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Genesis and Classification of Soils from a Toposequence at Wamaso, Ghana

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Abstract

The availability of pedogenic information and proper classification of soils is the right step and key in the fight against poor outputs of crop production. The soils of the university of Cape Coast research field in Twifo Wamaso were fully characterized along a toposequence and classified according to soil taxonomy and the WRB legend to assess the influence of topography on soil development. The morphology and the physicochemical properties of five pedons located at the upper. Shoulder, middle, foot and toe slopes were studied. The study revealed the existence of two soil orders, namely Ultisol and Entisol, along the toposequence and was categorized as Lixisols, Fluvisol and Regosols major groups according to the WRB legend.

Subject Areas

Agricultural Engineering, Environmental Sciences, Natural Geography

Keywords

Pedogensis, Soil Classification, Toposequence, Wamaso, WRB Legend

1. Introduction

Pedogenic processes are heterochronous and those related to soil fertility occur close to hundreds and thousands of years. Obtaining knowledge of these processes has always been an essential aspect of agronomy and, in recent, a major component of precision agriculture. Currently, precision agriculture is recognized as the most sustainable agricultural food security practice in Ghana and many West African countries (Bosompem, 2021) [1]. As a data driven process and management practice, knowledge of various aspects of soil systems including types and classes, is essential to developing knowledge bases for local farmers. However, such data acquisition is often challenged per location, slope gradients, topography and other edaphic factors which contribute to soil types and formation (Nadimi & Farpoor, 2013) [2].

Studies on the various soil formation factors have been reported (Jenny, 1994 [3]; Johnson & Schaetzl, 2015 [4]). The significant influence of topography and slope gradient on soil formation is reported, which are mostly characterized by well-drained to silt loam or sandy loam structures (Javadi, Sokouti, Pazira, & Massihabbadi, 2020) [5]. Although they become prone to erosion when the top soils are exposed, soil present in the middle and toe slopes is usually deep in formation with well-drained sandy loam textures (Liu *et al.*, 2020) [6]. In low-lying topography, special profile features characteristic of wetland soils may also develop (Brady & Weil, 2008) [7]. Toposequences are unique features defining an entire landform or topographic feature (Dash, Mishra, & Saren, 2019) [8]. They represent a spatial object that establishes and maintains flow connectivity from the summit to the base of inclined landforms hence capable of revealing physical, chemical, mineralogical and morphological) features across soil horizons (Sağlam & Dengiz, 2015) [9]. By this, the location of specific soil types in the toposequence can be used to differentiate various soil types across a landscape or region as they are linked to variation in geomorphic features (Conforti *et al.*, 2020) [10].

Pedogenic studies and a systematic classification of various soil types in Ghana can be attributed to earlier works of C. F Carter in the 1940's (Borden, Brammer, Baillie, & Hallett, 2021) [11]. Asiamah (2008) [12] and Effland (2009) [13] also provided a compendium of various soil resources in Ghana. Previous studies, however identified significant lapses in the soil series classification system originally adopted (Adjei-Gyapong & Asiamah, 2002) [14]. Hence corroboration with internationally accepted soil classification systems such as the World Reference Base (WRB) is currently in use (Adjei-Gyapong & Asiamah, 2002) [14]. A comparative evaluation of this system was first tested along local farmers' descriptions of various soil types in the Northern part of Ghana (Mikkelsen & Langohr, 1997) [15]. Clear differences were observed with the classification systems as the farmer-based classification systems concentrated precisely on good crop yields based on color and texture while the national soil classification system is focused on higher pedogenic formation such as secondary carbonate formation. This reveals that soil classification at more local and site levels are essential which may contribute to agriculture and food security.

The objective of any soil classification study may include, establishing groups or classes of soils under study in a manner useful for practical and applied purposes. Hence in this study, we focused our effects on determining various soil types and classes along a toposequence as a reference baseline to understand the general soil classes and types across a 419 km^2 study area. Observed soil types were classified per the World Resource Base system (WRB, 2015) [16].

2. Methodology

2.1. Study Area

The study area covers an estimated land-take of 419 acres located in Twifo Praso in the Twifo Atti-Morwka District, Central Region, Ghana and approximately 1.2 km west of Wamaso (latitude: 5.708333 and longitude: −1.658333) (Figure 1). The dominant vegetations are thickets consisting of an impenetrable mass of shrubs, climbers, coppice shoots and young trees and soft-stemmed leafy herbs, e.g. Ageratum conyzoid, Bambusa vulgaris that appear in abandoned farms and cultivated lands grown to cocoa, maize, plantain, cassava and rice. The topography generally shows a gentle slope that varies from 1% - 10% whilst the elevation ranges from 40 - 70 m above sea level (asl). Minimum plateaued summits were between 87.18 - 91.77 m with the highest summits ranging from 118.40 - 123.56 m (Figure 2). A few seasonal streams border the study site and tend to flood during the rainy seasons. The temperature and rainfall pattern across the study area is shown in (Figure 2). The geology of the area is generally undulating with gently rolling, steeped slope topography in few places, including a Cape Coast granite and Wamaso albitized rock type (Gyamera, 2014) [17].

