Pedological Classification Of Soils Along A Toposequence In Faculty Of Agriculture Shabu-Lafia Campus, Nasarawa State University Keffi, Nigeria.

Abubakar, M. A., Daar, W. J. Jayeoba, O. J.

ABSTRACT: This study was conducted along a toposequence in faculty of agriculture Nasarawa State University Shabu-Lafia Campus (8° 33' 22.07'' N and 8° 34' 00.49'' N and longitude 8°32' 37.63'' E and 8° 33' 14.07'' E) Nigeria. Digital Elevation Model (DEM) of the study site was developed using Google earth map and GIS software (Arch GIS 10.3 version) and the site was divided into three slope classes (upper, middle and lower). Morphologically the upper and middle slope soils were deep (200 cm) and well drained while lower slope soils was moderately deep (90 cm) and poorly drained. Soil colour ranged from 10YR3/4, 10YR4/4 and 5YR5/1 in the surface horizons of upper, middle and lower slope landscape position to 2.5YR4/8, 7.5YR7/8 and 2.5YR6/1 in the underlying horizons. Bulk density values across the study area were generally high (1.52-1.62 gcm^{-3}) and sand dominated the particle size fraction (648-848 gkg^{-1}), then Clay (98-278 gkg^{-1}) and finally silt. Soil reaction (pH) varied as strongly acid to moderately acid (4.67-5.73) and the soils were non saline (3.1-1.0 dSm^{-1}), Ca dominated the exchangeable bases and were in the order Ca > Mg > K > Na, CEC were low across the three landscape position and percentage base saturation were high (73.0- 80 %). Available P were generally high (36.1-28.8 $mgkg^{-1}$), OC were moderate (10.1-14.0 gkg^{-1}), TN were moderate too (2.1-2.8 gkg^{-1}). The soils were classified as Typic Endoustalfs and Typic Endoaquents according to USDA Taxonomy while Haplic Acrisols (skeletic, Eutric) and Haplic Gleysols (Eutric, Colluvic) according to WRB.

Keywords: Digital Elevation Model, soil classification, soil properties and toposequence.

INTRODUCTION

Soils are non-renewable natural resource that vary in their properties changing across the landscape (spatially) and vertically down the soil profile [5, 6]. According to [16] toposequence can be described as transect (not necessarily a straight line) which begins at a hilltop and ends at a valley bottom (lower slope) or a stream. Topography as a key factor in soil formation may speed up or delay the work of climatic factors, topography has significant effect on soil morphological, physical and chemical properties and also affects the pattern of soil distribution in the environment [7] even when the parent materials are of similar source. Consequently, soils on slopes exhibits remarkable differences in properties from those on the crest because of infiltration of water which tends to move laterally across a profile instead of vertically [1]. There is a very limited compilation of pedological soil information in the study site consequently, this study focused on addressing and filling these missing key gaps. The objectives includes classification of the soils based on USDA and WRB system of classification.

- *M. A. Abubakar, W.J., Daar, O.J. Jayeoba.*
- *Agronomy Department Faculty of Agriculture Shabu-Lafia Campus, Nasarawa State University Keffi. Email: dattijoh@nsuk.edu.ng, Tel:+2348038369200.*
- *Department of Agriculture Technology, College of Agriculture Garkawa, Plateau State*

MATERIALS AND METHOD

Description of the Study Area.

The study area is located between latitude 8° 33' 22.07'' N and 8° 34' 00.49'' N and longitude 8°32' 37.63'' E and 8° 33' 14.07'' E, in Shabu with a population of 330,712 according to 2006 National Population Commission in 2006 [13]. It has a perimeter of 3.13km and area of 58.29 ha. The study area has an average wet season of seven (7) months and dry season of five (5) months (Nov – April) with mean annual rainfall of 1,595.7mm and annual mean minimum temperature ranges between 21.8℃-22.2℃ and the annual maximum mean temperature is about 23.5℃ [4]. Data for digital elevation model (DEM) were generated from Google earth map, saved as KMZ format then converted to CSV and further transferred to Arch GIS and the sampling data were interpolated in 3D and divided into three slope classes (upper, middle and lower slope) as shown in figure 2.

