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CHARACTERIZATION AND CLASSIFICATION OF SOILS ALONG THREE TOPOSEQUENCES IN NJIKOKA AREA, ANAMBRA STATE, NIGERIA

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ABSTRACT: *The study aimed to characterize and classify soils in the Njikoka Area of Anambra State, Nigeria. Three toposequences (TA, TB, and TC) from three different communities: Abagana, Nimo and Enugu-ukwu were selected and divided into upper (US), middle (MS), and lower (LS) slopes using a Digital Elevation Model (DEM). Nine pedons were described following FAO guidelines, and 64 samples were collected for analysis. The soils were well-drained, with predominant dark reddish brown and reddish brown horizons. Soil structure varied from weak fine granular to moderately medium angular and subangular blocky structures, while texture varied due to variations in sand, silt, and clay fractions. Soil acidity ranged from extremely acidic to slightly acidic. Organic matter, total nitrogen, available phosphorus, and exchangeable bases were generally low to very low. Potassium content ranged from very low to moderate, while exchangeable acidity, base saturation, and cation exchange capacity (CEC) varied from very low to high. The trend in chemical fertility was MS > US > LS for TA, US > MS > LS for TB, and LS > MS > US for TC soils. Based on the USDA soil classification, TA soils were identified as Typic Hapludults (US), Typic Kandiudults (MS), and Aquic Arenic Hapludults (LS). TB soils were classified as Grossarenic Kandiudualf (US) and Typic Kandiudults (MS and LS), while TC soils were categorized as Vertic Hapludults (US), Grossarenic Hapludults (MS), and Grossarenic Kandiudults (LS).*

KEYWORDS: Toposequence, Characterization, Classification, Topographic units, Njikoka.

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INTRODUCTION

One of the major limiting factors of agriculture in Nigeria is poor knowledge of soils. There is not enough information on soil phyco-chemical properties as well as the influence of landscape on those properties (Atofarati et al., 2012; Chukwu et al., 2013). It has been reported that variations in soil properties across a landscape under similar conditions of parent material, climate, organism and time has a direct relationship with topography (Chikere-Njoku, 2015). Topography/relief has been reported as one of the major factors that control soil profile development (Lawal et al., 2013). Topography through redistribution of matter and energy affects pedogenesis (Esu, 2010). Researchers have developed indices that show that topography has direct influence on runoff, drainage, soil temperature, soil erosion, soil depth (Mulugeta & Sheleme, 2010). Esu et al. (2008) reported that topography-based soil studies play a significant role in the process that dictates the distribution and use of soils on the landscape.

Characterizing soils on a landscape basis will help in assessing productive values of soils, developing strategies for its conservation and reducing uniform soil management which could result in uneven distribution of input in an agricultural field (Oku et al., 2010). Characterization of soils will also provide the basic knowledge which is required in precision agriculture (Fedaku et al., 2018). Soil characterization is a powerful tool in the provider's database for formulating land use models (Bassanta*et al*., 2013). On the other hand, classifying soils facilitates technology transfer among scientists, decision makers, planners, researchers, and agricultural extension advisors (Assen and Yilma, 2010). This also presents the basis for effective utilization and appropriate management practices in any particular soil units (Rabia *et al*., 2013). Thus, this study tends to characterize and classify soils along three toposequences in Njikoka Local Government Area, Anambra State, Nigeria.

MATERIALS AND METHOD

Description of the Study Area

Njikoka Local Government Area, Anambra State Nigeria lies within latitudes 6° 8' 0" N and 6° 14' 0" N and longitudes 6° 56' 0" E and 7° 2' 0" E (Figures 1-3). It encompasses several towns, including Enugu-Agidi, Abba, Nawfia, Abagana, Enugu-Ukwu, and Enugu-Agidi. Two climatic seasons characterize the study area. These seasons are rainy and dry seasons which span from March to October. Its peaks are always observed in July and September with a short break in either July ending or August known as August break. The dry season falls between November and February with harmattan occurring mostly between the months of December and January. The mean annual maximum rainfall is above 1450 mm concentrated mainly in eight months of the year. The study area is also characterized by an average temperature of 27 °C with daily minimum and maximum temperatures in ranges of 22 °C to 24 °C and 30 °C to 34 °C respectively, while the relative humidity ranges from 75 to 95% (Hydrometeorological Department, Awka, 2018). The native vegetation of the area was originally a rainforest characterized by very tall, big trees with thick undergrowth and numerous climbers (Ezeigwe, 2015). However, as a result of human interference, the vegetation now consists of admixture of bush regrowth, arable crop farms and tree crops. Agriculture, hunting and cottage industries are predominant means of livelihood in the area (Orji & Obasi, 2012). The major crops along the selected topic sequences include: cassava (*Manihot spp*); cocoyam (*Colocasia esculenta*);

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yam (*Discoreaspp*); maize (*Zea mays*), plantain (*Musa spp*.), oil palm (*Elaeisguinensis*) and mango (*Mangifera indica*). The soils of the area are developed on sandstone parent material (Ezeigwe, 2015).

Field Studies

Three typical toposequences A, B, and C were selected from three different communities: Abagana, Nimo and Enugu-ukwu respectively with the aid of the DEM map acquired at a spatial resolution of 30 meters using ASTER data (https://doi.org/10.5067/ASTER/AST_L1A.003) and processed using ArcGIS software 10.8 (Figure 4). The toposequences (A, B, and C) were selected at 500 M interval and divided into three distinct topographic units: upper, middle, and lower slopes. In each of these topographic units, a profile pit measuring 2 × 1.5 × 2 meters was dug and georeferenced using a Global Positioning System (GPS). In all, nine pedons were dug and described in situ following the procedures in the guidelines for soil profile description (Food and Agriculture Organization FAO, 2014) and horizon designations of the Soil Survey Staff (2014).

Soil samples were collected from each of the identified diagnostic horizons from the bottom upwards. The reason for sampling this way is to prevent contamination of soils. Undisturbed core soil samples were also collected from the genetic horizons which were used to analyze for some physical properties (bulk density, saturated hydraulic conductivity and pore size distribution). A total of 64 samples were collected from the nine pedons. The samples were packaged into well labeled polyethene bags for onward transportation to the soil science laboratory for physico-chemical characteristics.

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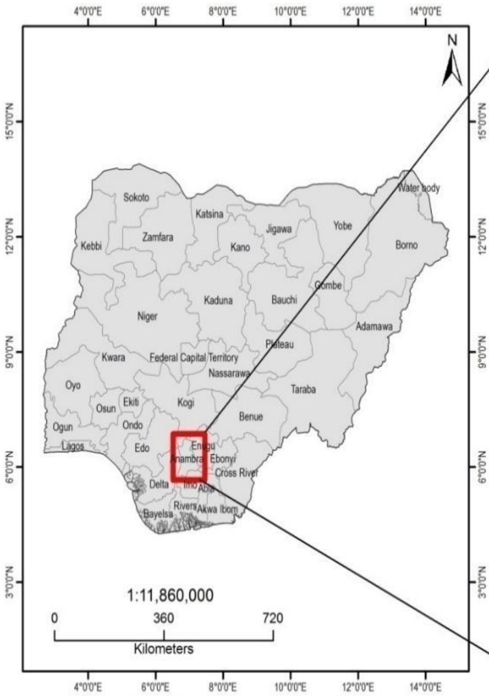

