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GENESIS AND CLASSIFICATION OF SOILS ALONG A TOPOSEQUENCE IN THE TEACHING AND RESEARCH FARM OF TARABA STATE UNIVERSITY, JALINGO, NIGERIA

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ABSTRACT

Investigations were made to reflect the genesis and classification of soils along a toposequence in the Teaching and Research farm of Taraba State University. The topographic map of the farm was developed in the ArcGIS 10.8 environment and a profile graph plotted out. One profile pit was sunk in each elevation range to represent soils in the summit, shoulder, back slope, foot slope and toe slope positions using the free survey approach. The soils were deep, well drained and generally described as A, B, C soils with extensive B horizons that showed clear illuviation of clay and sesquioxides. The soils were brown (7.5YR 3/4), dark brown (10YR 3/3) and dark yellowish brown (10YR 4/6) in the surface and dominated by sand with bulk density values that exceeded 1.5 Mg/m^3. Soil pH values were moderately acid to neutral while organic C and exchangeable bases were low in all but foot slope position where high values of organic carbon were obtained in the surface soils. The content of dithionite and oxalate Fe and Al, and their derivatives indicate intense weathering condition of the soils as well as their combined movement with clay to endopedons. However, moderately high CEC and the likely presence of montmorillonite (*via* CECE/clay) are indications that the soils had good potentials for agriculture. Among the soil forming processes in the area were mineralization, eluviation-illuviation as well as ferritization. The soils were classified as Typic Rhodustults (Pretic Acrisols), Arenic Haplustults (Chromic Acrisols) and Paleustults (Haplic Acrisols).

KEYWORDS: pedogenesis, sesquioxides, classification, Basement Complex

INTRODUCTION

Soil is one of earth's life-sustaining components; it serves as a physical support for crops and buildings and as a source of water and nutrients for crops as well as a medium in which organic materials are recycled for future generations. Soil is a multilayer porous medium either formed in place by the weathering of underlying rock or deposited by agents of transportation such as water, wind and ice (Esu, 2010). In whatever way in which soils are formed, the factors of soil formation interact, often in a complex manner to form soil. There is however no clear cut process between the weathering rock and soil development or between the processes of soil formation, such that these could be contiguous, hence the concept of point zero of soil formation. Our ideas about soil genesis as revealed by profile criteria are inferential, and account for the great diversity of opinion regarding the degree of maturity of specific soils, such as chernozems (Jenny, 1994). Hence, the upsurge of controversies regarding soil types and development. Soil formation is dynamic and develops where there is a dynamic interaction between air, water, parent materials and organisms (Tuncay *et al*., 2019). Interactions of this kind over time are responsible for soil heterogeneity.

Several indicators have been identified and used in evaluating the genesis of soils. For instance, Oliveira Girao *et al*. (2014) and Vanden Bygaart and Protz (1994) used soil depth while Osedeke *et al*. (2005), Kurihara *et al*. (2002), Igwe, (2001) and Durn *et al*. (2001) considered oxides of iron and aluminum, and their ratios as indices of evaluating soil genesis. Furthermore, Duzgoren-Ayen *et al*. (2002), and Price and Velbel (2003) used changes in major and trace metal concentrations as well as ratios of mobile to immobile elements in soil as means of estimating the intensity of chemical weathering.

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Topography has been identified as a factor that influences successive variation in soil properties from summit to valley bottom (Jenny, 1994, Forth, 1978). The gradient of a landscape results not only in variation in soil morphological, physical and chemical properties but also delays or hastensclimatic elements and biotic activities in soil formation. Topography has been identified as a variable that brings about differences in soils (Birkland, 1999; Esu, 2010; Fawole *et al*. 2016; Dengiz & Usul, 2018). In harmony with state factor equation, a different soil type is often identified for each degree of slope; thus, along a variable slope, an entire sequence of soil types is often encountered, each having different profile features (Jenny, 1994). Topography indirectly affects the rate of soil genesis and its distribution (Pregitzer *et al*., 2000; Wang *et al*., 2001). Soils vary vertically and laterally bringing about systematic changes (Wilding and Dress, 1983) in soil properties, for instance, Miller *et al*. (1998) identified organic matter content as an important soil property that varies down slope; consequently, Graham *et al.* (1990) noted that genesis and distribution of soils can best be understood in landscape context rather than at the level of individual pedons, hence the concept of a toposequence in the present study. In this vain, Nye (1966), Smyth and Montgomery (1962), Murdoch and Ojo-Atere (1976), and Ojanuga (1979) had earlier noted the study of soils along slope as the corner stone of most soil classifications in the Basement Complex area of Nigeria.

