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Mineralogy and physicochemical properties of soils at topounits along toposequence of shale derived soil in a tropical rainforest zone, Nigeria

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ABSTRACT

Sustainable crop production requires a correct understanding of the characteristics of soils on a landscape, which helps to curb the incidence of wrong generalization in soil use and management practices. This study was carried out to assess the mineral composition and physicochemical properties of soils at different positions along the toposequence of a shale-derived soil at Amaeke, Abia State. The experiment was laid out in a Randomised Complete Block Design involving topounit as treatment and of five (5) levels (crest, upper slope, middle slope, lower slope and valley bottom) with three (3) replicates each of disturbed and undisturbed soil samples randomly collected from each topounit to give a total of fifteen (15) observational units. The soil samples were processed and analzsed in a laboratory. Data obtained were subjected to analysis of variance using Genstat analytical software, while significant means were separated using Fisher's Least Significant Difference at a 5% probability level. The results showed that the topounits had similar mineral composition and rating except the crest which in addition to other common minerals, contained hematite and goethite. The crest was highest in bulk density (1.71 mg / m3), clay flocculation index (79.94%), and mean weight diameter (6.11 mm), but lowest in sand content (41.61%), and the upper slope was highest in available water capacity (30.31%). The valley bottom was highest in available phosphorus (30.02 mg/kg), organic carbon (1.32%), total exchangeable bases (16.68 cmol / kg) and extractible iron (0.42 mg/kg), at the same time, the middle slope was highest in exchangeable potassium (0.29 cmol / kg). The topounits varied in the physicochemical properties in such a way that soil structural stability indices and chemical properties decreased and increased, respectively, along the descending part of the slope.

Keywords: Topounits, toposequence, bulk density, organic carbon, crest, valley bottom

1. INTRODUCTION

The quality and suitability of soil for crop production largely depends on its mineralogical composition, which in turn influences its physical and chemical properties (Brady and Weil, 1999). Soil properties vary across the landscape, which may be a result of the influence of soil forming factors which includes topography (Brady and Weil, 1999). Therefore, variation in soil properties along a slope is inherent in soil, which refers to toposequence (Brady and Weil, 1999). The report of Amanze et al., (2024) showed that every soil on a landscape is unique in physical, chemical and biological characteristics. Hall, (1983) noted that soils along a toposequence possess varying attributes due to the effects of erosion, transportation, and deposition of soil particles.

Therefore, topography is an essential factor in soil formation, which significantly influences the pattern of soil distribution over the landscape (Akamigbo and Asadu, 2001). Recognition of the spatial variability of soil quality along a landscape provides essential information for the rational use of agricultural inputs and effective soil utilization and management decisions (Amanze et al., 2023). Reports have shown that a slope can be delineated into different positions, also known as topounits, which depend on the geometry, steepness, and length of the slope, and such topounits include: Crest, upper slope, middle slope, lower slope, valley bottom or bottom slope (Akamigbo and Asadu, 2001). Hall, (1983) reported that the topounits vary in mineral composition, chemical, and physical properties.

According to the crest and upper slope are known for shallow depth resulting from erosional processes; this corroborates Akamigbo and Asadu, (2001), that there is a gradual progressive increase in depth of soil from the crest to the valley bottom of a given toposequence. Akamigbo and Asadu, (2001) observed a change in soil texture along a slope in a pattern of progressive increase in clay content from crest to the valley bottom. Also, Akamigbo and Asadu, (2001) reported an irregular pattern of sand and silt distribution in some soils along a topography, and suggested that it may be due to the lithology or anthropogenic influences. Soil conditions tend to vary with topography, which is due to the orientation of the hilly surfaces on which soils form, which significantly affect the microclimate and the adjacent vegetation distribution, whch eventually results in the variation of soil properties (Sanchez, 1976).