Fig 1: Map of Nigeria showing Anambra State

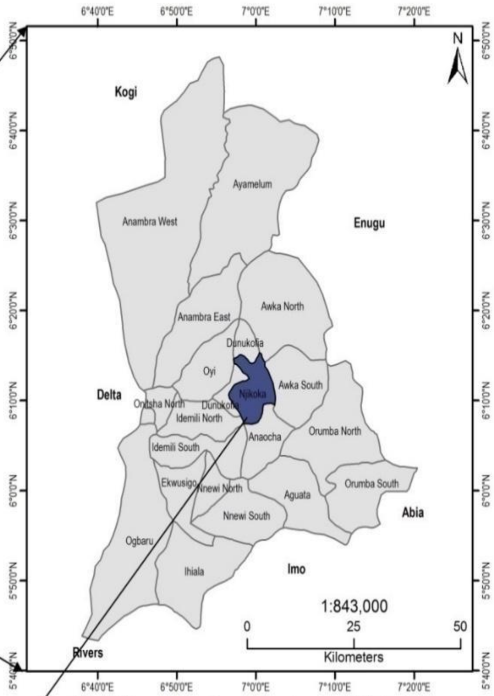

Fig 2: Map of Anambra State showing Njikoka LGA

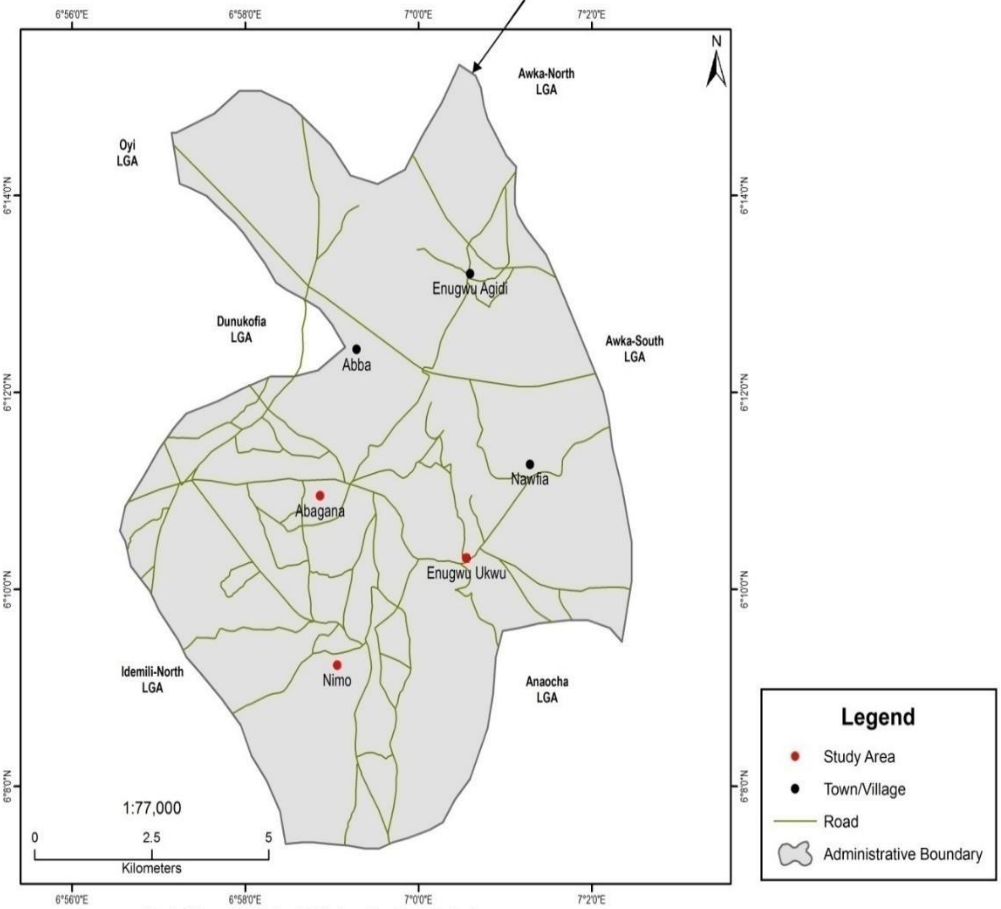

Fig 3: Map of Njikoka LGA showing the Study Area

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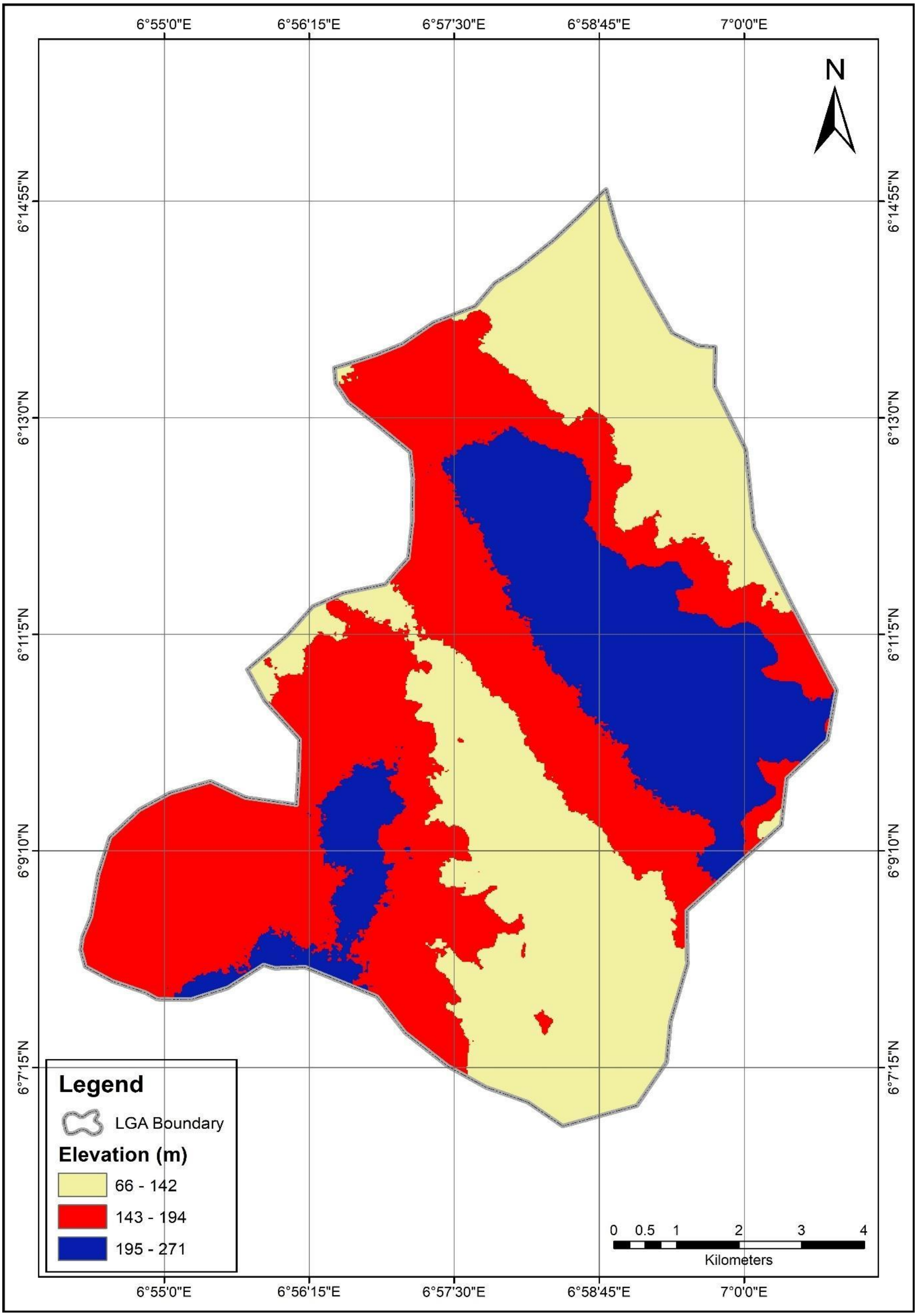

