fig. 1: Slope map of Ishibori, Northern agricultural zone   Fig. 2: Slope map of AgoiIbami, Central agricultural zone

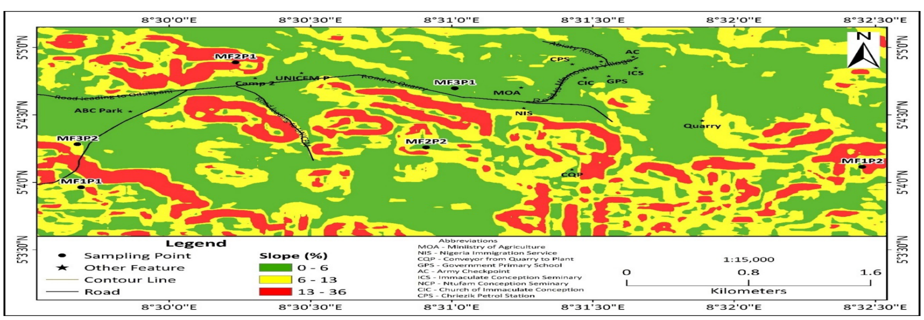


Fig. 3: Slope map of Mfamosing, Southern agricultural zone

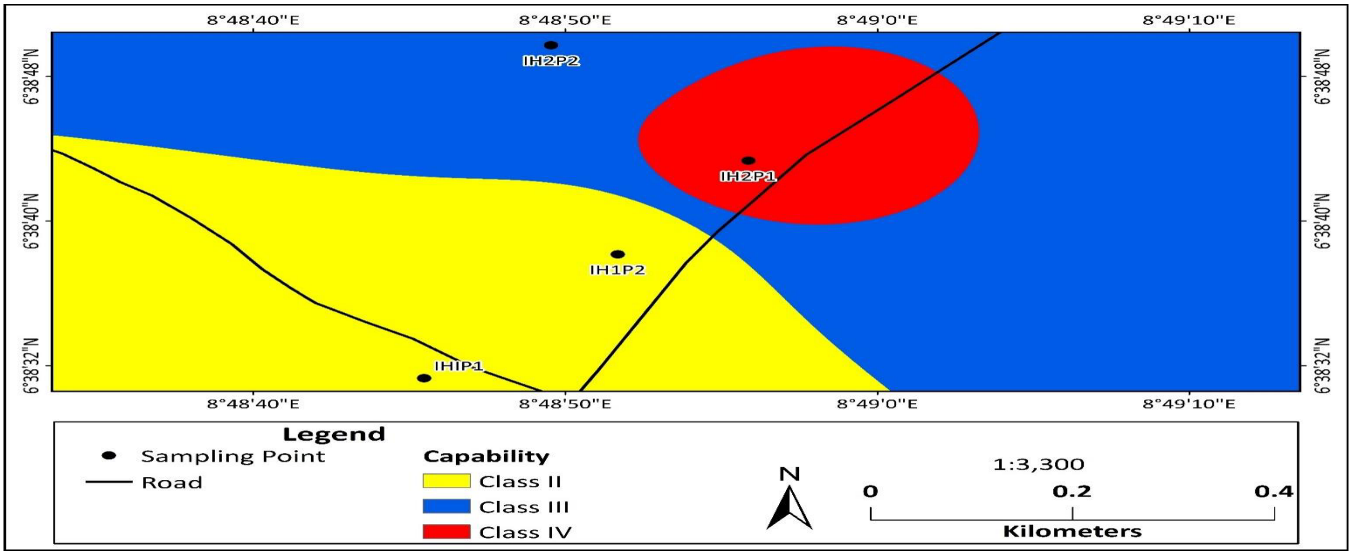


Fig. 4: Distribution of Land capability classes in the northern agricultural zone