Field Studies

Field studies was conducted in the month of April, 2018 before the unset of the rain to avoid effect of leaching and dilution. The Upper slope soil pit was dug between169.7-182 m, middle slope between 159-169 m and Lower slope between 149-159.3 meters above sea level as depicted in figure 1and 2. Soil morphological properties were described according to the procedure in the USDA Soil Survey Staff Manual [24]. Features like soil colour were determined using the Munsell colour chart, soil depth, mottles, texture, structure, consistency, horizon boundary, roots, concretions, pore distribution were also be determined in situ.

Fig 1. *Image of the study area showing soil units boundaries and possible soil profile pit locations.*

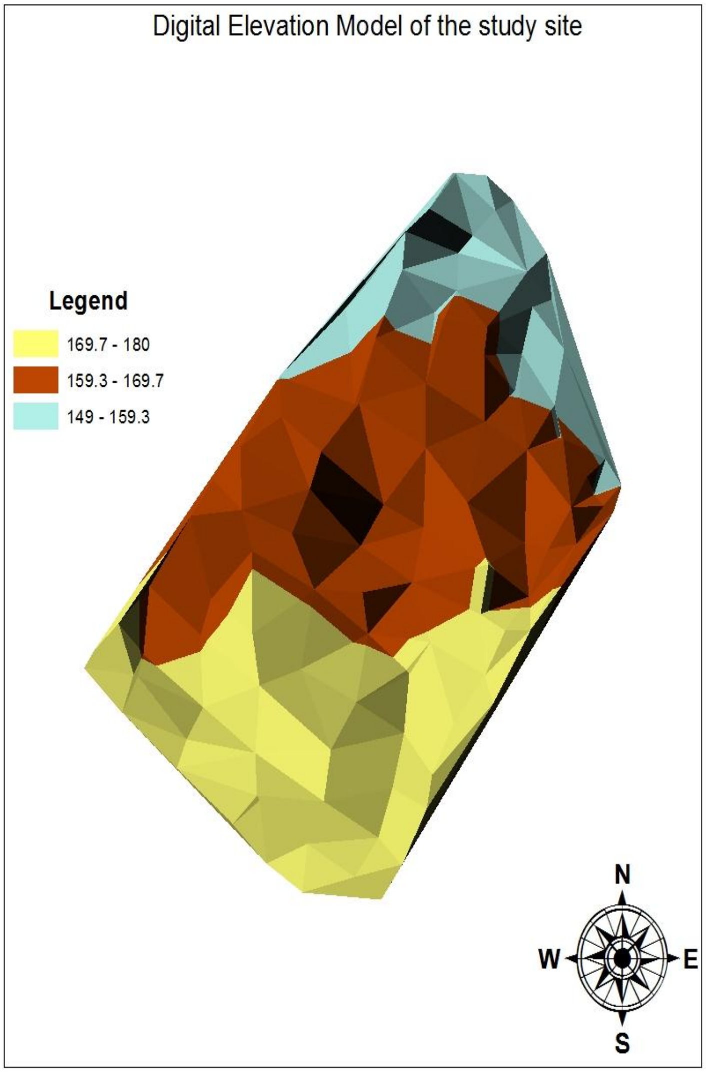

Fig 2. *Digital elevation model of the study site*

Soil Laboratory Analysis.

The bulk soil samples were air-dried, gently crushed and sieved to obtain the fine soil fractions (>2mm) and some were further passed through 0.5mm sieved for N determination. The samples were labeled and stored in plastic containers and subjected to routine elemental analysis using standard methods as outlined in [12].