Agriculture constitutes the most dominant occupation of the people of Taraba State. Over 75% of its populace is directly or indirectly involved in one form of agricultural activity or the other ranging from rain fed to irrigated agriculture, livestock rearing to tree crop plantation. In an attempt to make ends meet, the farmers indirectly exhaust the soil of its nutrients through continuous cultivation. Persistent practice of continuous cultivation without appropriate management measures leaves the soils vulnerable to losses through leaching and erosion; the result is low returns that can hardly sustain the ever-increasing population. More so, land use allocations are not dependent on the outcome of scientific research as the farmers tie such practice to tradition. This study was therefore designed to characterize and infer on the genesis of the soils as conditioned by the landscape positions. The soils will also be classified according to the requirements of the United States Department of Agriculture Soil Taxonomy and correlated with the World Reference Base for Soil Resources Systems.

MATERIALS AND METHODS

Location, geology and climate of the study area

The study was located in the Teaching and Research farm of Taraba State University. Taraba State is located at the north eastern part of Nigeria and characterized by the northern guinea savannah, and lies between latitude 6°30′ and 9°30′ N of the equator and between longitude 9°00′ and 12°00′ E of the Greenwich Meridian. Bauchi and Gombe states are located in its northern axis while Adamawa is in the east; on the south is Cameroun, and on the west are Benue, Nassarawa, and Plateau states. The soils in the study area are underlain by Basement Complex rocks and dominated by Precambrian granitic and migmatite gneisses with outcrops of the rocks occurring at intervals (Bawden, 1972).The area is tropical with distinct wet and dry seasons. The wet season lasts for 7 months while the dry season lasts for 5 months with a mean annual rainfall which ranges from 800 mm in the northern part of the state to over 2000 mm in the southern part (Adebayo, 2012). Precipitation is lowest in January with an average of 0 mm while in August, the most precipitation falls with an average of 217 mm. Mean annual temperature is 34^{o}C and varies in mean monthly values between 28.4^{o}C in the coolest month of December and 37^{o}C in the hottest month of March (NIMET, 2009).

Field studies

The topographic map of the study area was developed in the ArcGIS 10.8 environment and a profile graph plotted out. One profile pit was sunk in each elevation range to represent the summit, shoulder, back slope and toe slope positions using the free soil survey technique. The soil profiles were delineated and soil samples collected from pedogenic horizons, beginning with the base horizonsupwards. The soils were described based on the criteria of the Soil Survey Manual (Soil survey Staff, 2002) and core samples vertically collected for bulk density determination. Soil samples meant for laboratory analyses were stored in polythene bags, labeled, transported, air dried under laboratory conditions and ground using porcelain mortar and pestle. The ground soil samples were sieved through 2mm sieve and the fine earth fractions preserved for laboratory analyses.

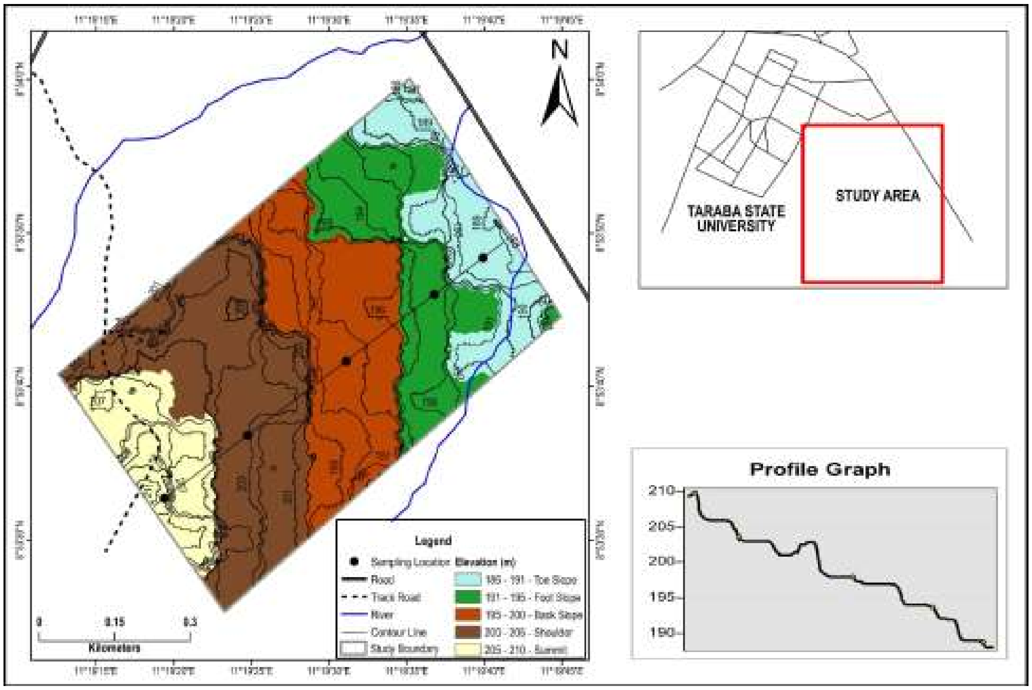

Fig. 1: Topographic map of the study area indicating elevation ranges and profile graph