Furthermore, Miller et al., (1988) showed that topounits vary significantly in soil depth, organic matter (OM) content of the surface soil horizon, water retention capacity, chemical, and mineral composition of soils. Soils formed on the upper slope have low pH, less clay content, reduced concentration of basic cations, and OM contents as well as lighter in color, and well drained than the soils at lower slopes (Gupta, 2004). Stated that the lower slope positions have higher soil OM content and thickness at the top soil. According to topography has a strong influence on soil chemical properties, and they explained that carbon stocks along a toposequence are associated with landscape position, clay content, and particle density.

Generally, differences in inherent soil characteristics such as mineralogy, texture, structure, OM content, water retention capacity, and overall fertility status at different slope positions (topounits) determine the ability of a soil to provide a suitable plant growth medium. Hence, for successful crop production, it is of primary importance to understand the inherent differences in soil fertility and productivity at different slope positions before making any decision related to management practices (Amanze et al., 2023). Therefore, it has been established that topography influences local microclimates by changing the pattern of precipitation, temperature and relative humidity Yimer et al., (2006) and these effects result in significant variation in some soil parameters including mineral composition. Consequently, this study aimed at investigating the effect of slope position on mineralogical composition and physicochemical properties of soil.

2. MATERIALS AND METHODS

Description of Study Area

The study was conducted along a toposequence on shale parent material at Amaeke Ibeku in Umuahia North Local Government Area of Abia State, South-Eastern Nigeria. The place is located on latitude 5o 32′ N and longitude 70 33′ E in the rainforest area of the South-Eastern Agro-climatic zone of Nigeria. The area has a mean annual precipitation of 2000 mm, relatively uniform mean daily temperature of 270 C all through the year, and a range of relative humidity from 51 to 87% (Amanze et al., 2023). The geology of the area is basement complex, which comprises of sand stones and shale (Lekwa and Whiteside, 1986). The area is used for agricultural activities, which involves the cultivation of arable crops such as cassava, maize, yam, vegetables, etc. The uncultivated plant species found at the area include: Raffia palm trees, oil palm trees, bamboo, etc.

Soil sampling and sample preparation

We carried out the field study by delineating the sloppy landmass into the five topounits. We randomly collected three core and auger samples from the epipedon of each topounit. The core soil samples were soaked in water at return from the field while the auger soil samples were air-dried at room temperature, crushed and sieved through a 2mm sieve and, packed into well- labeled soil bags and sent for laboratory analyses.

Laboratory analysis

The soil samples were analyzed for physical and chemical properties of soil as follows; Particle size distribution was determined using the hydrometer method as explained in Gee and Or, (2002), and reported in Amanze et al., (2022), while micro aggregate stability indices were determined using the amount of silt and clay in calgon-dispersed as well as water–dispersed samples during particle size analysis as described by. Afterward, we calculated the various micro aggregate stability indices as follows:

$\%\ \text{Dispersion ratio} = \frac{\%[\text{Silt} + \text{Clay(H2O)}]}{\%[\text{Silt} + \text{Clay(calgon)}]} \times 100$……………………………………Eq. 1

$\%\ \text{Aggregated Silt} + \text{Clay} = \%[\text{Silt} + \text{Clay(calgon)}] - \%[\text{Silt} + \text{Clay(H2O)}]$…….. Eq. 2

$\%\text{Clay flocculation index (CFI)} = \frac{\%\text{Clay(calgon)} - \%\ \text{Clay(H2O)}}{\%\ \text{Clay(calgon}} X\ 100$ ………..Eq. 3

$\%\text{Clay dispersion index (CDI} = \frac{\%\ \text{Clay (H2O)}}{\%\text{Clay (calgon)}} X\ 100$ ………………………… Eq.4

We determined the Mean weight diameter (MWD) of Water Stable Aggregates (WSA) by the wet-sieving method of (Kemper and Rosenau, 1986). We put twenty-five grammes of the < 4.00 mm soil samples (Mt) in the topmost of a nest of four sieves: 2.00, 1.00, 0.50- and 0.25-mm size and, presoaked the soil samples in water for 10 mins. After that, the nest of sieves with the soil sample was oscillated vertically ten times in water at 1 oscillation per second. The soil particles in the topmost sieve were consistently below the water surface during each oscillation. At the end of wet-sieving, resistant aggregates in each sieve were oven-dried and weighed to obtain the mass of resistant aggregate (Mr), then the proportion of water-stable aggregates in each sieve was calculated as follows;

$$Water\ Stable\ Aggregates = \frac{mass\ of\ resistant\ aggregates}{total\ mass\ of\ the\ wet - sieved\ soil} \dots\dots\dots\dots\dots\dots\dots\dots\dots .Eq. 5$$