Fig 4: Topographic Map of Njikoka Local Government Area

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Soil Analyses

The soil samples were air dried, crushed and sieved using a 2 mm sieve size. Particle size distribution was determined by Bouycous hydrometer method using sodium hydroxide as a dispersant (Gee & Or, 2002). Silt clay ratio was obtained by dividing the value of silt with that of clay. Bulk density was determined using the core method after oven drying the soil samples to a constant weight at temperature 105 ^{o}C for 24 hours (Grossman & Reinsch, 2002). Saturated hydraulic conductivity was measured by the core method as described by Klute and Dirksen (1986). Pore size distribution was determined using water retention data as follows: macro pores as volume of water drained at 60 cm tension/volume of bulk soil; micro porosity as volume of water retained at 60 cm tension/volume of bulk soil; and total porosity from the sum of macroporosity and microporosity (Brady & Weil, 2002).

Soil pH was determined both in water and 0.1N potassium chloride solution at the soil/liquid ratio of 1:2.5 using Beckman Zeromatic pH meter (Van Reeuwijk, 1992). Organic carbon content was determined by the dichromate wet oxidation method (Jackson, 1973) and multiplied by 1.724 to obtain organic matter. Total nitrogen was determined by the Kjeldahl digestion, distillation and titration procedure as described by Bremner (1965). Available phosphorus was determined using the Bray II method as described by Olsen and Sommers (1982). Cation Exchange Capacity was determined using the ammonium acetate method (Chapman, 1965). Exchangeable bases ($Ca^{2+,}$ Mg^{2+}, Na^{+} and K^{+}) were extracted using 1N ammonium acetate; calcium and magnesium was determined by titration method (Chapman, 1965) while sodium and potassium was determine using flame photometer as described by Rhoades (1982). Exchangeable hydrogen and aluminum were determined by titrimetric method using potassium chloride extract (Mclean, 1965). Exchangeable Acidity was calculated by summing the values of exchangeable aluminum and hydrogen.Base Saturation was calculated as thus in equation (1):

$$\frac{TEB}{ECEC} \times \frac{100}{1} \tag{1}$$

where TEB = total exchangeable bases and ECEC = effective cation exchange capacity which was obtained by summation of total exchangeable bases and total exchangeable acidity.

Soil Classification

The pedons were classified using USDA Soil Taxonomy System (Soil Survey Staff, 2014) and correlated with FAO/UNESCO World Reference Base (WRB) (FAO, 2014).

Statistical Analysis

Descriptive statistics (mean, range and coefficient of variation) was used to assess the variability in soil physicochemical properties along the toposequences. Coefficients of variation (CV) were ranked according to Aweto (1980) as follows:< 20% (low variation), 20 - 50% (moderate variation), 50% and above (high variation).

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RESULTS AND DISCUSSION

Soil Morphological Properties

All the pedons were well drained and rated very deep as they have depths >150 cm (SSS, 1999). The depth of the 'Ap' horizons were thicker on the lower slope than other topo-positions due to the lateral movement of soil materials by erosion (Idoga and Azegaku, 2005). The 'Ap' horizons of all the profiles were dark reddish brown (10R 3/3) and reddish brown (10R 4/3) in color underlined by red (10R 4/6, 10R 4/8 and10R 5/6) and reddish brown colors (10R 4/3, 10R 4/4 and 10R 5/4) with the exceptions of the pedons on the upper and lower slopes of toposequence A (TA) and toposequence B (TB) which had reddish brown (10R 4/3, 10R 4/4 and 10R 5/4) and red (10R 4/6 and 10R 4/8) throughout the entire horizons respectively.

The reddish color of the matrix might be attributed to high iron content of the parent material and its oxidation state (Nsor, 2017). Mottles of bright yellowish brown (10YR 6/8 and 10YR 6/6) were observed in the 'BC' horizon of TA and 'Bt_1'horizon of toposequence C (TC) on the upper slope and 'B_2'horizon of TA on the middle slope. Whereas on the lower slope, mottles of yellowish brown (10R 5/6) and bright yellowish brown (10YR 6/6) were found in 'Bt' and 'C' horizons of TA respectively. This serves as an evidence of oxidation-reduction reactions caused by seasonal rise in the water table or water logging during some period of the year (Akamigbo*et al*., 2001; Brady & Weil, 2006).

The textural characteristics of the soils by feel varied between sand to very gravelly sandy clay loam in the upper and middle slopes, while the subsurface soils varied between loamy sand and sandy loam of the lower slope. Weathering intensity may be attributed to the reason for the textural variation. The structure of the soils varied from coarse single grained structure to moderately developed fine granular structure in the surface soils and moderately developed fine granular structures to moderately developed medium angular and subangular blocky structure in the subsoils. Researchers have opined that presence of higher organic matter and root population may be responsible for the granular structures that dominated the soils (Yitbarek et al., 2016; Kebede et al., 2017) while low organic matter, low root population and higher clay content accounted for the angular or sub-angular blocky structures (Fedaku et al., 2018). Soil consistency varied from loose to firm (moist) and non-sticky to sticky (wet) on the upper and lower slopes whereas on the middle slopes it was friable (moist) and non-sticky to slightly sticky (wet). Fedaku et al. (2018) attributed friable consistency in the surface horizons to the higher organic matter content while Abay et al. (2015) associated slightly sticky and sticky consistency in the sub horizons to higher clay contents.

The roots in the soils varied between very fine to coarse and few to very many in size and relative abundance respectively. There were also the presence of ants and pores in 'B_1' and 'B_2' horizons of TB on the lower and middle slopes respectively. The presence of the roots, ants and pores may be indications of a considerable amount of biological activities in the soils. Clay skins were seen in the 'Bt_2' and 'BC' horizons of TA and 'Bt' horizon of TC on the upper slope; 'Bt' horizons of TC on the middle slope and 'Bt_1' and 'C' horizons of TA on the lower slope. This is an indication that the pedological process of eluviation/illuviation might have taken place in the soils, hence the movement of clay down the profiles (Esu, 2010). The presence of cracks at Bt horizons of TC on the upper slope inferred that the soils have expanding clay minerals (Alhassan et al., 2012). Charcoals were found in 'B' horizons of TA and TC on the upper and lower slopes respectively while few pieces of pottery were found at

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the 'B1 Horizon of TB on the middle slope. The charcoal and pottery were archeological evidence of human settlement in the past (Esu, 2010). Stones and gravels were present in surface and subsurface soil layers of the profiles at TC, upper slope soil of TA and lower slope soil of TB though not significant enough to hinder agricultural production. Boulders were observed in the 'Bt_1'horizon of TA on the upper slope. The horizon boundary varied between clear smooth, clear wavy, abrupt wavy, abrupt smooth, gradual smooth, gradual wavy and diffuse smooth.