RESULTS AND DISCUSSION

Soil morphology

The soils of the study area were generally considered to be very deep ranging from 200 cm except profile three which had a depth of 90 cm and was considered as being moderately deep and variation in soil depth might be ascribed to different level of elevation in the area. Soil colour of the study area ranged from pale brown (10YR5/3 dry, 10YR3/4 moist), yellowish brown (10YR6/3 dry, 10YR4/4 moist) and greyish brown (5YR5/1 moist) for P1, P2 and P3 in the surface soils while the subsurface soils ranged from 2.5YR2/8, 7.5YR7/8 and 2.5 YR6/2 respectively. The upper slope soils were dominated by brown colouration which could be attributed to oxidation state of the soils while the grayish coloration at lower slope was an indication that P3 was imperfectly or poorly drained as reported by [8]. Soils of upper slope (P1) were sandy loam in the surface while loamy sand in subsurface. Middle slope (P2) soils were sandy loam in both surface and subsurface soils. Lower slope soils (P3) ranged from sandy clay loam in the surface horizons to loamy sand in subsurface horizons The surface soils of the study area were weak medium sub angular blocky across the three pits while subsoil were massive angular block in upper and middle slope (P1 and P2) to massive in lower slope(P3). With the exception of the lower slope (P3), all the pits were well developed clear and smooth to diffuse and wavy different horizons. The weak to medium sub angular blocky might be attributed to the degree of soil formation in profile one and two. The surface soils of the study area were weakly structured across the three profile pits with absence of cracks on the surfaces of the pedons which might be ascribed to presence of nonexpanding clay minerals e.g. kaolinite in them [2]. The soils were characterized by three different drainage classes based on their landscape position. Soils on the upper and middle slope positions were well drained to imperfectly drain which may be attributed to the upper to middle slope position while the lower slope was poorly drained as evidenced by presence of shallow water table and mottles which could be as a result of the lower slope position. The surface horizon of P1 and P2 were free of mottles, indicating of good surface drainage condition. However, strong brown (10YR8/8) mottles were common at the subsurface of P3 which changed to red (7.5YR6/8) at lower horizon which is in conformity with [3]. The studied pedons (P1 and P2) were similar in consistence. They were non-sticky to slightly sticky (wet), very friable to friable (moist) in the Ap horizons. The subsoils were slightly sticky (wet), friable to very firm (moist). Lower slope was nonstick, non-plastic to massive. The increase in stickiness and hardness down the profile might be ascribed to the increase in clay content. [10] reported increase in stickiness and hardness down the profile. Horizonation is ascribed to additions, removals, transfers and transformations of organic matter and colour development. Generally horizon differentiation between Ap horizons and the B horizons were quite clear and smooth across the three pits (P1, P2 and P3) which might be due to melanization from humification of organic matter content added to the Ap horizons as form of fertilizers.

Table 1: *Summary of soil morphological properties of the study site.*

Horizons	Depth (cm)	Munsell Colour dry moist		Texture	Mottles colour	Structures	Consistency wet moist		Boundary
Pedon 1	**Typic**	**Endoustalfs**	**Latitude**	**N8°33'24.95"**	**Longitude**	**E8°33'45.84"**	**Elevation**	**182m**	
Ap	0-30	10YR5/3	10YR3/4	SL	--------	1msbk	so, po	fr	Cw
AB	30-48	10YR6/8	5YR6/8	SL	--------	1msbk	so, po	fr	Dw
B	48-100	-----------	2.5YR3/6	LS	--------	3mabk	S	Vfi	Dw
Bt	100-152	------------	2.5YR4/8	LS	--------	3mabk	Vs	Vfi	Dw
Btc	152-200	------------	2.5YR2/8	LS	--------	3mabk	S	Fi	-----
Pedon 2	**Typic**	**Endoustalfs**	**Latitude**	**N8°33'45.84"**	**Longitude**	**E8°22'59.45"**	**Elevation**	**162m**	
Ap	0-27	10YR6/3	10YR4/4	SL	--------	2msbk	Ss, sp	fr	Cw
E	27-51	10YR6/2	10YR7/3	SL	--------	2msbk	so, po	Vrf	Cw
B1	51-95	7.5YR6/8	7.5YR5/8	SL	--------	2mabk	Ss, sp	Fi	Cs
B2	95-156	-----------	7.5YR7/8	SL	--------	3mabk	Ss, sp	Fi	Dw
BCc	156-200	-----------	5YR6/8	SCL	5YR5/6	3maabk	Ss, sp	Fi	-----
Pedon3	**Typic**	**Endoaquents**	**Latitude**	**N8°33'58.37"**	**Longitude**	**E8°33'02.46"**	**Elevation**	**149m**	
Ap	0-31	**-----------**	5YR5/1	SCL	5YR4/6	1msbk	Ss, sp	fr	Cs
AC	31-67	**-----------**	2.5YR7/2	LS	7.5YR6/8	1msbk	so, po	l	Dw
Cw	67-90	**-----------**	2.5YR6/2	LS	10YR8/8	ma	so, po	l	-----