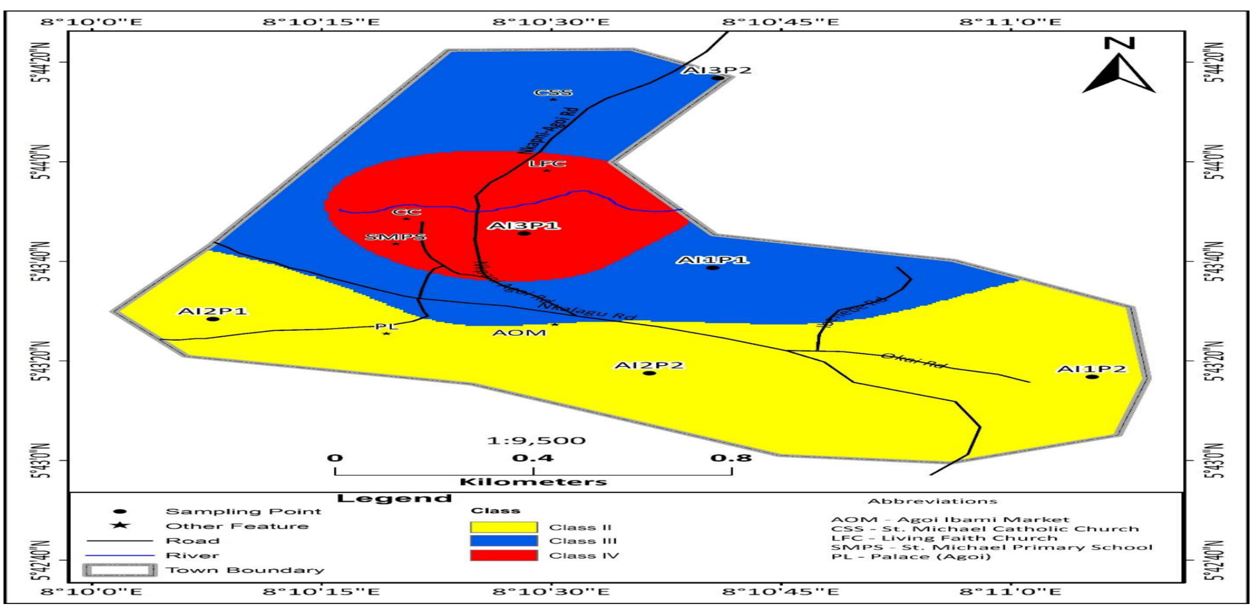


Fig. 5: Distribution of Land capability classes in the Central agricultural zone

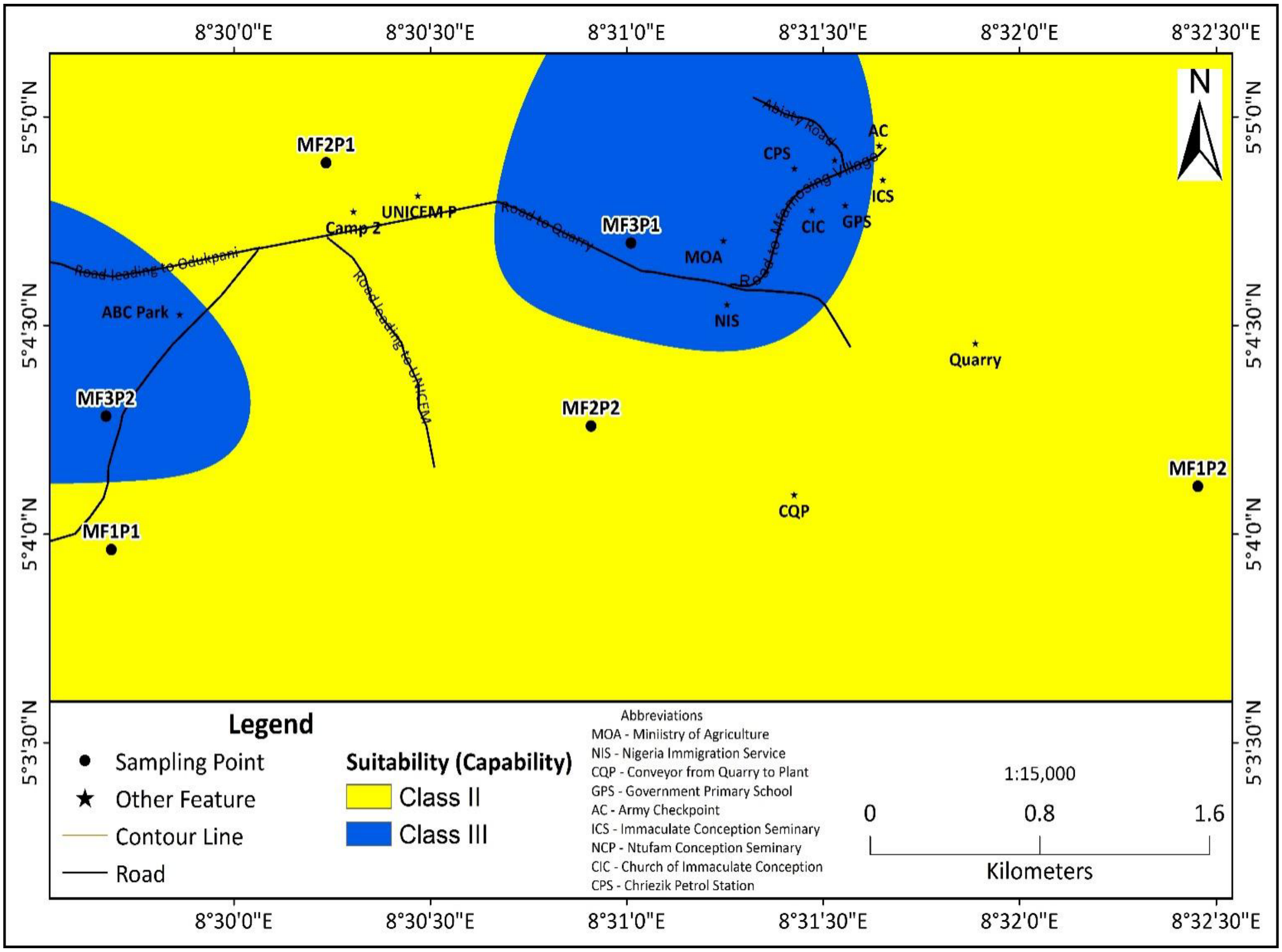


Fig. 6: Distribution of Land capability classes in the southern agricultural zone