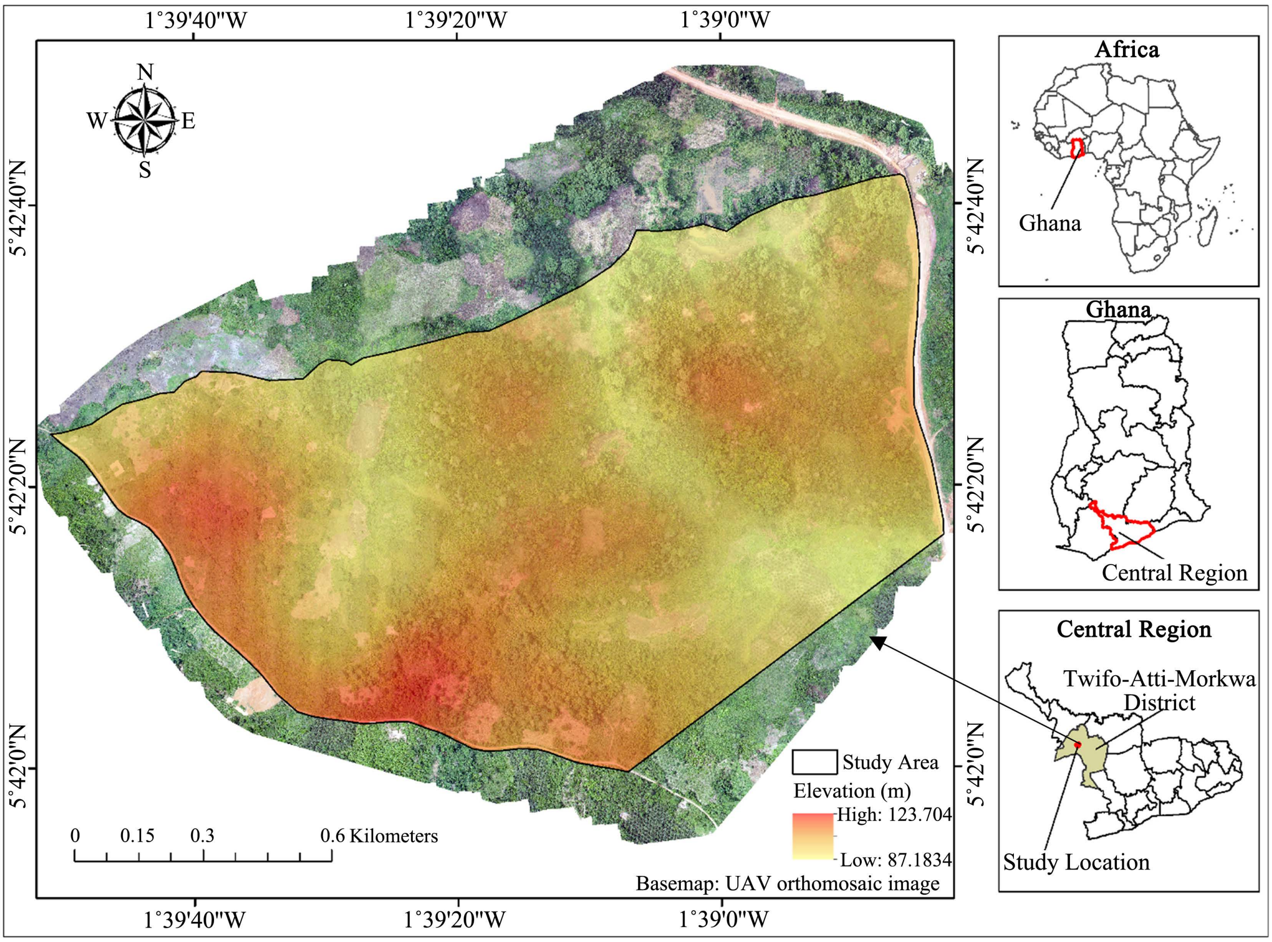

Figure 1. Study area.

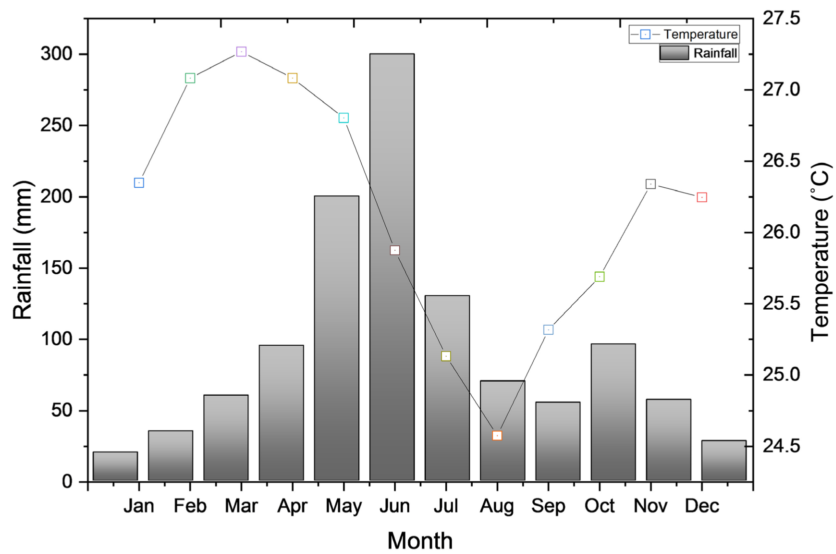

Figure 2. Slope elevation (left) and rainfall/temperature pattern of study area (right).

2.2. Field Work and Soil Sampling

Five profiles designated as PP1, PP2, PP3, PP4 and PP5 were dug at the study site representing the summit, shoulder, middle, foot slope and toe slopes, respectively. Each profile was dug to a maximum of about ±135 cm except where there was an impenetrable resistance (obstruction). The soil profiles of all the sampling slopes and aspects were described in situ following the guidelines for soil profile description (WRB, 2015) [16] and samples were collected from all identified horizons. Freshly excavated sites were used for sampling and profile description. A core sampler was used to collect undisturbed soil samples from each horizon to determine bulk density. **Figure 3** shows a cross-sectional illustration of the toposequence.

2.3. Laboratory Analysis

A total of 18 soil samples along respective soil profile pits were collected from the study site for laboratory analysis. The samples of soil collected were spread for air-drying, crushed using a mortar and pestle, and later sieved with a 2 mm-sieve (Sigma Aldrich). The soil samples were later analyzed for some physical and chemical properties following the procedures outlined below.