Laboratory Analysis

Particle size distribution was determined by the Bouyoucos hydrometer method with sodium hexametaphosphate acting as dispersing agent (Soil Survey Staff, 2014). Soil pH was determined in 1:1 soil to water and 1:2 soil to1 *N*$CaCl_2$ ratio using a coromel glass electrode pH meter while electrical conductivity was determined by using electrical conductivity meter in 1:5 soil to water ratio (Udo *et al*., 2009). Organic carbon was determined by the Walkley and Black wet oxidation method and total N by macro Kjeldahl digestion method as modified by Udo *et al*. (2009).Bray 1 method was used to determine available phosphorus while exchangeable bases of Ca, Mg, K, and Na were determined by neutral NH_4OAc displacement method and read through by atomic absorption spectrophotometer as described by Udo *et al*. (2009). Cation exchange capacity was determined by 1 *N*NH_4OAc at pH 7 while base saturation was obtained by expressing the sum of exchangeable bases as a percentage of the CEC at pH 7. Dithionite and oxalate forms of iron and aluminum oxides were determined by the method of Mehra and Jackson (1960) as modified by Udo *et al*. (2009).

RESULTS AND DISCUSSION

Morphological soil properties

Morphological properties of the soils are presented in Table 1. The soils were dominated by A (plough layers), B (argillic horizons) and C (weathered rock layers) horizons; except in the back slope and foot slope positions where only A and B horizons were identified.

The B horizons were quite extensive and developed with the illuviation of clay and subsequent occurrence of clay skins as well as sesquans, an indication that lessivation had occurred in the company of oxides of Fe and Al. This soil forming process was facilitated by the presence of vertical cracks, especially in the summit and foot slope areas. Findings by Ofem *et al*. (2015) highlighted the movement of clay and iron compounds in suspension and subsequent deposition in the illuvial horizons as Bt and partly Crt horizons. The soils were also very deep; with soil depth exceeding 150 cm in all the landscape positions; a further indication that the soils were either quite developed or the rate of soil removal *via* erosion was less than that of soil formation. However, the foot slope soil was impeded by duripan at 163 cm depth. Soil colour varied between dark brown in the summit and back slope to brown in the foot slope and dark yellowish brown in the shoulder and toe slope positions with dominant hue of 3 and 4 in the surface soils while the subsurface soils varied between reddish and brownish yellow to strong brown and yellowish brown with dominant hue of 5 and 6. Similarity, dark, brown and dark yellowish brown surface soil colour indicates either uniformity in organic matter distribution or mineralization occurred at the same rate while dominant reddish and yellowish subsurface colours indicate the presence of hematite and goethite as forms of Fe oxides, hence ferrugination.

Soil textural class ranged between loamy sand in the shoulder and sandy loam in other landscape positions for surface soils while sandy loam and sandy clay loam textures dominated the subsurface soils with textural class trend that shows an increase in finer classes in the B horizons. The surface and subsurface soils were therefore moderately coarse and moderately fine textured, respectively (Soil Science Division Staff, 2017). Soil structures ranged between weak fine and moderate granular structures in the surface soils while moderate and strong, medium and coarse, angular and subangular blocky structures were obtained in the subsurface soils. Non sticky and slightly sticky (wet) soil consistencies were obtained in the surface soils while sticky (wet) as well as firm (moist) consistencies were mainly obtained in the subsurface soils. Increasing clay amount with depth may have been responsible for the moderate and strong, coarse, subangular and angular blocky structures as well as the firmness that increased with soil depth.