Mr is mass of resistant aggregates in each sieve size and, Mt is the total mass of wet-sieved soil sample (25g). We categorized the water-stable aggregates (WSA) into 4 – 2, 2 – 1, 1 – 0.5, 0.5 – 0.25 and <0.25. Then we calculated the mean weight diameter (MWD) of the water-stable aggregates as follows:

$\text{MWD} = \sum_{i=1}^{n} XiWi$…………………………………………………………………....... 6

Where Xi is the mean diameter of the ith sieve and Wi is the proportion of the weight of aggregates in the ith sieve.

We determined the Bulk density (BD*)* through the core method highlighted by Anderson and Ingram, (1993), and, reported in Amanze et al. (2022); and then computation was done as shown in the equation below;

$$BD = \frac{\text{Mass of oven dried soil}}{\text{Bulk volume of the soil}} \dots\dots\dots\dots\dots\dots .\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .Eq. 6$$

Bulk volume of the soil is equal to the volume of cylindrical core sampler given as πr2h where π = 22/7, r is the inner radius of the base of the cylindrical core sampler and h is its height.

Total porosity (Pt)

This was determined by calculation using the bulk density (BD) values, assuming a particle density (PD) of 2.65 mg/m3. The formula is as follows;

$$\%\,Total\ porosity = 1 - \frac{bulk\ density}{particle\ density}\ X\ 100 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .Eq. 7$$

Saturated hydraulic conductivity (Ksat)

We determined the Ksat by the constant head method explained by (Klute, 1986). Here, we trimmed both ends of the core soil samples, and fastened a cheese clothing material at the base of the core soil sample with a rubber band then, we allowed the core soil sample to saturate in water. After that, an empty core with the same diameter was placed on top of the soil core sample and held in place with masking tape and wax so as to avoid water leakage. We maintained a constant head of water above the sample, observed, and recorded rate of water flow rate for three consecutive runs. Then, we calculated the saturated hydraulic conductivity (Ksat) of the soil using Darcy's equation as explained by as shown in Eq. 8.

$$Ksat = \frac{\mathrm{QL}}{AT\Delta \mathrm{H}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . Eq. 8$$

Where Q is quantity of water discharged (cm3), L is length of soil column (cm), A is the interior cross – sectional area of the soil column (cm2), ΔH is head pressure difference causing the flow or hydraulic gradient and T is time of water flow (s).

Soil water retention characteristics

We determined the field capacity (FC), permanent wilting point (PWP) and available water content (AWC) following the procedure reported in (Amanze et al., 2022). Available phosphorus was determined using the Bray 2 method by. Organic carbon was determined using the wet oxidation method of Walkley and Black, as reported in (Udo, 2009). Exchangeable cations were determined by extracting the supernatant solution with standard Ammonia Acetate (NH4OA6) at pH 7. Calcium (Ca2+) and magnesium (Mg2+) were determined in the extract by ETDA titration method, while we measured Potassium (K+) and sodium (Na+) by the use of flame photometer (Udo, 2009).

Exchangeable acidity was determined by extracting the supernatant solution with a standard potassium chloride solution. Then, exchangeable acidity and the exchangeable aluminum were determined by titration as described by (Thomas, 1996). Effective cation exchange capacity was obtained by calculation as the sum of exchangeable bases (Ca, Mg, K, Na) and exchangeable acidity. Percent base saturation was obtained by calculating the sum of all exchangeable bases multiplied by 100% and divided by the effective cation exchange capacity, as shown below:

$$\%\, Base\ saturation = \frac{Total\ exchangeable\ cations}{Effective\ cation\ exchange\ capacity}\ X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots . Eq. 9$$

Extractable Fe and Al were determined after extraction with Dithionite-Citrate using Calorimetric methods as explained in (McKeague, 1967). Clay Mineralogy was determined using the ignition loss method, as outlined in (Watanabe, 1976).