2.3.1. Exchangeable Cations and Micronutrients

Exchangeable cations were extracted using ammonium acetate solution. 5 g of soil sample was weighed into 100 ml extracting bottle and 20 ml of IM ammonium acetate solution was added, stirred and allowed to stand overnight. The suspension was then filtered into a 100 ml volumetric flask. The leaching process was continued with successive 20 ml volumes of ammonium acetate allowing the funnel to drain between each addition. The process was continued till nearly 100 ml of filtrate was collected. The filtrate was made up to 100 ml with ammonium acetate solution. Aliquots of the extract were used for the determination of Ca^{2+},

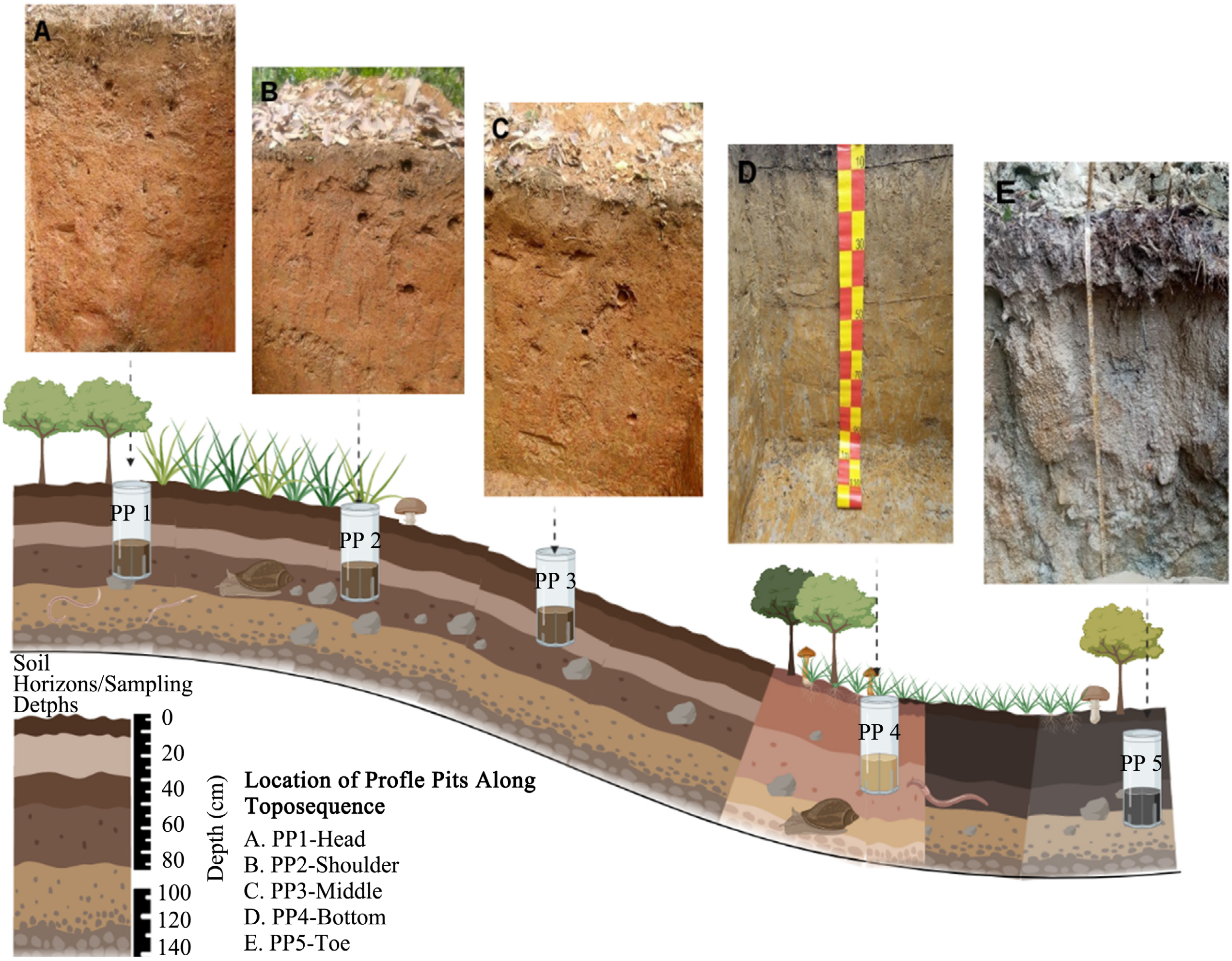

Figure 3. Cross-sectional view of toposquence and profile pits location.

Mg^{2+}, K^+ and Na^+ (Rowell, 1994). Concentrations of K and Na in the extract were determined by flame photometry. Using the concentration of exchangeable cations, the Ca/Mg ratio as a measure of soil balancing was calculated (Schulte & Kelling, 1993) [18].

2.3.2. Soil Organic Carbon

Total soil organic carbon (TSOC) concentration was determined by modified Walkley-Black wet digestion (Janitzky, 1986) [19]. The procedure involved the oxidation of oxidizeable organic carbon using 0.17 M $K_2Cr_2O_7$ and concentrated H_2SO_4. The digestate was then placed in a spectrophotometer with an adjustable wavelength for organic carbon.

2.3.3. Available Phosphorus

1 g of soil sample was weighed into a 15 ml centrifuge tube and 10 ml of Bray No. 1 extracting solution was added. The suspension was agitated for 15 minutes on a mechanical shaker. The suspension was filtered and 2 ml aliquot of the filtrate was pipetted for color development using ascorbic acid.