Source: *Author's field work (2018). Symbols used are given in Soil Survey Manual (Soil Survey Staff, 2017)*

Physical properties

The particle size distribution data for the soils is presented in Table 2 Sand dominated the particle size fraction of the fine earth (<2mm) portion of the soils. The sand content of the study site varied from 648 to 848 gkg^{-1} in the Ap horizons (Table 2), while the values for the sand content in the underlying horizon were in the order 653 and 7283 gkg^{-1}. Clay values for the study site were 118-278 gkg^{-1} in the Ap horizon of upper, middle and lower slopes and values of clay at the subsurface horizon of upper lower and middle slopes were 98-218 gkg^{-1} respectively. Generally sand content of the surface horizons were slightly higher than the subsoil horizons. In most of the profiles studied, sand content decreased with an increasing soil depth which might be partly related to parent material rich in quartz mineral, an essential component in granite [26], and partly to geological processes involving sorting of soil materials by biological activities, clay migration through eluviation and illuviation, or surface erosion by runoff or their combinations [1]. Sand content of the surface horizons was in the order of arrangement as P1 > P2 > P3. The silt content increased with soil depth irrespective of topographical positions, probably because these soils were developed *in situ*. It was also observed that P3 had the highest amount of silt and that may be linked to the depositional effect of the seasonal stream in addition to receiving colluvial material from upper and middle slopes (P1 and P2). The trend of silt content in the surface horizon were P1 < P2 < P3. Soil on lower slope, recorded the highest silt value which could also be attributed to fine sediments eroded from upland to the lower slope position. Clay fraction was next to sand in abundance and was higher in the subsurface than surface horizons, with an irregular pattern of distribution, the upper slope soils showed high clay content when compared with lower slope soils. Generally, values increased from A-horizon to B-horizons. The higher clay content often observed in subsurface horizons of many soils may be ascribed to illuviation and pedoturbation processes [15]. This confirms the presence of argillic B horizons (accumulation of clay in B-horizon) in the pedons of upper and middle slope. The lower clay content of the surface soil could be characteristic of soils formed on Basement Complex in Nigeria [14]. The bulk density (BD) values are presented in Table 2. The values of bulk densities for upper, middle and lower slopes were 1.45, 1.50 and 1.52 gcm^{-3} in the Ap horizons while in the subsoil, the values ranged as 1.67, 1.69 and 1.75 gcm^{-3} respectively. The high bulk density is attributed to compaction caused by grazing animals and tillage operation [21]. Root growth could also be inhibited due to high bulk density because of soil resistance to root perpetration, poor aeration, slow movement of nutrients and water and build-up of toxic gases and root exudates [17].