Experimental design and data analysis

We carried out the research on five levels of topounits of the land area (crest, upper slope, middle slope, lower slope and valley bottom). The topounit was the treatment, and we replicated it three times to give fifteen observational units, which we laid out in a Randomized Complete Block Design (RCBD). We subjected the data obtained to analysis of variance (ANOVA) using Genstat version 15, and we separated significant means using Fisher's Least Significant Difference at 5 % probability level.

3. RESULTS AND DISCUSSIONS

Mineralogical composition of the topounits

The soil at the crest contained greater number of minerals than the other topounits (Table 1). The crest contains hematite and goethite the ores of iron (Fe) which were not observed at the soils of the other topounits. This observation was possibly because the crest was greatly exposed to weathering processes that precipitated the iron-containing minerals. However, across the topounits, quartz had the highest dominance being a very resistant mineral. The amount of Kaolinite at all the topounits was low except at the crest where its rating was medium.

This observation could also be attributed to the excessive loss of basic cations at the crest due to intensive weathering and erosional processes (Belay, 1997). Conversely, mordenite, a sodium-containing mineral, was of higher concentration at the other topounits than the crest, and this was perhaps because soils at the descending slope were depositional surfaces where dissolved sodium eroded from the crest were deposited and possibly incorporated into the clay minerals by chemical processes (Sanchez, 1976).

Table 1 Mineralogical information of soils the topounits

Topounits	Minerals	Rating
Crest	Quartz	High
	Mordenite	Low
	Kaolinite	Medium
	Hematite	Low
	Goethite	Low
Upper	Quartz	High
	Mordenite	Medium
	Kaolinite	Low
Middle slope	Quartz	High
	Mordenite	Medium
	Kaolinite	Low
Lower slope	Quartz	High
	Mordenite	Medium
	Kaolinite	Low
Valley bottom	Quartz	High
	Mordenite	Medium
	Kaolinite	Low

Variability in soil physical properties among the topounits of the toposequence

Table 2 reveals that the topounits varied significantly ($P \leq 5\%$) in sand silt and clay. The clay content (32.60%) observed at the upper slope was the highest compared to the amount observed at the other topounits, though it was not significantly different from the clay content at the crest. The clay content (20.44%) observed at the lower slope was the lowest compared to those of the other topounits, which differed significantly from the other topounits. Sand content was highest (51.07%) at the lower slope and lowest (41.61%) at the crest. The lower slope was not significantly different from the valley bottom and middle slope in sand content, while the crest was not different from the upper slope in sand content. The highest (28.49%) and lowest (20.50%) values of silt content were observed at the lower slope and crest, respectively, and these varied significantly from the others, accordingly.

The crest and upper slope contained more clay than the other descending slopes, but this contradicts the report of Akamigbo and Asadu, (2001) that the descending slopes contained more clay than the ascending slopes. Notwithstanding, this observation could result from increased weathering process at the crest which may have resulted in the production of clay particles by the breakdown of rocks. Consequently, the sand fraction which was produced during weathering was easily moved from these regions to the lower part of the slope by erosional processes while the clay particles that were better aggregated and stable were significantly retained. This effect therefore, accounted for the relatively increased clay content and reduced sand fraction at the crest and upper slope, while the descending positions of the slope had higher sand fraction and relatively lower clay content as the depositional surfaces.

This finding agrees with the report of Amanze et al., (2016) that old soils were characterized by increased concentration of clay while the young soils had more of a sandy texture. The implication is that soils at the crest and upper slope would have a fine texture and characteristic nature of high-water retention capacity, difficult to till, and prone to increased surface run-off and its resultant increase in erosion problems (Amanze et al., 2022). Contrariwise, soils at the descending slope (middle and lower slopes) and valley bottom had coarse texture with characteristics nature of increased infiltration and percolation, easy to work on, well aerated, and reduced surface run-off (Amanze et al., 2022). The Table 2 further shows that topounits differed significantly ($P \leq 5\%$) in bulk density (BD), saturated hydraulic conductivity (Ksat), and total porosity. The crest had the highest (1.71 mg/m3) of bulk density, which differed significantly from the other topounits.