2.3.4. Micronutrients

The micronutrients were extracted using 1 diethylene triamine penta-acetic acid (DTPA). 10 g of soil sample was placed in polypropylene bottle and 20 ml of DTPA extracting solution was added. The bottle was stoppered and shaken for 2 hours. The contents were then filtered. The extract obtained was used for the estimation of different micronutrients using the Atomic Absorption Spectrophotometer (Shimadzu AA7000).

2.3.5. Total Nitrogen

A weight of between 0.5 and 1.0 g of soil sample was weighed into a digestion flask and 0.2 g of catalyst and 3 ml of concentrated H_2SO_4 were added. The contents were digested on a bloc digester at 380˚C for 2 hours. After the digestion, the digest was allowed to cool and then diluted to 50 ml with distilled water. Then an aliquot of 20 ml was pipetted into the reaction chamber of a steam distillation apparatus. 10 ml of alkali mixture was added and distillation commenced. About 40 ml of distillate was collected in a boric acid indicator. The distillate was titrated against 1/140 HCl from green to wine color. Blank determination was carried out alongside.

$$\%\text{N} = \frac{(\text{S} - \text{B}) \times \text{Solution volume}}{10^2 \times \text{aliquot} \times \text{sample weight}} \quad (1)$$

2.3.6. Electrical Conductivity

40 g of soil was placed in 250 ml plastic bottle and 80 ml of distilled water was added, stoppered and shaken on a reciprocating shaker for 1 hour. The suspension was then filtered through 0.45 µm whatman No. 1 filter paper. The conductivity meter was calibrated and the Electrical Conductivity of the filtrates was determined (Hanna H198308).

2.3.7. Particle Size

Soil particle size analysis was carried out using the pipette method as described by (Rowell, 1994) [20]. An amount of soil (10 g + 0.01) was weighed into a 500 ml beaker. 20 ml of hydrogen peroxide was added and allowed to stand until frothing ceased. The suspension was then heated to complete the destruction of organic matter and then allowed to cool. The peroxide-treated soil was quantitatively transferred into a 500 ml plastic bottle and 10 ml of the dispersing agent was added and the soil suspension was made up to 200 ml and shaken overnight. The contents were then transferred quantitatively into a 500 ml measuring cylinder and made up to 500 ml with distilled water.

The suspension was further stirred using a plunger for thorough mixing and allowed to settle for 40 secs after which 25 m was drawn off from 10 cm below the surface into a weighed beaker to obtain the mass of silt. The suspension was allowed to settle and 25 ml of the suspensions were drawn off at 10 cm depth after 5 hrs. This gives the mass of clay. The pipetted suspensions were dried at 105˚C till constant weight. Most of the supernatant liquid was gently poured off and the sediment was quantitatively transferred into a beaker. The sediment was repeatedly washed through stirring, settling and decanting till a clear supernatant was obtained. The sand was transferred to a weighed beaker and dried at 105˚C till constant weight.

$$\text{Sand}\left(\text{m/m}\right)\left(\%\right)=\frac{\text{mass of sand}}{\text{mass of oven dry soil}}\times 100 \quad (2)$$

3. Results and Discussion

3.1. Physical Properties

The physical properties of the soils are presented in (**Table 1**). Particle size distribution of the entire soil was dominated by sand, followed by clay and then silt. Sand content in the surface soils ranged between 79.08% in the toe slope and 62.23% in the middle soils. In the subsurface soils, sand content varied between 79.29% in the toe slope and 57.99% in the summit soils.

Clay content regularly increased with soil depth along the landscape positions, giving rise to clay bulges in the toe slope. The increasing value of clay with a corresponding decrease in sand content as soil depth increases is occasioned by

Table 1. Soil physical properties along toposequence.

Profile Pit (PP)	Soil Layer	Depth (cm)	Bulk Density	Soil Fraction (%)			Textural Class
				Sand	Silt	Clay	
Summit	OA	0 - 10	1.36	73.71	6.8	19.5	Sandy loam
	AB	10 - 40	1.28	57.99	6.12	35.89	Sandy loam
	Btcs	40 - 60	1.43	34.27	8.89	56.84	Clay
	Btg	60 - 135	1.5	28.61	16.25	55.14	Clay
Shoulder	Ap	0 - 18	1.13	74.5	6.51	18.99	Sandy loam
	AB	18 - 25	1.52	58.35	7.79	33.86	Sandy clay loam
	Btc1	52 - 75	1.64	41.8	6.88	51.32	Clay
	Btc2	75 - 137	1.5	35.15	9.48	55.37	Clay
Middle	OA	0 - 17	1.14	62.23	8.98	28.79	Sandy clay loam
	A/B	17 - 52	1.22	56.17	8.37	35.46	Sandy clay
	Btv	52 - 125	1.82	39.28	17.12	43.6	Clay
Foot slope	Ap	0 - 23	1.30	70.27	7.8	21.93	Sandy clay loam
	Btg1	23 - 44	1.25	67.4	7.77	24.83	Sandy clay loam
	Btg2	44 - 66	1.52	63.2	7.03	29.78	Sandy clay loam
	Btg3	66+	1.68	58.22	6.96	34.82	Sandy clay loam
Toe slope	Oe	0 - 19	1.3	79.08	5.51	15.41	Sandy loam
	A	19 - 78	1.55	79.29	7.85	12.86	Sandy loam
	Bw	78 - 96	1.62	72.79	9.57	17.64	Sandy loam

eluviation-illuviation, an indication of greater intensity of weathering. High clay content is likely to increase the soil's capacity to adsorb cations. This gives an indication that clay and silt are more easily eroded and leached down the slope than sand. This is in line with (Malgwi & Abu, 2011) [21], 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 to clay ratio increased with depth in the summit, shoulder, middle and toe slope. This trend was not so for the foot slope pedon. Bulk density values ranged between 1.01 on the foot slope and 1.30 g/cm^3 on the toe slope with a mean of 1.15 g/cm^3 in the surface soils while values in the subsurface soils had a range of 1.04 - 1.83 g/cm^3.