Table 1: Morphological Properties of Soils along Toposequence A

Depth (cm)	HD	Colors matix	mottles	T	Structure	Consistence moist	wet	Roots	Hb	Other features
Upper slope										
0-25	Ap	10R 4/3 (RB)	-	LS	f ma g	fr	ns	VM vf	cs	few stones
25-88	Bt_1	10R 4/4 (RB)	-	StSCL	vf ma g	fr	ns	F vf	gs	many stones, few boulders
88-140	Bt_2	10R 5/4 (RB)	-	SCL	mod m ab	fr	ss	-	cw	thin clay skin on the ped face
140-200	BC	10R 5/4 (RB)	F vfbYB (10YR 6/8)	VgSCL	mod m ab	fr	s	-	-	Moderately thick clay skins, very many gravel
Middle slope										
0-30	Ap	10R 4/3 (RB)	-	SL	f ma g	fr	ns	M vf; F f	cs	-
30-105	B_1	10R 4/6 (R)	-	SL	mod m sab	fr	ss	F vf	gs	very few charcoal
105-200	B_2	10R 4/6 (R)	VF vfByb (10YR 6/6)	SCL	mod m sab	fr	ss	-	-	very few charcoal
Lower slope										
0-14	Ap_1	10R 3/3 (DRB)	-	LS	f ma g	fr	ns	M vf; M f	cs	-
14-65	Ap_2	10R 4/3 (RB)	-	SL	mod m sab	fr	ns	VF C;VF m	gs	-

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65-115	Bt	10R 5/6 (R)	F vf Yb (10YR 5/8)	SL	mod m sab	fi	ss	-	aw	thin clay skins on the ped face
115-180	C	10R 5/4 (RB)	M vfByb (10YR 6/6)	SL	mod m sab	fi	s	-	-	Moderate thick clay skins on the ped face

HD: horizon designation; T: texture; Hb: horizon boundary; RB; reddish brown; R: red; DRB: dark reddish brown; bYB: bright yellowish brown; YB: yellowish brown; LS: loam sand; SCL: sandy clay loam; SL; Sandy loam; vg: very gravelly; st: stony f: fine; ma: massive, g: granular; vf: very fine; m: medium; mod: moderate, ab: angular blocky; sab: sub angular blocky; fr: friable; vfr: very friable; fi: firm; ns: not sticky; ss: slightly sticky; s: sticky; vs: very sticky; VM; very many; F: few; C: coarse; M: many; cs: clear smooth; gs: gradual smooth; gw: gradual wavy; aw: abrupt wavy; -: absent

Table 2: Morphological Properties of Soils along Toposequence B

Depth (cm)	HD	Colour	T	Structure	Consistency moist	wet	Roots	Hb	Other features
Upper slope									
0-30	Ap	10R 3/3 (DRB)	S	w sg g	l	ns	M vf	cs	-
30-116	B_1	10R 4/4 (RB)	SL	w m sab	vfr	ns	F vf	ds	-
116-200	B_2	10R 4/8 (R)	LS	w m sab	vfr	ss	-	-	-
Middle slope									
0-27	Ap	10R 4/3 (RB)	S	f ma g	vfr	ns	M vf; F f	cw	-
27-114	B_1	10R 4/6 (R)	SL	mod m sab	fr	ss	VF f	gs	Very few medium pores, very few pottery
114-200	B_2	10R 4/6 (R)	SL	w m sab	vfr	ns	-	-	-
Lower slope									
0-40	Ap	10R 4/6 (R)	SL	f ma g	fr	ss	M f	cs	-
40-125	B_1	10R 4/8 (R)	SL	mod m sab	fr	ss	F f	gs	very few gravel

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125-200	B_2	10R 4/8 (R)		SL	mod m sab	fr ss	-	-	very few gravel, many ants

HD: horizon designation; T: texture; Hb: horizon boundary; RB; reddish brown; R: red; DRB: dark reddish brown; LS: loam sand; S: sand; SL; Sandy loam; f: fine; ma: massive, g: granular; vf: very fine; m: medium; mod: moderate, ab: angular blocky; sab: sub angular blocky; fr: friable; vfr: very friable; fi: firm; ns: not sticky; ss: slightly sticky; s: sticky; p: perfect; F: few; ; M: many; cs: clear smooth; ds: diffuse smooth; cw: clear wavey; -: absent

Table 3: Morphological Properties of Soils along Toposequence C

Depth (cm)	HD	Colour matix	mottles	T	Structure	Consistence moist wet	Roots	Hb	Other features
Upper slope									
0-35	Ap	10R 3/3 (DRB)	-	Gls	f ma g	fr ns	M vf; F f	gw	many gravels; few stones
35-70	AB	10R 3/4 (DR)	-	VgLS	f ma g	l ns	-	cs	very many gravels
70-160	Bt_1	10R 4/4 (RB)	F m Byb (10YR 6/6)	SL	mod m ab	fr s	-	as	thin clay skin on the ped face, cracks
160-200	Bt_2	10R 4/6 (R)	-	SL	mod m ab	fi s	-	-	moderately thick clay skin, cracks
Middle slope									
0-36	Ap	10R 3/4 (VDRB)	-	LS	f ma g	vfr ns	M vf	cw	few stones
36-80	AB	10R 4/4 (RB)	-	LS	f m sab	fr ns	F vf	cs	very few stones
80-145	Bt_1	10R 4/6 (R)	-	SL	mod m ab	fr ss	-	as	thin clay skins on the ped face
145-200	Bt_2	10R 4/6 (R)	-	SL	w m ab	fr ss	-	-	moderately thick clay skins on the ped face
Lower slope									
0-14	Ap_1	10R 3/2 (DRB)	-	LS	vf ma g	vfr ns	M vf; F f	cs	very few stones

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14-65	Ap_2	10R 3/3 (DRB)	-	LS	mod m sab	fr	ns	VF m	gs	very few stones
65-115	B_1	10R 3/3 (DRB)	-	LS	mod m sab	fr	ss	-	as	very few charcoal
115-200	B_2	10R 4/3 (RB)	-	SL	mod m sab	fr	ss	-	-	very few charcoal

HD: horizon designation; T: texture; D: drainage; Hb: horizon boundary; RB; reddish brown; R: red; DRB: dark reddish brown; bYB: bright yellowish brown; LS: loam sand; g: gravelly; vg: very gravelly; f: fine; ma: massive, g: granular; vf: very fine; m: medium; mod: moderate, ab: angular blocky; sab: sub angular blocky; fr: friable; vfr: very friable; fi: firm; ns: not sticky; ss: slightly sticky; s: sticky; p: perfect; imp: imperfect; VM; very many; F: few; M: many; cs: clear smooth; gs: gradual smooth; gw: gradual wavy; aw: abrupt wavy; as: abrupt smooth; -: absent

Soil Physical Properties

Generally, the trend in particle size distribution is sand >clay >silt. The dominance of sand fraction in profiles may be attributed to high content of quartz mineral in the parent material (Lawal et al., 2013; Osujieke et al., 2016) while the least values of silt fraction was linked to high weathering intensity (Akamigbo, 1984). The sand fraction varied from 687 to 862 g kg^{-1} with CV of 8% at TA; 742 to 903 g kg^{-1} with CV of 8% at TB and 762 to 862 g kg^{-1} with CV of 5% at TC. The silt fraction varied from 33 to 73 g kg^{-1} with CV of 25%; 33 to 53 g kg^{-1} with CV of 19% and 33 to 73 g kg^{-1} with CV of 36% for TA, TB and TC soils respectively. The trend in silt was upper slope >middle slope >lower slope for TA; middle slope >upper slope = lower slope for TB; and upper slope >middle slope = lower slope for TC. This contradicts the findings of Noma et al. (2011) and Musa and Gisilanbe (2017) who found highest silt values on the lower slope owing to its enrichment supply by erosion or runoff. The clay fraction varied from 105 to 265 g kg^{-1} with CV of 28 % at TA; 65 to 205 g kg^{-1} with CV of 43% at TB and 84.80 to 205 g kg^{-1} with CV of 31% at TC. Clay fraction decreased down the slopes of TA and TC due to clay accumulation from the selective dissolution of more soluble minerals in the upper slopes (Buol et al., 2003). The increase in clay fraction down the slope of TB was linked to its selective removal, transportation and deposition by the lateral moving water (Obalum et al., 2011).