Chemical properties

The pH (in water) values were in the order of 5.58, 5.95 and 5.73 in the surface horizons of upper, middle and lower slope while in the subsoil the values ranged as 4.67, 4.75 and 6.61 respectively (Table 3). [5] had established pH range of 5.5-7.0 as optimal for overall satisfactory availability of plant nutrients. The results obtained agrees with that of [14]. The exchangeable bases comprise of exchangeable calcium, magnesium, potassium and sodium. The Ca values in the surface horizons were 3.01, 3.26 and 3.28 for Ap horizons of upper, middle and lower slope while 2.86, 3.31 and 3.69 respectively for the subsoil. Magnesium values were in the order 0.33, 0.36 and 0.40 in the Ap horizons while 0.28, 0.40 and 0.48 for sub surface horizons of upper, middle and lower slope. Potassium content were 0.26, 0.30 and 0.28 for the three pits (P1, P2 and P3) in the Ap layers while in the lower horizons they ranged as 0.21, 0.28 and 0.38. Sodium (Na) ranged as 0.11, 0.22 and 0.31 in the Ap and 0.09, 0.09 and 0.38 in the lower horizons of the upper, middle and lower slope landscape. The values of cation exchange capacity (CEC) in the surface horizons were 3.71, 4.14, and 4.27 cmol(+)kg^{-1} for upper, middle and lower slope in the Ap horizon while 3.56, 4.26 and 4.99 were the values for CEC at the subsurface horizons respectively. Low CEC values were reported to be an indication of dominance of sesquioxide and kaolinitic clays in the fine earth fractions [25]. The slightly higher CEC values of A-horizons may be attributed to low leaching and the slight increase down the profiles of P1 and P2 was as a result of increase in clay content. Exchangeable acidity comprises exchangeable hydrogen (H^+) and aluminium (Al^{3+}). The values ranged as 1.00, 0.80 and 1.00 $cmolkg^{-1}$ in the surface horizons of the upper, middle and lower slope positions while 1.67, 0.83 and 0.83 $cmolkg^{-1}$ in the surface horizons of the underlying horizons as shown in Table 3. The organic carbon values for surface horizons were 14.0, 14.2, and 14.9, gkg^{-1} for upper, middle and lower slope while 8.1, 11.6 and 11.0 gkg^{-1}were for the subsoil respectively. The OC and OM content of the soils decreased with soil depth and were both rated moderate irrespective of soil depth and landscape positions. The moderate values of OC and OM inferred that the studied site have been under continuous or intensive cultivation because high agricultural activities deplete soil organic matter content [9]. The organic carbon decreased down the profiles which may be linked to immobilization of organic matter by clay in the Ap horizons in forms of organo-clay-complexes [22]. The total nitrogen values in the surface horizons varied as 2.8, 2.8 and 2.8 gkg^{-1} for upper, middle and lower slope and subsurface soils varied as 1.4, 1.4 and 1.3 gkg^{-1} respectively. Total N was moderately high in upper, middle lower slopes position. Pedon P2 and P3 were slightly higher than P1 which might be ascribed to their advantages of receiving soluble nutrients from the upper slope. The available phosphorus content values varied from 28.6, 26.7 $mgkg^{-1}$ in the Ap horizon to 20.6, 30.6 and 33.7 $mgkg^{-1}$ respectively in the underlying horizon. The high level of available P may be due to its low solubility/ mobility in soil and fixation with other compound. However, high available P content in the subsoil of P3 could be due to deposition of P as also reported in a study elsewhere in south-eastern Nigeria [19] and it might be attributed to high rate of mineralization of organic carbon due to low clay content in the lower slope position.