3.2. Morphological Properties

Table 2 shows morphological features of various soils at the study site. Surface soil color (moist) ranged from reddish brown (5YR 3/3) to 5GY 2.5/1 greenish black. Soil color varied between dark reddish brown in the summit and shoulder and middle slope to dark grayish brown in the foot slope and greenish black in toe slope positions with a dominant hue of 5 and 10 in the surface soils while the subsurface soils varied between yellowish red and red to strong brownish yellow. Similarity, reddish and yellowish subsurface colors indicate the presence of hematite and goethite as forms of Fe oxides, hence ferrugination. The results showed that surface soil color is highly influenced by soil OM, where the darkness in the A-horizon decreased with depth. Dark-colored surface horizons (values ≤ 3) are often enriched with OM, offering many benefits to the soil. Soils on slopes that are unsaturated with water usually have reddish and brownish subsoil colors, which are indicatives of well drained and aerated conditions. The reddish color is due to the presence of iron compounds in various states of oxidation and hydration (H. D. Foth & Ellis, 2018) [22]. Soil textural class ranged between sandy loam within the summit, shoulder, foot and toe slope surface soils and sandy clay loam in the middle landscape position while sandy clay loam and clay textures dominated the subsurface soils of the summit through to the foot landscape positions with the toe slope position being dominated by clay. The textural class trend 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 structures ranged between weak fine and very fine granular structures in the surface soils while moderate and strong, medium and coarse, angular and sub angular blocky structures were obtained in the subsurface soils. Non-sticky, non-plastic 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. These exhibits of firmness, moderate to strong subangular and blocky structures down the various pedons could be attributed to the increase in clay content with depth.

Plants' roots were very few in the subsurface soils as compared with the surface soils and this was observed for all dug pedons. In some cases there was no

Table 2. Morphological Characteristics of Toposequence.

Horizon		Depth	Munsell	Texture	Structure	Consistency	Boundary	Root	Miscellaneous
				GPS: **N**: 05.11044 | **W**: 001.29568					
Summit	OA	0 - 10	5YR 3/3	Sandy loam	wfg	ns. Fr	CS	Fmr	few ants casts, worms
	AB	10 - 40	5YR 4/5	Sandy loam	wsablk	ns. Np	CD	vfr and mr	Common Fe and Mg_2O
	Btg	40 - 60	5YR 5/6	Clay	msablky	ss. np	GS	vfr. Mr	Common Fe and Mg_2O
	Btsc	60 - 135	2.5YR 3/8	Clay	msablky	ss. Sp	CD	vfmr	
				GPS: **N**: 05.70709 | **W**: 001.64699					
Shoulder	Ap	0 - 18	5YR 3/3	Sandy loam	wfg	qs. Fr	CS	fmr	Borrows of ants
	AB	18 - 52	2.5YR 4/6	Sandy clay loam	wsablk	qs	CD	vffr	few ants cast
	Btc1	52 - 75	10R 4/8	Clay	blky	s and p	CS	-	few gravels
	Btc2	75 - 120	5YR 5/8	Clay	sblky	vm, p and s	CS	-	
				GPS: **N**: 05.70729 | **W**: 001.64725					
Middle	OA	0 - 17	5YR 3/4	Sandy clay loam	wgs	ns	CS	ffr	ants, earthworms
	A/B	17 - 52	5YR 5/6	Sandy clay	gs	ss, sp	GC	vffr	Few quartz gravels
	Btv	52 - 125	5YR 5/8	Clay	sblky	vm	WC	-	10R 4/8 mottling
				GPS: **N**: 05.70729 | **W**: 001.64725					
Foot Slope	Ap	0 - 23	10YR 3/3	Sandy loam	vfg	ns, np	CS	ffr, fcr	few ants cast
	Btg1	23 - 44	10YR 5/8	Sandy clay loam	wsablk	ss, np	CS	ffr	10YR 4/6 mottling
	Btg2	44 - 66	10YR 6/8	Sandy clay loam	wsablk	ss, np	CS	ffr	
	Btg3	66+	2.5Y 6/8	Sandy clay loam	sablk	s	WC		
				GPS: **N**: 05.70766 | **W**: 001.64745					
Toe Slope	Oe	0 - 19	5GY 2.5/1	Sandy loam	wgs	ns	CS	ffr	-
	A	19 - 78	N5/5	Sandy loam	sblk	s	CS	ffr	-
	Bw	78+	5GY 5/2	Sandy loam	sblk	se	CS	-	-

Key: **Wfg**: weak fine granular; **wsablk**: weak sub angular structure; **blk**: blocky; **sblky**: strong blocky; **vfg**; very fine granular; **gs:** granular structure; **wgs**: weak granular structure; **ns**: non sticky; **fr**: friable; **np**: non plastic; **ss**: slightly sticky; **sp**: slightly plastic; **qs**: quite sticky; **p**: plastic; **vm**: very massive; **CS**: clear smooth; **CD**: clear Diffuse; **GS**: gradual smooth; **WC**: wavy clear; **GC**: gradual clear; **vffr**: very few fine roots; **ffr**: few fine roots; **fmr**: few medium roots; **vfr**: very fine roots; **mr**: medium roots.

trace of roots within the C horizon most specifically in the toe slope position. This is traced to the relatively high bulk density which may have restricted root growth. The presence of ants cast and earthworms 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.