Table 1: Summary of the morphological features of the soil profiles

Horizon	Depth (cm)	Munsell colour (moist)	Texture	Structure	Consistency	Boundary	Root	Pores	Miscellaneous Observations
Summit:8°53'32.86"N; 11°19'09.38"E; 210.8 m									
Ap	0-28	10YR 3/3 (Dark brown)	Sandyloam	1fgr	Ns,mfr	CS	vfv	mf	Ants seen
Bt	28-61	7.5YR 5/8 (Strong brown)	Sandyloam	2mabk	Ss,mfi	GS	mv	mc	Vertical cracks/clay wash
BA	61-151	5YR 6/8 (Reddish yellow)	Sandyloam	2msbk	St,mfi	GS*	cv	mf	Silica/clay accumulation
Crt	151-205	7.5YR 7/8 (Reddish yellow)	Sandyclay loam	3csbk	St,mfi		-	mf	Silica/clay illuviation
Shoulder: 8°53'36.95"N; 11°19'69.64"E; 203.0 m									
Ap	0-24	10YR 4/6 (Dark yellowish brown)	Loamysand	1fgr	Ns,mfr	GS	Fv	fc	Ants seen
Bt1	24-58	5YR 5/6 (Yellowish red)	Sandy loam	3mabk	Ss,mfi	GW	vfv	ff	Clay skin on ped surface
Bt2	58-133	5YR 6/8 (Reddish yellow)	Sandyclayloam	2mabk	Ss,mfi	CS	-	cc	Ant cast
Crt	133-205	7.5YR 6/8 (Reddish yellow)	Sandyclay loam	3msbk	St,mfi		-	mv	Mn nodules seen
Backslope: 8°53'41.76"N; 11°19'08.36"E; 198.0 m									
Ap	0-16	7.5YR 3/4 (Dark brown)	Sandy loam	1fgr	Ss,mfr	CS	Mv	fv	Charcoal materials seen
BA	16-35	10YR 4/6 (Dark yellowish brown)	Sandy loam	2msbk	S,mfi	CI	-	cf	
Bt1	35-78	7.5YR 5/8 (Strong brown)	Sandyclayloam	2csbk	S,mfi	DW	-	mc	Gravelly material seen
Bt2	78-102	7.5YR 5/8 (Strong brown)	Sandyclayloam	2csbk	Ss,mfr	GW	-	mf	Gravel material/iron nod.
Bt3	102-190	7.5YR 5/8 (Strong brown)	Sandyclay	3csbk	S,mfi			mc	Sesquioxides material
Foot slope: 8°53'41.76"N; 11°19'36.75"E; 193.98 m									
Ap	0-16	7.5YR 3/4 (Brown)	Sandy loam	1mgr	Ns,mfr	CS	Fv	Fv	Ants
Bt1	16-66	5YR 5/4 (Reddish brown)	Sandy clay loam	2msbk	Ss,mfi	CS	vf	mv	
BC	66-163	10YR 5/8 (Yellowish brown)	Sandy clay loam	3msbk	Ss,mfi		-	mc	Vertical cracks, duripan
Toe slope: 8°53'48.58"N; 11°19'39.98"E; 189.0 m									
Ap	0-19	10YR 3/4 (Dark yellowish brown)	Sandyloam	1fgr	Ns,mfr	AW	Vff	Mc	
Bt	19-47	10YR 3/4 (Dark yellowish brown)	Sandy loam	2fabk	Ss,,mfr	GS	fv	mc	C=Clay skin in pockets
Bt2	47-102	10YR 5/8 (Yellowish brown)	Sandyclay loam	2mabk	Ss,mfi	CS	fv	mc	CS=Clay sesquioxide
CB	102-180	10YR 6/6 (Brownish yellow)	Sandy loam	2msbk	S,mfi	CS*	-	cc	CS=Clay sesquioxide
Cr	180-200	10YR 6/6 (Brownish yellow)	Sandy loam	2msbk	S,mfi		-	mc	Clay accumulation

3msbk= strong medium subagular blocky, 2msbk= moderate medium subangular blockey, 1fgr = weak fine granular, 1fpr = weak fine prismatic, 1= weak, 2= moderate, 3= strong, Ss= slightly sticky, S= Sticky, Fr= friable, Fi= firmSC= Smooth clear, SG= smooth gradual, WG= wavy gradual, WA= wavy abrupt, WC= wavy clear, IC= irregular clear, WD= wavy diffuse, mf= medium few, mc= medium common, fc= fine common, ff= fine few, cc= coarse common, mv= medium very few, fv= fine very few, cf= coarse few, mv= medium very few, fv= fine very few, vff= very fine very few, cv= coarse very few.

According to Idoga (1985), subsoil clay is the most active aggregate forming colloid. Fine and medium roots were found dominating the surface soils irrespective of landscape positions; however, plant roots were either absent or very few in the C and Bt2 horizons, especially in the back slope position. This is traced to the relatively high bulk density which may have restricted root growth. The presence of ants in the surface soils was an indication of faunal pedoturbation while vertical cracks as observed in the subsurface soils of the summit and foot slope was an indication of the presence of expanding clay minerals. Particles of charcoal, especially in the back slope is historical and indicates anthropogenic activities in the area.

Physical properties

The physical properties of the soils are presented in Table 2. Particle size distribution of the entire soils was dominated by sand, followed by silt and then clay. Sand content in the surface soils ranged between 712 in the toe slope and 804 g/kg in the shoulder with mean of 752 g/kg. In the subsurface soils, sand content varied between 482 in the back slope and 722 g/kg in the summit and shoulder with mean of 641 g/kg. High sand content in the soils was in agreement with studies on similar soils in different parts of Nigeria (Malgwi *et al.*, 2000; Lawal *et al* 2014; Maniyunda *et al.,* 2015) as well as in the Basement complex soils of Biase in Cross River State (Ofem & Esu, 2015). Means of 119 and 136 g/kgwere obtained for silt in the surface and subsurface soils, respectively while clay content ranged between 105 and 385 g/kg with a mean of 200.5 g/kgin the entire soils and values that increased regularly with soil depth, giving rise to clay bulge in the toe slope. Increasing value of clay with a corresponding decrease in sand content as soil depth increases is occasioned by eluviation-illuviation, an indication of greater intensity of weathering; this process characterizes most soils in northern Nigeria (Esu, 1982). High clay content is likely to increase the soil's capacity to adsorb cations. A similar result was obtained by Maniyunda and Gwari (2014) in the northern guinea savannah of Nigeria. Coefficient of variation of 35, 19 and 12 % were obtained for clay, silt and sand; an indication that the finer fractions of clay and silt were more easily eroded down slope than sand, hence the higher CV. This finding is in agreement with those of Malgwi and Abu (2011) in a similar environment, who observed that clay and silt were easily eroded, resulting in higher sand content. However, sand correlated negatively with CEC, perhaps due to its small surface area and low capacity to hold nutrients, clay however correlated positively with CEC.