Table 2: *Physical properties of the study site*

Horizon	Depth (cm)	Sand ----------	Clay gkg^{-1}	Silt ---------	MC %	Texture	BD gcm^{-3}	MC %
Pedon 1	**Latitude**	**N8°33'24.95"**	**Longitude**	**E8°33'45.84"**	**Elevation**	**182m**		
Ap	0-30	848	118	34	14.0	SL	1.52	14.0
AB	30-48	848	118	34	13.9	SL	1.52	13.9
B	48-100	868	98	34	11.12	LS	1.50	11.12
Bt	100-152	868	98	34	18.7	LS	1.58	18.7
Btc	152-200	868	98	34	5.7	LS	1.75	5.7
Pedon 2	**Latitude**	**N8°33'45.84"**	**Longitude**	**E8°22'59.45"**	**Elevation**	**162m**		
Ap	0-27	788	178	34	14.0	SL	1.56	14.0
E	27-51	748	178	54	12.0	SL	1.67	12.0
B1	51-95	768	178	54	18.6	SL	1.60	18.6
B2	95-156	788	178	34	12.2	SL	1.67	12.2
BCc	156-198	728	218	54	12.0	SCL	1.67	12.0
Pedon 3	**Latitude**	**N8°33'58.37"**	**Longitude**	**E8°33'02.46"**	**Elevation**	**149m**		
Ap	0-31	648	278	74	6.70	SCL	1.62	6.70
AC	31-67	868	98	54	8.7	LS	1.80	8.7
Cw	67-90	868	98	34	5.7	LS	1.75	5.7

Table 3. *Chemical properties of the study site.*

Horizon	Depth (cm)	pH (H_20)	EC dSm^{-1}	Ca -----	Mg -----	K cmolkg^{-1}	Na ----	CEC ------	EA	PBS %
Pedon 1	**Latitude**	**N8°33'24.95"**	**Longitude**	**E8°33'45.84"**	**Elevation**	**182m**				
Ap	0-30	5.58	2.0	3.01	0.33	0.26	0.11	3.71	1.00	73.0
AB	30-48	5.65	1.8	3.26	0.46	0.28	0.16	4.16	0.83	80.0
B	48-100	4.67	3.0	2.86	0.30	0.21	0.09	3.56	1.67	53.0
Bt	100-152	3.51	2.0	2.42	0.28	0.18	0.09	2.97	1.67	44.0
Btc	152-100	4.93	3.0	2.91	0.31	0.27	0.21	3.70	1.67	55.0
Pedon2	**Latitude**	**N8°33'45.84"**	**Longitude**	**E8°22'59.45"**	**Elevation**	**162m**				
Ap	0-27	5.95	2.0	3.26	0.36	0.30	0.22	4.14	0.83	80.0
E	27-51	6.52	2.6	3.46	0.48	0.42	0.32	4.68	0.50	89.0
B1	51-95	5.72	3.1	3.31	0.39	0.28	0.28	4.26	0.83	81.0
B2	95-156	5.65	3.40	3.42	0.40	0.24	0.32	4.38	0.83	81.0
BCc	156-198	4.75	3.9	2.97	0.29	0.21	0.21	3.68	1.00	73.0
Pedon3	**Latitude**	**N8°33'58.37"**	**Longitude**	**E8°33'02.46"**	**Elevation**	**149m**				
Ap	0-31	5.73	1.0	3.28	0.40	0.28	0.31	4.27	1.00	77.0
AC	31-67	6.01	1.0	3.78	0.48	0.38	0.38	5.02	0.83	83.0
Cw	67-90	6.61	1.3	3.69	0.51	0.40	0.39	4.99	0.50	80.0

Table 4: *Chemical properties of the study site*

Horizon	Depth cm	OC ---------	OM gkg^{-1}	TN ----------	C:N	Aval P mgkg^{-1}
Pedon 1	**Latitude**	**N8°33'24.95"**	**Longitude**	**E8°33'45.84"**	**Elevation**	**182m**
Ap	0-30	14.0	24.1	2.8	6.00	28.6
AB	30-48	14.0	24.1	2.8	5.71	30.1
B	48-100	12.0	20.7	2.1	5.00	26.7
Bt	100-152	8.1	14.0	2.1	2.89	20.7
Btc	152-200	11.0	19.0	1.4	7.86	28.0
Pedon 2	**Latitude**	**N8°33'45.84"**	**Longitude**	**E8°22'59.45"**	**Elevation**	**162m**
Ap	0-27	14.2	24.5	2.8	4.29	31.1
E	27-51	10.1	17.4	1.5	4.06	36.7
B1	51-95	13.8	23.8	2.1	4.93	31.2
B2	95-156	14.1	24.3	2.1	5.53	30.6
BCc	156-200	11.6	19.9	1.4	10.0	30.4
Pedon 3	**Latitude**	**N8°33'58.37"**	**Longitude**	**E8°33'02.46"**	**Elevation**	**149m**
Ap	0-31	14.9	25.7	2.8	5.07	32.1
AC	31-67	14.0	24.1	2.1	6.76	33.7
Cw	67-90	11.0	18.9	1.3	5.24	38.6