3.3. Physicochemical Properties

Table 3 shows soil physicochemical properties. The surface soils Cation exchange capacity ranged between 3.26 and 4.11 cmol/kg while values in the subsurface soil ranged between 1.30 and 3.4 cmol/kg with the toe slope surface soil recording comparatively the highest value. CEC decreased with increasing depth across all landscape positions. Surface soil values of CEC were moderately high while subsurface values were low. According to (Aprile & Lorandi, 2012) [23], tropical soils, especially sand and low pH soils have very low CEC. Minerals such as oxides of aluminum, iron and manganese that are very abundant in tropical soils also contribute to the low CEC. Cation EC was strongly and positively correlated with Ca^{2+}, Mg^{2+}, Zn^{2+}, OC and available Phosphorus poorly and negatively correlated with exchangeable acidity and clay. CEC decreased in value with depth whereas clay content increased with value with depth. This trend indicates that humus rather than colloidal clay has provided exchange sites for the

Table 3. Physicochemical properties along pedons.

Horizon	Layer	pH	Exchangeable Complex													
			Ca (cmol/kg)	Mg (cmol/kg)	Na (cmol/kg)	K (cmol/kg)	Ex. Acidity (cmol/kg)	TCEC (cmol/kg)	% OC	% N	Av. P (µg/g)	Fe (µg/g)	Cu (µg/g)	Zn (µg/g)	EC
Summit	OA	4.8	2.31	0.72	0.06	0.16	0.005	3.25	1.14	0.11	0.77	18.84	0.25	0.35	84.34
	AB	4.77	0.78	0.31	0.07	0.12	0.006	1.30	0.68	0.06	0.10	9.20	0.10	0.25	0.415
	Btcs	4.75	1.19	0.32	0.07	0.06	0.013	1.66	0.59	0.10	0.07	3.93	0.30	0.25	0.16
	Btg	4.93	1.34	0.63	0.07	0.12	0.004	2.17	0.34	0.04	0.10	3.88	0.20	0.15	0.16
Shoulder	Ap	5.12	2.33	0.78	0.06	0.10	0.001	3.26	0.63	1.05	0.07	14.69	1.15	0.85	86.65
	AB	4.94	1.20	0.56	0.06	0.09	0.009	1.91	0.10	0.54	0.06	9.12	0.35	0.20	0.29
	Btc1	5.02	1.27	0.40	0.06	0.03	0.009	1.77	0.10	0.54	0.07	7.88	0.20	0.45	22.61
	Btc2	5.06	1.40	0.23	0.07	0.03	0.007	1.74	0.07	0.28	0.04	6.09	0.20	0.30	17.355
Middle	OA	4.83	1.94	1.32	0.21	0.06	0.003	3.53	1.59	0.18	0.87	22.83	1.35	0.95	10.7
	A/B	4.91	1.17	0.31	0.07	0.06	0.008	1.62	0.65	0.08	0.10	11.61	0.80	0.30	30.865
	Btv	5.07	1.11	0.40	0.02	0.06	0.006	1.59	0.47	0.06	0.13	8.12	0.25	0.25	15.135
Foot Slope	Ap	4.97	2.99	0.94	0.09	0.06	0.002	4.08	1.67	0.09	0.98	79.75	30.64	1.14	1.19
	Btg1	4.99	1.26	0.32	0.05	0.07	0.007	1.71	0.49	0.14	0.10	35.455	16.26	1.14	0.30
	Btg2	4.99	1.10	0.47	0.06	0.07	0.005	1.72	0.36	0.04	0.03	36.285	13.78	0.74	0.10
	Btg3	5.14	0.79	0.71	0.04	0.19	0.008	1.75	0.29	0.04	0.07	40.285	14.66	1.24	0.30
Toe Slope	Oe	5.09	2.51	1.26	0.14	0.20	0.002	4.11	1.83	0.16	0.67	161.26	1.34	1.88	105.1
	Ag	5.865	1.39	0.31	0.03	0.23	0.001	1.95	0.14	0.02	0.55	17.89	1.54	0.25	46.595
	Cr	5.89	1.09	1.95	0.04	0.16	0.001	3.24	0.07	0.02	0.39	14.93	1.04	0.25	31.85

Av. P = Available Phosphorus; TN = Total Nitrogen; CEC = Cation Exchange Capacity; BD = Bulk Density; EC = Electrical Conductivity; EA = Exchangeable Acidity; OC = Organic Carbon; Ca = Calcium; Mg = Magnesium; Na = Sodium; K = Potassium, Fe = Iron, Cu = Copper; Zn = Zinc.

exchangeable cations. The concentrations of the basic cations in the surface soils were in the of $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$. The surface soils recorded higher Ca^{2+} values with the foot slope surface soil having the highest and this might be due to its strong absorption to soil colloids as compared to other cations because of its higher charge and its small hydrated radius (H. Foth, 1990) [24]. The order of abundance of the Ca ions however decreased with depth in all the topographic positions. Mg^{2+}, K and Na^{+} values also followed the same trend as Ca^{2+}.

Soil pH ranged between 4.8 - 5.89 which is acidic to moderately acidic according to (Staff, 2014) [25]. The organic carbon and nitrogen contents decreased with depth in all five pedons. Generally, the organic carbon content was relatively higher in the surface soil of the depression pedon than in the other ones. The highest organic carbon value was 1.83% and this might be attributed to the accumulation of materials from the summit through to the toe slope region. The total nitrogen along the toposequence also followed the same trend as the percentage of organic carbon. The differences in organic carbon and nitrogen content among the pedons could be attributed to variation in the land use systems along the toposequence. Organic carbon was positively correlated with total nitrogen and available phosphorus.