Silt – clay ratio ranged between 0.35 and 1.46 in the entire soils with values that decreased irregularly with soil depth in the summit and toe slope and regularly in the shoulder, back slope and foot slope positions. The entire soils had values of silt/clay ratio greater than the separating limit of 0.15, a further

Table 2: Physical properties of the soils

Horizon	Depth	Bulk Density	Particle Size Distribution			silt/clay
			Sand	Silt	Clay	
	cm	Mgm^{-3}	←	g/kg	→	
Summit						
Ap	0-28	1.85	762	113	125	0.9
Bt	28-61	1.67	722	113	165	0.68
BA	61-151	1.63	642	173	185	0.94
Crt	151-205	1.76	642	133	225	0.59
Shoulder						
Ap	0-24	1.68	802	73	125	0.58
Bt1	24-58	1.85	722	93	185	0.5
Bt2	58-133	1.7	682	93	225	0.41
Crt	133-205	1.93	622	133	245	0.54
Back slope						
Ap	0-16	1.63	742	153	105	1.46
BA	16-35	1.54	702	133	165	0.81
Bt1	35-78	1.47	562	153	285	0.54
Bt2	78-102	1.88	502	153	345	0.44
Bt3	102-190	1.89	482	133	385	0.35
Foot slope						
Ap	0-16	1.59	742	113	145	0.78
Bt1	16-66	1.84	662	133	205	0.65
BC	66-163	1.75	642	133	225	0.59
Toe slope						
Ap	0-19	1.8	712	143	145	0.99
Bt	19-47	1.83	672	153	175	0.87
Bt2	47-102	1.58	652	143	205	0.7
CB	102-180	1.53	652	163	185	0.88
Cr	180-200	1.56	682	153	165	0.93

indication that the soils were not highly weathered. Sharu *et al*. (2013) reported similar results for some soils in the northern guinea savanna. Bulk density values ranged between 1.59 in the foot slope and 1.85 Mg/m^3 in the summit with a mean of 1.71 Mg/m^3 in the surface soils while values in the subsurface soils had a range of 1.47-1.93Mg/m^3. The relatively high values were traced to traction by mechanical equipment and grazing animals; these activities may have been evenly carried out in the area as bulk density seemed to have been poorly varied with CV of 8 %. Bulk density values exceeding 1.8 Mg/m^3 indicate the likely presence of duripans or fragipans especially in the subsurface soils of the shoulder to toe slope positions while values between 1.6 and 1.8 Mg/m^3 as was the case in most epipedons and endopedons indicates poor aeration and water movement that may be deficient for optimum crop growth (Esu, 2010). Bulk density correlated positively and highly with dithionite, oxalate and crystalline Fe and Al, and negatively with co-migrated Fe and Al. This indicates that an increased amount of sesquioxides due to intense chemical weathering condition of the soils is likely to increase soil bulk density.

Chemical properties

Soil chemical properties are presented in Table 3. Soil pH (H_2O) ranged between 5.9 and 6.8 while pH ($CaCl_2$) ranged between 5.3 and 6.0 with CVs of less than 5 % in the entire soils. Such values indicate moderately acid to neutral pH (Soil Survey Division Staff, 2017). Soil pH ($CaCl_2$) was weakly positively or negatively correlated with clay and CEC. Lower values of pH were obtained by Hassan *et al.* (2004) in the same agro ecological zone. Delta pH values indicate that the soils have net negative charges and will hold positively charged ions. Organic carbon was higher in the surface soils and decreased with soil depth with values that ranged between 2.2 and 20.1 g/kg in the foot slope with CV of over 50 %. Such values are low for tropical soils; however, the surface soil of the foot slope was rated very high (Enwezor *et al*., 1989). Organic C correlated positively and highly with total N, exchangeable Ca and Mg as well as base saturation; these parameters are most likely enhanced when soil organic matter content increases. Low organic carbon in the area is traced to continuous cultivation, bush burning, high rate of mineralization occasioned by high temperature as well as crop removal for livestock feeding, fuel and roofing (Odunze, 1998; Bownan *et al.,* 1990). Total N decreased regularly with soil depth and ranged between 0.7 and 2.19 g/kg with mean of 1.12 g/kg and CV of over 55 % in the surface soils; it however was correlated with similar parameters as organic matter. Such values are low for soils in the tropics and below a range of 2-10 g/kg recommended by Enwezor *et al*.(1989) for such soils. Available P in the surface soils ranged between 4.31 in the back slope and 8.39 mg/kg in the toe slope while values in the subsurface soils had a range of 2.68-11.34 mg/kg. Suchvalues are low for tropical soils (Enwezor *et al*., 1989); however, the shoulder appeared to have had the highest values in the landscape with a range of 4.46-11.34 $mgkg^{-1}$.