Soil classification

The soils of the three profiles were classified according to the USDA Soil Taxonomy [23] and World Reference Base for soil Resources [11]. The differentiating properties used for the classification include some morphological, physical and chemical properties. These parameters are considered important for the two systems of soil classification and are discussed below. The soil moisture regime of the study area is considered as Ustic, as it has an annual rainfall of 1280-1438mm and the amount is concentrated between 5 - 7 months. This implies that the soil is moist for more than 180 cumulative days and is dry for 90 or more cumulative days also implying there is a limited moisture level suitable for plant growth [22]. The mean annual soil temperature of the study area is more than 22℃ (34℃). The mean summer and mean winter soil temperatures differ by less than 6℃, therefore the soil temperature regime of the study area is Isohyperthermic [23]. The epipedons across the three profile were too thin, too light, poor in humus, poor in bivalent cations, low in phosphorus (>250mgkg^{-1}), to be mollic, anthropic, histic, melanic, plaggen or umbric epipedons. The soils had a colour value of 3 to 4 (moist) and a chroma of 3, in the surface horizons, thus were considered as being Ochric epipedon Profile one and two had significant accumulations of illuviated layer-latice silicate clays formed below the elluvial horizons except at profile three, with the profile showing saturation with moisture at some depth. At the Order level, profile one and two (upper and middle slope) were classified as Alfisols because they have high base saturation greater than 50% (NH_4OAc) in addition to the presence of argillic B horizons. While profile three (lower slope) was classified as an Entisol due to absence of complete B horizon. At the suborder level, profile one and two were classified as Ustalf because they have an Ustic soil moisture regime while profile three was classified as Aquent due to saturation of water ponded at some depth of the profile pit which exhibit gray colours and presence of reddish or brownish Fe mottles. At the great group level profile one and two were classified as Endoustalfs while profile three was classified as Endoaquent while at the subgroup level, pedon one and two (upper and middle slope) were classified as Typic Endoustalfs, while pedon three (lower slope) were classified as Typic Endoaquents. At the Family level of Soil Taxonomy pedon one and two (upper and middle slope) were classified as Typic Endoustalfs, sandy-loam, Isohyperthermic and pedon three (lower slope) were classified as Typic Endoaquents, sandy-loam, Isohyperthermic. At the World reference base for Soil resources,pedon one (upper slope) were classified as Haplic Acriosols (skeletic Eutric) while pedon two (middle slope) were classified as Haplic Acrisols (endoskeletic Eutric) due to higher clay content in the subsoil than in the topsoil as a result of pedogenic processes (especially clay migration) leading to argic subsoil horizon, with CEC of <24cmolkg^{-1} and base saturation (NH_4OAc) greater than 50%.Pedon three (lower slope) were classified as Haplic Gleysols (Eutric, colluvic) because, they were saturated with water for long enough periods to develop a characteristics gleyic colour pattern (reddish brownish/yellowish).

CONCLUSION

The results from the study showed that the upper, middle and lower slope soils were low in soil fertility and are well drained, a confirmation of the general characteristic of Savanna soils reported by previous researchers. This indicates that the lower slope were more fertile than adjacent upper slope as the lower slope was significantly higher in BS than the adjacent upper slope and washing down of nutrients from upper slope. The classification ranged from Alfisols and Entisols (USDA) while Acrisols and Gleysols (WRB).

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