The texture of the soils varied from loamy sand to sandy clay loam at TA, sand to loamy sand at TB and sandy loam to loamy sand at TC. This variation within the profiles and along the slopes might be attributed to the selective removal of soil particles from one horizon/location to another by agents of soil erosion and variations in weathering intensity. The silt clay ratio (SCR) ranged from 0.15 to 0.50 with CV of 41% at TA, 0.16 to 0.51 with CV of 47% at TB and 0.16 to 0.86 with CV of 57% at TC. The SCRs of the soils were ≥0.15 and <1.00 depicting young parent materials and ferralitization process respectively. Van Wanbeka(1962) reported that old parent materials usually have a SCR below 0.15 while above 0.15 are indicative of young parent materials. Ashaye (1969) affirmed that SCR of <1 is an indication that the soils had undergone ferralitic pedogenesis. The trend in SCR was lower slope >upper slope >middle slope for TA; upper slope >middle slope >lower slope for TB and upper slope > middle slope = lower slope for TC suggesting that the soils on the middle slope of TA; lower slope of TB; and middle and lower slopes of TC were more developed than those on the other topographic units.

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The values of bulk density varied from 1.20 to 1.72 g cm^{-3} with CV of 9% at TA, 1.62 to 1.82 g cm^{-3} with CV of 5% at TB and 1.43 to 1.82 g cm^{-3} with CV of 8% at TC. Hydraulic conductivity ranged from 0.27 to 36.67 cm hr^{-1} with CV of 85% at TC, 11.27 to 69.72 cm hr^{-1} with CV of 63% at TB and 1.27 to 29.98 cm hr^{-1} with CV of 72% at TC. The wide variation in Ksat might be due to variation in particle size distribution and moisture contents (Shelton, 2003; Obalum et al., 2011). The lower slopes of TA and TC had the highest mean values when compared with other topographic units due to higher total porosity (Ofori et al., 2013). At TB, the upper slope soil had the highest mean value which was attributed to its higher moisture content relative to other topographic units (Antiono et al., 2001; Bagaireaello & Lovino, 2003).

The macro, micro and total porosity of soils at TA varied from 5.12 to 7.50%, 29.29 to 52.92% and 34.25 to 60.42% respectively. At TB, macro, micro and total porosity varied from 5.13 to 5.70%, 34.29 to 39.08% and 39.68 to 44.46% respectively. The soils of TC had their macro, micro and total porosity in the range of 5.01 to 7.70%; 30.42 to 41.02% and 35.43 to 46.86% respectively. Generally, the values of the macroporosity were low when compared with that of the microporosity due to compaction resulting from tillage operations (Tekwa et al., 2008; Salem et al., 2017).

Table 4: Physical Properties of Soils along Toposequence A

Depth (cm)	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	TC	SCR	Bd (g cm^{-3})	Ksat (cm hr^{-1})	Map (%)	Mip (%)	Tp (%)
Upper slope										
0-25	862	33	105	SL	0.31	1.63	14.95	5.77	33.22	38.99
25-88	702	53	245	SCL	0.22	1.65	12.06	5.38	32.75	38.13
88-140	687	48	265	SCL	0.18	1.70	1.80	5.16	29.26	34.42
140-200	687	48	265	SCL	0.18	1.74	3.74	5.12	29.13	34.25
Mean	735	45	220	SCL	0.22	1.68	8.14	5.36	31.09	36.45
Middle slope										
0-30	782	53	165	SL	0.32	1.68	5.91	5.64	31.75	37.39
30-105	762	33	205	SL	0.16	1.68	3.07	5.59	30.91	36.50
105-200	724	33	225	SCL	0.15	1.72	1.21	5.75	30.26	36.01
Mean	756	39	198	SL	0.21	1.69	3.40	5.66	30.97	36.63
Lower slope										
0-14	862	33	105	LS	0.50	1.20	36.67	7.50	52.92	60.42
14-65	782	33	185	SL	0.39	1.57	28.17	6.82	34.76	41.58
65-115	762	33	205	SL	0.26	1.57	11.29	5.60	33.88	39.48
115-180	722	53	225	SCL	0.23	1.69	0.27	5.82	32.27	38.09
Mean	781	36	180	SL	0.35	1.51	19.10	6.44	38.46	44.89
CV (%)	**8**	**25**	**28**		**41**	**9**	**85**	**12**	**20**	**18**

TC: textural class; SL: sandy loam; LS: loam sand; SCL: sandy clay loam; SCR: silt clay ratio; Bd: bulk density; Ksat: saturated hydraulic conductivity; Map: macroporosity; Mip: microporosity; Tp: total porosity; CV: coefficient of variation

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Table 5: Physical Properties of Soils along Toposequence B

Depth (cm)	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	TC	SCR	Bd (g cm^{-3})	Ksat (cm hr^{-1})	Map (%)	Mip (%)	Tp (%)
Upper slope										
0-30	902	33	65	S	0.51	1.61	68.01	5.62	38.74	44.36
30-116	882	33	85	LS	0.39	1.65	69.72	5.58	36.40	41.98
116-200	862	33	105	LS	0.31	1.74	65.45	5.39	34.29	39.68
Mean	882	33	85	S	0.40	1.67	67.73	5.52	36.48	42.01
Middle slope										
0-27	903	33	65	S	0.51	1.63	33.43	5.70	38.14	43.84
27-114	742	53	205	SL	0.29	1.68	11.80	5.58	37.09	42.67
114-200	762	33	205	SL	0.16	1.74	17.33	5.49	34.26	39.75
Mean	803	39	158	SL	0.32	1.68	20.85	5.59	36.50	42.09
Lower slope										
0-40	802	33	165	SL	0.20	1.65	23.61	5.38	39.08	44.46
40-125	782	33	185	SL	0.18	1.82	31.59	5.23	37.06	42.29
125-200	762	33	205	SL	0.16	1.82	17.02	5.13	34.62	39.75
Mean	782	33	185	SL	0.18	1.76	24.07	5.25	36.92	42.17
CV (%)	**8**	**19**	**43**		**47**	**5**	**63**	**3**	**5**	**5**

TC: textural class; S: sand; SL: sandy loam; LS: loam sand; SCR: silt clay ratio; Bd: bulk density; Ksat: saturated hydraulic conductivity; Map: macroporosity; Mip: microporosity; Tp: total porosity; CV: coefficient of variation