The soil colloidal complex was dominated by exchangeable Ca which occupied over 70 % of the complex with values that ranged between 1.47 and 3.86 cmol/kg with mean of 1.87 cmol/kg while exchangeable K and Na were the least amongst the bases. The values of exchangeable Ca, Mg, K and Na obtained in the present study are lower compared to basic requirement of 4-20, 1-8, 0.3-2 and 0.3-2 $cmolkg^{-1}$, respectively for soils in the tropics (Enwezor *et al*., 1989). Exchangeable Ca and Mg had CVs of over 35 % and were both highly and positively correlated with organic C, total N, and base saturation, and negatively with clay. Olaitan and Lombin (1984), and Brady and Weils (1999) reported that Ca^{2+} dominates the exchange complex of semi-arid tropical soils. Ca and Na are highly mobile during chemical weathering (Nesbitte *et al*.,1980; Babechuk *et al*., 2014) and are likely to be low in

Table 3: Chemical properties of the soils

Horizon	Depth	Soil pH		Org.C	Total N	Avail. P	K	Na	Ca	Mg	CEC	CEC/Clay	BS
	cm	H_2O	$CaCl_2$	← (gkg^{-1})	→	$(mgkg^{-1})$	←		$(cmol_c/kg)$			→	(%)
	Summit												
Ap	0-28	6.8	5.7	4.2	1.4	4.95	0.08	0.16	2.5	0.76	9	72.1	39
Bt	28-61	6.3	5.6	2	0.7	5.14	0.12	0.16	2.11	0.63	10.4	63.1	29
BA	61-151	6.0	5.4	2	0.4	2.68	0.2	0.15	1.86	0.42	12.2	66.0	22
Crt	151-205	6.4	5.9	1	0.4	4.57	0.19	0.19	1.75	0.42	13.2	58.7	19
	Shoulder												
Ap	0-24	6.2	5.5	2.4	0.7	6.13	0.09	0.15	1.7	0.64	6.4	51.3	40
Bt1	24-58	6.1	5.6	2	0.4	5.56	0.15	0.14	1.64	0.52	8.8	47.6	28
Bt2	58-133	5.9	5.4	1	0.4	11.34	0.14	0.13	1.61	0.5	11.8	52.5	21
Crt	133-205	6.2	6.0	0.4	0.4	4.46	0.19	0.16	1.62	0.5	14	57.2	18
	Back slope												
Ap	0-16	6.2	5.8	20.13	2.1	4.31	0.2	0.17	3.86	1.34	9.6	91.6	58
BA	16-35	6.4	5.8	2	1.1	4.54	0.1	0.14	1.62	0.53	9.2	55.8	26
Bt1	35-78	6.3	6	3	0.7	4.2	0.2	0.15	1.53	0.42	17.2	60.4	13
Bt2	78-102	6.1	5.9	1.2	0.4	3.55	0.08	0.18	1.51	0.4	24.0	69.6	9
Bt3	102-190	6.2	6	3	0.4	3.63	0.12	0.21	1.47	0.36	34.4	89.4	6
	Foot slope												
Ap	0-16	6	5.4	4	0.7	4.38	0.15	0.13	2.16	0.66	12.98	89.6	24
Bt1	16-66	6	5.4	2	0.4	5.03	0.2	0.16	1.87	0.52	15.8	77.1	17
BC	66-163	6.5	6	0.8	0.4	4.08	0.11	0.17	1.54	0.44	21.4	95.2	11
	Toe slope												
Ap	0-19	6.1	5.3	5	0.7	8.39	0.14	0.17	2.13	0.73	10.0	69.1	32
Bt	19-47	5.9	5	2	0.3	5.1	0.13	0.15	1.87	0.59	10.2	58.4	27
Bt2	47-102	6	5.7	1	0.4	3.86	0.15	0.14	1.75	0.53	14.2	69.3	18
CB	102-180	6.2	5.7	1	0.4	4.35	0.6	0.16	1.63	0.53	7.8	42.2	37
Cr	180-200	6.2	5.8	1	0.4	4.01	0.2	0.18	1.6	0.54	10.4	63.1	24

tropical soils. Cation exchange capacity ranged between 6.4 and 12.98 cmol/kg in the surface soils while values in the subsurface soils ranged between 7.8 and 34.4 cmol/kg with the back slope recording comparatively higher values. Surface soil values of CEC (NH_4OAc) were low while subsurface values were moderate to high (Enwezor *et al*., 1989).Cation EC was poorly and negatively correlated with organic carbon (r= -0.15) but highly and positively correlated with clay (r= 0.89), Fed as well as crystalline Fe, and increased in values with soil depth; a trend similar to that of clay and indicates that colloidal clay rather than humus may have provided exchange sites for the exchangeable cations. Base saturation ranged between 24 and 58 % in the surface soils while values in the subsurface soils ranged between 6 and 37 % with values that decreased regularly with increase in soil depth. Such values are low (Enwezor *et al*., 1989), especially in the subsurface soils. This indicates that shallow rooted crops are most likely to benefit from the soil's exchange properties. Base saturation correlated negatively with clay and CEC; however, BS and CEC had CVs that exceeded 35 %.