Available phosphorus of the surface soils was higher than the subsurface soils. The highest value was recorded on the foot slope, followed by that on the middle slope. The surface soil of the pedon dug at the shoulder recorded the lowest value (0.07). Available P also decreased with depth. Available P had experienced inconsistencies along the slope. However, there was an increase from the PP2 (shoulder) through to the foot slope pedon and this can be attributed to the fact that the relationship of slope position to soil properties is to a great extent controlled by erosion processes that alter the distribution of soil particles and water redistribution over a field. The relatively higher available P values recorded for the surface soils compared to the subsurface soils could also be linked to differences in the organic matter content of the layers. Available P was positively correlated with organic carbon (0.76). High organic matter content and a good rate of its mineralization could ensure the release of phosphate ions adequate for crop production, so most of the phosphate ions released this way will be in the surface soils. If not immediately taken by plants or soil organisms it will be converted to non-liable forms (Ahn & Motomatsu, 1993) [26].

Organic carbon decreased down the slope with surface soils recording in all five slope positions the higher percentages. It however increased from the summit surface soils through to the toe slope surface soils and this might be due to the partial accumulation of materials from the summit soils through to the toe slope soils. The results were consistent with the observation by (Peternella & da Costa, 2021) [27].

The micronutrients decreased with increasing depth in all five pedons with the order $Fe^{3+} > Cu^{2+} > Zn^{2+}$. The concentrations of Fe^{3+} and Zn^{2+} were relatively very sufficient. Fe consistently decreased down each profile with Cu^{2+} and Zn^{2+}

experiencing some inconsistencies in their distribution with increasing depth. There was a strong positive correlation between Fe^{3+} – OC and Zn^{2+} and OC. This is so because soil organic matter, according to (Boguta & Sokołowska, 2016) [28] plays a complex role in Zn^{2+} partitioning in soils. Whereas solid organic matter decreases Zn^{2+} solubility by sorbing Zn^{2+} onto surface functional groups the complexation of Zn^{2+} with dissolved organic compounds increases Zn^{2+} solubility and mobility (Houben & Sonnet, 2012 [29]; Wang & Huang, 2020 [30]). Soil organic matter turnover is an additional process that can affect Zn^{3+} solubility as Zn^{3+} released during litter decomposition may be leached into the soil or become sorbed by the organic matter of the soil surface (Scheid, Günthardt-Goerg, Schulin, & Nowack, 2009) [31]. The higher the organic carbon percentage signifies litter decomposition and therefore the release of Zn^{2+} in the soils; therefore an increase in soil organic matter propels a further increase in Zn^{2+} and hence their positive correlation. Moreover, with organic matter transformation, metallic elements such as Zn^{2+} are progressively incorporated and retained into organo mineral associations. Fe^{3+}, on the other hand, is the most abundant transition metal on the Earth's surface, and of which its biogeochemical cycle is closely related to the dynamics of soil organic matter. Moreover, up to 21.5% of the global OC is associated with reactive forms of Fe^{3+} in soils and sediments (Lalonde *et al.*, 2012) and this could account for the higher values obtained for Fe^{3+} in the surface soils.

Pearson's correlation analysis at ($p > 0.05$) is shown in (**Table 4**). It was observed a significant positive correlation between most of the cations. Example between Na^+ and Ca^{2+} at ($R^2 = 0.516$), Mg^{2+} and Ca^{2+} at ($R^2 = 0.307$). However, most of these cations show a negative correlation with other critical parameters such as pH vs. Ca^{2+} at ($R^2 = -0.114$). Correlation between the physical properties (% soil, % clay and % silt) were variable across other parameters e.g., clay showed a significant negative correlation with most of the cations. A similar trend of association was detected for silt but for sand, the association was more positive. The results indicate that soil properties were highly distributive across the study area and contributed by multiple sources.

3.4. Classification of Soils

A classification of the various soil types are shown in **Table 5**. The soil profiles with the exception of the two at the depression zone had shallow surface horizons (10 - 18 cm) and had the moist color of 5YR 3/3-4 dark and very weak structure. The organic carbon content of the surface horizons of the pedons ranged from 0.63% - 1.59%. Thus, the surface horizons of all three pedons (Summit, upper and middle) possessed ochric epipedon.

The surface soils of all five pedons in **Table 5** were horizons that had relatively little development. They often had light-colored, narrow (10–23 cm), and poorly constructed profiles. The surface horizons of the pedons included 0.63 to 1.59 percent organic carbon. As a result, all five pedons had ochric epipedon on their surface horizons (Summit, upper, and middle).

Table 4. Correlation between soil physicochemical properties.

	pH	Ca	Mg	Na	K	Fe	Cu	Zn	Av. P	OC	TN	Sand	Silt	Clay	EA	CEC	EC	BD
pH	1																	
Ca	−0.11474	1																
Mg	0.38386	0.37051	1															
Na	−0.39242	0.56181*	0.17615	1														
K	0.39624	0.16152	0.51107*	−0.047	1													
Fe	0.16628	0.66871*	0.46714	0.08224	0.41214	1												
Cu	0.49364*	0.35287	0.46116	−0.02826	0.60971*	0.70457*	1											
Zn	−0.06142	0.79066*	0.48519*	0.76689*	0.30167	0.55342*	0.50769*	1										
Av. P	0.1251	0.87302*	0.56571*	0.28613	0.48791*	0.826*	0.53506*	0.70304*	1									
OC	−0.41874	0.83837*	0.35893	0.71183*	0.20839	0.60083*	0.29738	0.87037*	0.76216*	1								
TN	−0.50076*	0.51077*	0.20942	0.51066*	0.16728	0.38339	0.2592	0.62441*	0.46518	0.78492*	1							
Sand	0.40665	0.46492	0.45907	0.03569	0.58896*	0.75896*	0.7255*	0.46338	0.64113*	0.38754	0.22716	1						
Silt	0.02302	−0.23542	−0.06684	−0.13453	−0.27729	−0.38986	−0.35275	−0.32956	−0.25042	−0.31535	−0.24594	−0.62159*	1					
Clay	−0.46048	−0.46978*	−0.49972*	−0.01089	−0.59967*	−0.76571*	−0.73632*	−0.44776	−0.6639*	−0.36585	−0.20124	−0.98555*	0.4799*	1				
EA	−0.53759*	−0.52906*	−0.59172*	−0.10302	−0.51877*	−0.59942*	−0.57963*	−0.47964*	−0.69042*	−0.31165	0.01263	−0.6425*	0.01745	0.71582*	1			
CEC	0.12324	0.87281*	0.77311*	0.48541*	0.42431	0.70425*	0.50034*	0.80467*	0.89773*	0.76828*	0.46925*	0.57383*	−0.21464	−0.59627*	−0.67666*	1		
EC	0.17579	0.76702	0.33425	0.4045	0.30213	0.62776*	0.52704*	0.68588*	0.67145*	0.57241*	0.27852	0.72309*	−0.45945	−0.71045*	−0.56206*	0.70552*	1	
BD	0.41799	−0.38494	−0.07161	−0.20037	−0.25676	−0.55539*	−0.33056	−0.34291	−0.3882	−0.53703*	−0.38248	−0.44774	0.59178*	0.37345	0.16333	−0.31922	−0.40051	1