Table 6: Physical Properties of Soils along Toposequence C

Depth (cm)	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	TC	SCR	Bd (g cm^{-3})	Ksat (cm hr^{-1})	Map (%)	Mip (%)	Tp (%)
Upper slope										
0-35	842	73	85	LS	0.86	1.58	7.33	7.70	39.16	46.86
35-70	782	73	145	LS	0.50	1.74	1.33	5.76	37.08	45.67
70-160	782	53	165	SL	0.26	1.79	1.27	5.85	37.91	43.76
160-200	762	33	205	SL	0.16	1.80	1.57	5.63	35.16	42.84
Mean	792	58	150	LS	0.45	1.73	2.88	6.24	37.33	44.78
Middle slope										
0-36	862	53	85	LS	0.62	1.38	18.21	5.74	41.02	46.76
36-80	862	33	105	LS	0.31	1.61	12.67	5.51	35.05	40.56
80-145	822	33	145	LS	0.27	1.65	11.26	5.13	31.32	36.45

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145-200	762	53	205	SL	0.25	1.73	12.88	5.01	30.42	35.43
Mean	827	43	135	LS	0.36	1.59	6.26	5.35	34.45	39.80
Lower slope										
0-18	822	73	105	LS	0.69	1.43	29.98	6.10	39.92	46.02
18-60	842	33	125	LS	0.26	1.65	25.90	5.56	38.92	44.48
60-135	822	33	145	LS	0.26	1.67	24.14	5.33	38.46	43.79
135-200	762	33	205	SL	0.23	1.82	24.58	5.30	37.66	36.54
Mean	827	43	135	LS	0.36	1.64	26.15	5.35	34.45	39.80
CV (%)	**5**	**36**	**31**		**57**	**8**	**72**	**12**	**9**	**10**

TC: textural class; LS: loam sand; SCR: silt clay ratio; Bd: bulk density; Ksat: saturated hydraulic conductivity; Map: macroporosity; Mip: microporosity; Tp: total porosity; CV: coefficient of variation

Soil Chemical Properties

At TA, pH in H_2O and KCl ranged from 4.80 to 6.00 with CV of 7% and 4.30 to 5.50 with CV of 8% respectively. At TB, pH in H_2O and KCl ranged from 4.80 to 5.60 with CV of 5% and 4.40 to 5.00 with CV of 4% respectively. At TC, pH in H2O and KCl ranged from 4.80 to 6.20 with CV of 6% and 4.40 to 4.70 with CV of 2% respectively. The pH values both in H_2O and KCl were extremely acidic to slightly acidic according to the ratings of Enwezor et al. (1989). This might be attributed to the movement of exchangeable bases to the valley bottom.

The values of organic matter ranged from 2.24 g kg^{-1} to 10.68 g kg^{-1} with CV of 54% for soils of TA, 2.76 g kg^{-1} to 8.96 g kg^{-1} with CV of 43% for soils of TB and 1.72 g kg^{-1} to 12.76 g kg^{-1} with CV of 65% for soils of TC. The low values of OM could be attributed to the effect of high temperature and relative humidity which favor rapid mineralization of organic materials (Fasina et al., 2005). The upper slope of TA had the highest OM and this might be attributed to its flatness which offered some natural protection from erosion and hence, OM accumulation (Ezeaku & Iwuanyawu, 2013). The higher mean value of OM on the lower slope of TC when compared with the other topographic units might be linked to the fact that it receives considerable quantities of organic material from the adjacent slope positions (Amuyuo & Kontigo, 2015).

Total nitrogen (TN) at TA, TB and TC varied from 0.06 to 1.80 g kg^{-1} with CV of 37%, 0.20 to 1.13 g kg^{-1} with CV of 60% and 0.30 to 1.10 g kg^{-1} with CV of 60% respectively. Njoku (2012) and Uzoho et al. (2014) linked low TN to losses through runoff, low organic matter, high N mineralization and crop removal. The increase in TN down the slopes of TA and TC might be attributed to slope factors involved in transportation and redeposition of organic and inorganic materials down the slopes (Esu et al., 2008; Udoh et al., 2011). The lower TN observed at the lower slope of TB when compared with the other topographic units might be linked to the higher water-table which contributes immensely to leaching of N especially the nitrate form (Adegbite et al., 2019).

Available phosphorus ranged from 1.87 to 9.33 mg kg^{-1} with CV of 36%, 1.47 to 11.90 mg kg^{-1} with CV of 72% and 1.87 to 5.60 mg kg^{-1} with CV of 29% at TA, TB and TC respectively. The

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values of available P were rated low as they were below or slightly above the 10 mg kg^{-1} critical limit recommended for most commonly cultivated crops (Obigbesan, 2009). The low values of available P might be partly due the nature of the parent material and partly to the fixation of phosphorus by iron and aluminum oxides under well drained acidic conditions (Nuga et al., 2006). Amhakhian and Osemuota (2012) opined that tropical soils are generally low in available P due to low apatite content of the soil forming materials. Available P exhibited an increasing trend down the slopes of TA and TC and a decreasing trend at TB.

Exchangeable hydrogen ranged between 0.20 cmol kg^{-1} and 2.80 cmol kg^{-1} with CV of 92%; exchangeable aluminum varied from 0.00 to 8.80 cmol kg^{-1} with CV of 84% and exchangeable acidity varied from 1.00 to 11.60 cmol kg^{-1} with CV of 77% for soils of TA. TB soils had their exchangeable hydrogen, aluminum and acidity in the range of 0.20 to 2.80 cmol kg^{-1} with CV of 86 %, 0.20 to 2.00 cmol kg^{-1} with CV of 54% and 1.00 to 2.80 $cmolkg^{-1}$ with CV of 36% respectively. At TC, exchangeable hydrogen, aluminum and acidity ranged from 0.20 to 6.60 $cmolkg^{-1}$ with CV of 60%, 4.40 to 8.20 cmol kg^{-1} with CV of 29% and 5.20 to 14.80 cmol kg^{-1} with CV of 47% respectively. EA was found to be higher on the upper slope of TC and lower slope of TA and TB when compared with other topographic units. Mustapha et al. (2003) and Fasina et al. (2005) attributed higher value of EA on the lower slope to the solubility and movement of exchangeable acidity down the slope.

The trend in dominance of the exchangeable bases at the colloid is Ca^{2+} >Mg^{2+} >K^{+} >Na^{+}. Exchangeable calcium (0.20 to 2.00 cmol kg^{-1}), magnesium (0.20 to 0.60 cmol kg^{-1}), sodium (0.05 to 0.10 cmol kg^{-1}) and potassium (0.08 to 0.92 cmol kg^{-1}) were all rated low with the exception K^{+} which was considered low to high based on the scale by Shehu et al. (2015). Total exchangeable bases ranged from 0.54 to 1.99 cmol kg^{-1} with CV of 36% at TA, 0.53 to 2.04 cmol kg^{-1} with CV of 50% at TB and 1.18 to 2.51 cmol kg^{-1} with CV of 28% at TC. The low values of the exchangeable bases and TEB might probably be as a result of leaching that the soils had undergone and the nature of the parent material. Ritter (2006) noted that soils developed over sandstone have coarse texture which facilitates leaching. The higher TEB on the lower slope of TC relative to other topographic units might be attributed to the transportation and deposition of exchangeable bases on the lower slope (Tsui et al., 2004). TEB was observed to be higher on the upper slopes of TA and TB when compared with middle and lower slopes due to lower rate of OM mineralization.

The CEC values varied between 5.20 cmol kg^{-1} and 32.40 cmol kg^{-1} with CV of 58% at TA; between 4.00 cmol kg^{-1} and 8.80 cmol kg^{-1} with CV of 32% at TB, and between 8.40 cmol kg^{-1} and 33.20 cmol kg^{-1} with CV of 36% at TC. The CEC toed a similar trend with the clay content suggesting that clay is the major contributor to CEC in the study area. The trend in CEC was lower slope >upper slope >middle slope at TA; middle slope >lower slope >upper slope at TB and upper slope >middle slope >lower slope at TC. The higher clay contents of these topographic units accounted for the higher CEC when compared with the others.