Forms of Fe and Al

The forms of Fe and Al species with their derivatives are presented in Table 4. Dithionite Fe (Fed) decreased with increasing soil depth except in the Bt and Cr horizons where values seemed to have increased. Soil surface values ranged between 315.21 in the foot slope and 736.47 mg/kg in the summit while subsurface values had range of 187.01-1206.05 mg/kg. Dithionite Fe correlated positively with bulk density and oxalate as well as crystalline Fe and Al; an indication that an increase in Fe_d will lead to increased bulk density. Values of Fed were similar to those reported by Kparmwang (1993) but higher than those reported by Essoka *et al*. (2007) and Ibia (2002) for basement complex soils; they further attributed variation of values with landscape positions to drainage condition. Comparatively, lower values were obtained for oxalate Fe (Feox) with values that ranged between 205.17 and 521.17 mg/kg with a trend similar to that of Fed. Contrary to the trend of values obtained for Fed and Feox, crystalline Fe (Fed-Feox) increased in the Bt and Cr horizons and had values with ranges of 37.37-257.47 mg/kg and 55.89-730.96 mg/kg in the surface and subsurface soils with means of 169.8 and 230.0 mg/kg, respectively. Co-migration of Fe with clay increased with soil depth, particularly in the Bt and Cr horizons, with values that ranged between 228.8 and 1523 mg/kg with a mean of 487 mg/kg in the entire soils; this indicates that illuviation of clay occurred in the company of Fe, and is most likely to lead to ferritization. Oxalate and crystalline Fe had CVs exceeding 40 %. Feox correlated positively with Fed and crystalline Fe and negatively with co-migrated Fe.

Dithionite Al (Ald) decreased with soil depth and increased in the Bt and Cr horizons and had ranges of 216.52-511.22 mg/kg and 141.33-642.55 mg/kg in the surface and subsurface soils with means of 313.9 and 312.9 mg/kg, respectively while oxalate Al (Alox) had range of 53.09-356.54 mg/kg in the entire soils. Lower amounts of Alox compared to Ald could be attributed to neoformation process of clay silication (Hassan *et al*., 2004). Crystalline Al (Ald-Alox) decreased with soil depth but increased at the Bt and Cr horizons and ranged between 9.89 and 356.29 mg/kg in the entire soils; however, the trend of co-migrated Al with increased soil depth indicates that Ald was co-migrated alongside clay in the Bt and Cr horizons. This trend resulted in mean values of 453.0 and 845.1 mg/kg for the surface and subsurface of the entire soils. Soils in the summit, shoulder and back slope had the highest values of Fe and Al oxides followed by the foot slope and toe slope soils.

According to Yakubu and Ojanuga (2013), the content of sesquioxides increases as the soil ages due to the influence of weathering, while Zhao and Zheng (2015) stated that the concentration of immobile elemental oxides such as those of Fe and Al increase after intensive chemical weathering as a result of dissolution and transport. This therefore implies that soils in the summit, shoulder and back slope were older or more developed with lower CEC values; an indication that the mobile components may have been lost to leaching. The degree of activation of Fe ($Fe_{act.}$) had range of 0.38-0.88 with a mean of 0.60 mg/kg with values that decreased irregularly with soil depth while the degree of activationof Al ($Al_{act.}$) had range of 0.33-0.95 with a trend of values that seems to contradict that of Fe_{act}. Values of $Fe_{act.}$ were higher than 0.5 in all landscape positions except back slope and indicates a less degree of weathering or less degree of Fe crystallization in the area (Alexander, 1974). The lesser degree of weathering depicts that the soils are pedologically young while the back slope appeared relatively old, and aligns with the earlier assertion of Yakubu and Ojanuga (2013), and Zhao and Zheng (2015).