*Significant correlation at $P \leq 0.05$; †Av. P = Available Phosphorus; TN = Total Nitrogen; CEC = Cation Exchange Capacity; BD = Bulk Density; EC = Electrical Conductivity; EA = Exchangeable Acidity; OC = Organic Carbon; Ca = Calcium; Mg = Magnesium; Na = Sodium; K = Potassium, Fe = Iron, Cu = Copper; Zn = Zinc.

Table 5. Soil classification along the study area.

Pedon	Order	Suborder	Great Group	Subgroup	Major	Unit
Pit 1	Ultisol	Ustults	Haplustults	Typic Haplustults	Lixisol	Ferric Lixisol
Pit 2	Ultisol	Ustults	Rhodustults	Typic Rhodustults	Lixisol	Chromic Lixisol
Pit 3	Ultisol	Ustults	Plinthustults	Typic Plinthustults	Lixisol	Plinthic Lixisol
Pit 4	Ultisol	Aquult	Epiaquult	Typic Epiaquult	Fluvisol	Endogleyic Fluvisol
Pit 5	Entisol	Aquent	Endoaquent	Aquic Endoaquent	Regosol	Gleyic Regosol

Except for PP4 and PP5, all exhibited thick strata (120+) with subsurface clay contents ranging from 24.83 to 56.84 percent. It was discovered that the clay content of the first three pedons' underground horizons was higher than that of their ensuing surface layers. Clay increments were found within 20 cm of one another in the subsurface strata, which had 15% more clay than the horizon above, which had between 30% and 57 percent clay. The apparent cation exchange capacities of the horizons were in the range of 1.62 to 2.17 cmol/kg. Argillians, which are faint and noticeable pedfaces, were also seen in the horizons.

These traits would classify the horizons of the four pedons as argillic subsurface diagnostic horizons, as shown by (Buol, 2003) [32]. These traits led to the four pedons being categorized as Ultisols. Although there were no signs of significant clay accumulation in the toe pedon's subsurface layers, there was proof of color change with stagnic and gleyic qualities in the foot slope pedon. The amount of clay in the horizons in the overlying horizons were not noticeably higher. The toe slope pedon, however, was classified as an entisol since it lacked a possible diagnostic horizon (gleyic).

The region is characterized by isothermic temperature and ustic moisture regimes, according to estimates made using the region's mean annual and monthly temperature and moisture distributions. (Sempéré, 2003).

The suborder level soil moisture regime was used to classify PP1, PP2, and PP3 as Ustults. Furthermore, Pit 1 was further classified as Haplustults at the great group level and a Typic haplustults at the subgroup level under USDA Soil Taxanomy, which correlates with a lixisol (ferric lixisol) at the WRB classification system, in the absence of any clay drop of 20 percent or more from the maximum clay concentration, and in the absence of any other diagnostic properties. Pit 2: Rhodustults (according to the WRB classification system, Typic Rhodustults at considerable groups transgress into a chromic lixisol due to the existence of a dark surface layer, a reddish argillic horizon of 2.5YR within 100 cm, and these features together).

Pit 3-Plinthustults (as a result of the plinthic material that was found in the argillic horizon, followed by a Typic Plinthusults at the subgroup level and a plinthic lixisol at the unit level. However, due to the indication of a water table, which includes the existence of redoximorphic traits, Pit 4 was identified at the sub-order level as an aquult (gray and red color pattern). Epiaquult was added to the grouping at the subgroup level, while endogleyic fluvisol was added at the unit level.

As a result of the saturation of water close to the surface for extended periods of time without oxygen, PP5 had poorly developed horizons and was therefore categorized as Entisol at the order level and Aquent at the subgroup level. Grayish, bluish, and redoximorphic colors and features are other characteristics of aquents. Because of end osaturation, aquics are classified as end oaquents at the subgroup level, which correlates to a gleyic regosol at the unit level. The distinction between Ultisols and Entisols in terms of soil categorization amply illustrates how topography affects soil development.

4. Conclusion

This study, for the first time, classified and characterized soils along a catena with inference from Soil Survey Staff and WRB for soil resources. The differences in soils encountered along the catena could be said to have resulted from erosion, translocation, leaching and deposition of chemicals or soil particles. These differences at the various topographic positions depict the fact that indeed topography plays a role in the formation of soil. Many relevant soil quality indicators such as bulk densing, % carbon, nitrogen, potassium, phosphorus and so on were influenced by different landscape positions, particularly at the surface levels. This information is needed for proper management and soil amendment practices amidst continuous cropping or usage of the land. Further study of the area is recommended, especially soil landscape microbial type and population so as to give a sound recommendation of biological amendment practices like compost application.

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Conflicts of Interest

There are no conflicts to declare.

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