The values of base saturation varied from 15.63 to 59.18% with CV of 59%, 29.41 to 62.62% with CV of 35% and 7.81 to 20.49% with CV of 30% for soils of TA, TB and TC respectively. The wide variation in BS at TA and TB indicated the degree of leaching of the exchangeable bases (Meena et al., 2014). The highest mean values of BS were found on the upper, middle and lower slopes of TB, TA and TC respectively. This might be attributed to lower rate of leaching of basic cations at these topographic units relative to the others.

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Soil Classification

The classification of soils along the toposequences is presented on Table 13. On the upper slopes, the soils of TA and TC possessed argillic horizons and base saturation of <35% throughout the entire horizons, thus classified as order Ultisols. An udic moisture regime was inferred for the soils as they are not dry in any part for more than 90 consecutives days in a normal year and this placed them at sub order Udults. The soils were classified as great group Hapludults due to presence of argillic horizons (Soil Survey Staff, 2014). At the sub group level, TA soil was classified as Typic Hapludults and TC soil was classified as Vertic Hapludults owing to the presence of cracks within the 125 cm of the mineral soil surface (Soil Survey Staff, 2014). TB soil met the characteristics of order Alfisols as it had kandic horizon and base saturation of >35% in all the horizons and suborder Udalfs. The presence of kandic horizon with no densic, lithic, paralitic or petrolithic contacts within 150 cm of mineral soils and a clay increase of 3% or more in the fine-earth fractions qualified the soil as great group Kandiudalfs (Soil Survey Staff, 2014). It had sandy skeletal particle-size classes throughout the layers extending from the mineral soil surface to the top of the kandic horizon at the depth of 100 cm and more, thus classified as GrossarenicKandiudalfsat the sub group level (Soil Survey Staff, 2014). According to FAO's World Resource Base (WRB), all the soils were correlated with Acrisols as they had agric horizons, CEC values of <24 and exchangeable bases of <50% within the upper 100 cm depth (FAO, 2014). TA soil had texture of sandy loam in a layer ≥30 cm thick within a 100 cm depth and thus, correlated as LoamicAcrisols while TB and TC soils correlated as Arenic Acrisols owing to the presence of sandy and loamy sand textures respectively in a layer ≥30 cm thick within <100 cm (FAO, 2014).

The soils on the middle slopes were classified as order Ultisols and sub order Udults (Soil Survey Staff, 2014). The soils of TA and TB were further classified as great group Kandiudults as they possessed kandic horizons with no densic, lithic, paralitic or petrolithic contacts within 150 cm of mineral soils and a clay increase of 3% or more in the fine-earth fractions (Soil Survey Staff, 2014). At the sub group level, they were classified as Typic Kandiudults (Soil Survey Staff, 2014). TC soil had argillic horizon and sandy skeletal particle-size classes throughout the layers extending from the mineral soil surface to the top of the argillic horizon at the depth of 100 cm and more, thus qualified as great group Hapludults and sub group Grossarenic Hapludults respectively (Soil Survey Staff, 2014). Based on the FAO/UNESCO WRB, the soils were correlated as Acrisols (FAO, 2014). The soils were further correlated as Arenic Acrisols for TB and TC andLoamicAcrisols for TC (FAO, 2014). On the lower slopes, the soils of TB and TC were classified as Ultisols at the order level, Udultsat sub order level and Kandiudults at great group level (Soil Survey Staff, 2014). At the sub group level, TB and TC soils were classified as Typic Kandiudults and GrossarenicKandiudults, respectively (Soil Survey Staff, 2014). TA soil was classified as order Utisols and sub order Udults and great groupHapludults. The sandy skeletal texture throughout a layer extending from the mineral soil surface to the top of an argillic horizon at a depth of 50 to 100 cm; and the presence of redox depletions with a color value, moist, of 4 or more in one or more subhorizons within the upper 60 cm of the argillic horizon accompanied by both redox concentrations and aquic conditions for some time in normal years (or artificial drainage) qualified the soil as Aquic Arenic Hapludults (Soil Survey Staff, 2014). The soils correlated as Acrisols at FAO WRB for soils (FAO, 2014). TA and TB soils were further correlated as Loamy Acrisols and TC soil was correlated as Arsenic Acrisols (FAO, 2014).

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CONCLUSION

The soils of all the topographic units had low fertility levels exhibited by low pH, OM, TN, available P and exchangeable bases. Most of the soil properties were influenced by topography, however, the trend in fertility was middle slope >upper slope >lower slope for TA; upper slope >middle slope >lower slope for TB and lower slope >middle slope >upper slope for TC. The soils were classified as Typic Hapludults, GrossarenicKandiudults and Vertic Hapludults on the upper slopes; Typic Kandiudults and Grossarenic Hapludults on the middle slopes and; Aquic Arenic Hapludults, Typic Kandiudults and GrossarenicKandiudults on the lower slopes. The soils were correlated as LoamicAcrisols and Arenic Acrisols. The study showed that soil properties and types varied remarkably across the toposequences; and this is very vital towards sustainable use and management of the soils.

Table 7: Chemical Properties of Soils along Toposequence A

Depth (cm)	pH (H_2O)	pH (KCl)	OM (g kg^{-1})	TN	Av. P (mg kg^{-1})	H^+ CEC (cmol kg^{-1})	Al^{3+}	EA		Ca^{2+}	Mg^{2+}	Na^+	K^+	TEB	BS (%)
Upper slope															
0-25	5.40	4.70	10.68	1.30	9.33	0.80	1.60	2.40	0.80	0.20	0.09	0.09	1.18	7.60	32.96
25-88	5.30	4.60	7.41	0.80	1.87	0.20	3.80	4.00	1.40	0.40	0.10	0.09	1.99	10.08	33.22
88-140	5.40	4.60	3.45	0.70	2.80	2.40	3.80	6.20	0.80	0.40	0.07	0.08	1.35	14.80	17.88
140-200	5.20	4.50	3.24	0.70	1.87	1.80	3.00	4.80	1.00	0.20	0.07	0.31	1.58	17.20	27.88
Mean	5.33	4.60	6.20	0.88	3.97	1.30	3.05	4.35	1.00	0.30	0.08	0.14	1.53	12.42	27.89
Middle slope															
0-30	5.80	5.40	9.82	1.80	6.53	1.00	0.00	1.00	0.60	0.60	0.09	0.16	1.45	5.20	59.18
30-105	4.90	4.50	3.62	1.00	2.80	0.80	1.40	2.20	0.20	0.20	0.07	0.09	0.56	9.20	20.29
105-200	5.60	4.70	3.45	0.60	2.80	0.40	1.80	2.20	1.00	0.20	0.05	0.09	0.54	10.80	19.71
Mean	5.43	4.87	5.63	1.13	4.04	0.73	1.07	1.80	0.60	0.03	0.07	0.11	0.85	8.40	33.06
Lower slope															
0-14	6.00	5.50	9.83	1.70	6.53	2.00	0.00	2.00	0.80	0.60	0.08	0.11	1.79	10.00	47.23
14-65	4.90	4.50	6.79	1.40	3.73	2.80	4.00	6.80	0.80	0.20	0.05	0.12	1.26	11.60	15.63
65-115	4.80	4.30	3.45	1.30	9.33	2.80	8.80	11.60	0.60	0.40	0.05	0.21	1.46	24.40	11.18
115-180	5.10	4.40	2.24	1.30	2.80	6.60	6.00	12.60	0.60	0.20	0.06	0.19	1.05	32.40	7.69
Mean	5.20	4.68	4.79	1.43	5.60	3.55	4.70	8.25	0.70	0.35	0.06	0.16	1.39	19.60	20.43
CV (%)	**7**	**8**	**54**	**37**	**62**	**92**	**84**	**77**	**39**	**49**	**25**	**51**	**36**	**58**	**59**