Table 4: Forms of Fe and Al and their derivatives

Horizon	Depth	Fed	Fe_{ox}	Feox/Fed	Cry. Fe	CoFed	Al_d	Al_{ox}	Alox/Ald	Cry. Al	CoAld
	(cm)	← $mgkg^{-1}$ →		$Fe_{act.}$	$mgkg^{-1}$ ←		$mgkg^{-1}$	→	Alact.	$mgkg^{-1}$	
					Summit						
Ap	0-28	736.47	521.17	0.71	215.3	169.6	354.25	213.54	0.6	140.71	361.7
Bt	28-61	538.25	341.93	0.64	196.32	306.3	201.86	189.25	0.94	12.61	815.8
BA	61-151	444.44	253.11	0.57	191.33	416.2	180.55	170.66	0.95	9.89	1021
Crt	151-205	642.15	455.06	0.71	187.09	350.2	451.09	195.72	0.43	255.37	498.4
					Shoulder						
Ap	0-24	426.85	239.7	0.56	187.15	526.5	256.17	154.29	0.6	101.88	497.2
Bt1	24-58	337.11	230.47	0.68	106.64	548.4	162.31	118.06	0.73	44.25	1141
Bt2	58-133	349.2	189.26	0.54	159.94	644.1	278.14	139.92	0.5	138.22	808.6
Crt	133-205	938.84	475.29	0.51	463.55	260.7	642.55	338.49	0.53	255.55	381.3
					Back slope						
Ap	0-16	357.08	205.17	0.57	151.91	293.6	231.5	143.78	0.62	87.72	453.7
BA	16-35	229.75	173.86	0.76	55.89	716.5	163.92	90.71	0.55	73.21	1005.5
Bt1	35-78	187.01	70.86	0.38	116.15	1523	141.33	53.09	0.38	88.24	2015.6
Bt2	78-102	859.18	353.1	0.41	506.08	401.4	453.68	219.52	0.48	234.16	760
Bt3	102-190	1206.05	475.09	0.39	730.96	319.1	598.26	356.54	0.6	241.72	643.5
					Foot slope						
Ap	0-16	315.21	277.84	0.88	37.37	459.4	216.52	193.2	0.89	23.32	668.8
Bt1	16-66	387.49	255.21	0.66	132.28	528.5	262.73	196.67	0.75	66.06	779.6
BC	66-163	334.93	211	0.63	123.93	671.2	246.25	123.75	0.5	122.5	912.7
					Toe slope						
Ap	0-19	632.87	375.4	0.57	257.47	228.8	511.22	253.23	0.5	257.99	283.4
Bt	19-47	628.15	331.8	0.53	296.35	278.3	531.54	175.25	0.33	356.29	328.9
Bt2	47-102	372.1	241.71	0.65	130.39	550.5	251.99	160.06	0.64	91.93	812.7
CB	102-180	359.26	196.79	0.55	162.47	514.8	209.87	129.01	0.61	80.86	880.5
Cr	180-200	317.22	196.54	0.62	120.68	519.9	230.18	124.91	0.54	105.27	716.2

Soil classification

Based on the criteria of the USDA Soil Taxonomy, the entire soils had base saturation (NH_4OAc) values of less than 50 % at the Bt horizons as well as argillic horizons and low exchangeable basic cations and are placed in the order Ultisols while ustic soil moisture regime in the area qualifies them in the suborder Ustults. Toe slope soil does not have a densic layer within 150 cm of the mineral soil surface and a clay decrease of 20 % from maximum clay content within 150 cm of the soil surface, it is therefore placed in the great group Paleustult and Typic Paleustult in the sub group category. Summit, back slope and foot slope soils had epipedons with colour value of 3 while endopedons in the upper 100 cm of the argillic horizon had hue of 2.5YR or redder; the soils qualify as Rhodustults while the shoulder qualify as Haplustult in the great group category. In the sub group category, soils in the summit, back slope and foot slope typify the great group and are classified as Typic Rhodustults. Loamy sand textural class (fine earth fraction) overlie the argillic horizon of the shoulder pedon and qualify as Arenic Haplustults in the subgroup category. The soils had base saturation of less than 50 % (NH_4OAc pH 7) in all horizons with argic horizons that underlie sandy loam and loamy sand textural classes and correlate with Acrisols at the Reference Soil Group (First Level) in the World Reference Base for Soil Resources. Summary of classification is presented in Table 5 for the second level.

CONCLUSION

The study was designed to characterize and infer on the genesis of soils along a toposequence as well as classify same based on the criteria of USDA and WRB for Soil Resources. The soils had capacity to hold cations hence the moderately high CEC that characterized the soils as well as CEC/clay values that suggested the presence of montmorillonite and mixed mineralogy. The dominance of Fe and Al species in the soils, especially the crystalline forms suggest that the Basement Complex soils were highly weathered. However, the moderately high CEC and the presence of montmorillonite are likely indications that the soils have good potentials for agriculture. Co-migration of Fe and Al with clay indicated the movement of sesquioxides in the company of clay to endopedons. Among the soil forming processes in the area were mineralization, eluviation-illuviation as well as ferritization and ferrugination. Soils in the summit, backslope and foot slope were classified as Typic Rhodustults (Chromic, Pretic and Haplic Acrisols) while the shoulder soil was Arenic Haplustult (Chromic Acrisol) and toe slope was Typic Paleustult (Haplic Acrisol).

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