OM: organic matter; TN: total nitrogen; Av. P available phosphorus; H^+: exchangeable hydrogen; Al^{3+}: exchangeable aluminum; Ca^{2+}: exchangeable calcium; Mg^{2+}: exchangeable magnesium; Na^+: exchangeable sodium; K^+: exchangeable potassium; EA: exchangeable

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acidity; TEB: total exchangeable bases; CEC: cation exchange capacity; BS: base saturation; CV: coefficient of variation

Table 8: Chemical Properties of Soils along Toposequence B

Depth (cm)	pH (H_2O)	pH (KCl)	OM (g kg^{-1})	TN	Av. P (mg kg^{-1})	H^+ CEC (cmol kg^{-1})	Al^{3+}	EA	Ca^{2+}	Mg^{2+}	Na^+	K^+	TEB		BS (%)
Upper slope															
0-30	5.30	4.90	8.96	0.80	11.90	0.40	0.80	1.20	0.60	0.40	0.09	0.92	2.01	4.00	62.62
30-116	5.00	4.60	4.14	0.40	5.60	0.40	1.20	1.60	0.80	0.20	0.07	0.43	1.30	4.00	44.83
116-200	4.90	4.70	3.45	0.30	1.87	0.80	1.60	2.40	1.00	0.40	0.07	0.55	1.41	4.80	39.83
Mean	5.07	4.73	5.52	0.50	6.46	0.53	1.20	1.73	0.80	0.33	0.08	0.63	1.57	4.20	49.40
Middle slope															
0-27	5.30	5.00	6.72	0.70	5.60	0.80	0.20	1.00	0.20	0.20	0.08	0.13	0.61	4.80	37.89
27-114	4.80	4.40	6.55	0.40	1.87	2.80	0.40	3.20	0.40	0.40	0.09	0.55	2.04	6.40	38.93
114-200	5.10	4.60	3.62	0.20	4.66	1.00	0.80	1.80	1.00	0.40	0.09	0.09	0.78	8.80	30.23
Mean	5.07	4.67	5.63	0.43	4.04	1.53	0.47	2.00	0.53	0.33	0.09	0.27	1.14	6.67	35.68
Lower slope															
0-40	5.00	4.60	8.89	0.40	0.93	0.80	1.20	2.00	0.40	0.40	0.04	0.09	0.93	3.20	31.74
40-125	5.60	4.70	4.48	0.20	4.66	0.20	1.60	1.80	0.40	0.20	0.06	0.09	0.75	5.60	29.41
125-200	4.90	4.70	2.76	0.10	3.73	0.80	2.00	2.80	0.20	0.20	0.05	0.08	0.53	6.00	15.94
Mean	5.17	4.67	5.37	0.23	3.11	0.60	1.60	2.20	0.33	0.27	0.05	0.09	0.74	4.93	25.69
CV (%)	**5**	**4**	**43**	**60**	**72**	**86**	**54**	**36**	**56**	**34**	**26**	**93**	**50**	**32**	**35**

OM: organic matter; TN: total nitrogen; Av. P available phosphorus; H^+: exchangeable hydrogen; Al^{3+}: exchangeable aluminum; Ca^{2+}: exchangeable calcium; Mg^{2+}: exchangeable magnesium; Na^+: exchangeable sodium; K^+: exchangeable potassium; EA: exchangeable acidity; TEB: total exchangeable bases; CEC: cation exchange capacity; BS: base saturation; CV: coefficient of variation

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Table 9: Chemical Properties of Soils along Toposequence C

Depth (cm)	pH (H_2O)	PH (KCl)	OM (g kg^{-1})	TN	Av. P (mg kg^{-1})	H^+ CEC (cmol kg^{-1})	Al^{3+}	EA	Ca^{2+}		Mg^{2+}	Na^+	K^+	TEB	BS (%)
Upper slope															
0-35	5.50	4.70	10.17	0.70	4.66	4.60	6.40	10.00	0.60	0.40	0.09	0.27	1.36	18.40	10.19
35-70	5.50	4.40	9.82	0.30	4.66	5.60	4.40	10.60	1.00	0.60	0.05	0.14	1.79	23.60	14.48
70-160	5.70	4.50	2.45	0.30	2.80	6.60	8.20	14.80	1.00	0.60	0.07	0.25	1.92	27.20	11.48
160-200	5.70	4.50	1.72	0.30	4.66	5.60	5.60	11.20	0.80	0.60	0.04	0.16	1.60	33.20	7.81
Mean	5.60	4.53	6.04	0.40	0.55	5.60	5.70	11.65	0.85	0.55	0.06	0.19	1.64	23.10	10.99
Middle slope															
0-36	5.30	4.50	7.41	0.70	4.66	4.00	5.60	9.60	0.20	0.60	0.10	0.28	1.18	14.00	10.95
36-80	4.80	4.60	3.97	0.30	3.73	6.40	6.80	13.20	1.80	0.40	0.08	0.23	2.51	17.60	15.98
80-145	6.20	4.50	3.62	0.30	1.87	4.00	4.60	8.60	0.60	0.40	0.07	0.12	1.19	20.80	12.16
145-200	5.30	4.40	3.45	0.30	2.80	0.20	8.00	8.20	0.80	0.40	0.09	0.18	1.47	24.80	15.20
Mean	4.50	4.45	4.61	0.68	3.27	2.56	6.25	9.90	0.85	0.45	0.09	0.09	1.59	19.30	13.57
Lower slope															
0-18	5.40	4.50	12.76	1.10	3.73	4.00	4.60	8.60	0.60	0.20	0.06	0.39	1.25	11.60	12.69
18-60	5.40	4.40	8.96	1.00	4.66	0.60	4.60	5.20	0.60	0.40	0.08	0.26	1.34	15.60	20.49
60-135	5.10	4.40	2.76	0.40	2.80	5.40	4.00	9.40	1.20	0.60	0.06	0.14	2.00	16.00	12.16
135-200	5.50	4.40	2.76	0.30	5.60	4.60	6.00	10.60	2.00	0.20	0.07	0.21	2.48	18.40	17.54
Mean	5.35	4.43	6.81	0.70	4.20	2.11	4.80	8.45	1.10	0.35	0.07	0.20	1.77	15.40	18.96
CV (%)	**6**	**2**	**65**	**60**	**29**	**47**	**24**	**25**	**56**	**34**	**24**	**35**	**28**	**36**	**26**

Upper slope; Middle slope; Lower slope; OM: organic matter; TN: total nitrogen; Av. P available phosphorus; H^+: exchangeable hydrogen; Al^{3+}: exchangeable aluminum; Ca^{2+}: exchangeable calcium; Mg^{2+}: exchangeable magnesium; Na^+: exchangeable sodium; K^+: exchangeable potassium; EA: exchangeable acidity; TEB: total exchangeable bases; CEC: cation exchange capacity; BS: base saturation, CV: coefficient of variation

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