In comparison, the middle slope had the lowest value of bulk density (1.50 mg/m3), but was not significantly different from the valley bottom (1.53 mg/m3). The highest value (11.56 cm/min) of Ksat observed at the valley bottom differed significantly from the other topounits. In comparison, the lowest (2.13 cm/min) of Ksat observed at the crest was significantly different from the other topounits. The variation in total porosity among the topounits showed that middle slope had the highest value (42.70%), but was not significantly different from the valley bottom and upper slope. The relatively higher BD at the crest compared to the other topounits could be attributed to its content of iron minerals (Geothite and Hametite) which are known for their increased mass per unit volume relative to the other clay minerals (Mbagwu et al., 1984).

Table 2 Mean values of physical properties of soils at the topounits

Parameters	Crest	Upper	Middle	Lower	Valley B.	LSD
Sand (%)	41.61	44.30	49.91	51.07	48.41	5.06
Silt (%)	20.50	23.10	24.77	28.49	25.11	2.74
Clay (%)	31.35	32.60	25.32	20.44	26.48	4.90
BD (mg/m3)	1.71	1.57	1.50	1.63	1.53	0.04
Ksat (cm/min)	2.13	3.39	4.72	7.01	11.56	0.98
TP (%)	33.54	40.68	42.70	38.36	41.77	3.22
ASC (%)	40.19	40.05	30.62	31.82	32.13	6.01
CFI (%)	79.94	82.73	72.31	70.47	71.65	8.38
CDI (%)	15.39	16.63	33.86	32.19	28.39	9.04
DR (%)	32.08	28.4	39.73	34.20	38.31	6.32
MWD (mm)	6.11	5.44	4.72	4.74	4.27	0.21
AWC (%)	17.77	30.31	19.59	20.51	22.35	1.50
PWP (%)	4.28	5.11	6.38	6.96	8.16	0.28
FC (%)	22.06	25.42	25.97	26.80	30.51	1.67

KEY: BD = Bulk density, TP = Total porosity, Ksat = Saturated hydraulic conductivity, FC = field capacity, AWC = Available water capacity, PWP = Permanent wilting point, DR =Dispersion ratio, CDI = Clay dispersion index, ASC=Aggregated silt and clay, CFI = Clay fluctuation index, MWD = Mean weight diameter

Also, we can infer that the increase in bulk density at the crest was possibly a result of increase in human activities such as soil tillage, movements of man and machineries at this region. The tillage operation perhaps enhanced the BD because of the compression forces and pressure exerted on the soil by the farm tools. The weight of humans and machineries possibly imposed an overburden force on the soils, which resulted in the compaction of the soil particles, and caused increased BD (Amanze et al., 2022). Mbagwu and Piccolo, (1990) had earlier reported that the compaction of soil particles by tillage operation, movement of humans and machineries caused an increase in soil BD. On the contrary, the valley bottom was a young soil and contained unconsolidated sediments characterized by reduced BD (Amanze et al., 2016).

Conversely, the increase in Ksat and PT at the descending positions of the slope was perhaps a result of a decrease in BD and clay content down the slope. Clay has a characteristic nature of tiny pore spaces, which is exacerbated by increased compaction (Chaudhary, 2002). Consequently, the total pore volume and ability of the soil to allow for water transmission increased with decrease in clay content and BD at the descending positions of the slope. This finding implies that soils at the ascending slope (upper slope and crest) would be faced with increased run-off and erosion while soils at the descending topounits will be associated with increased drainage and well aerated; hence can support the cultivation of many crops. This claim corroborates the report of Amanze et al., (2017) that increased bulk density and decreased drainage resulted in increased run-off and erosion while permeable soils are well aerated.

Further in Table 2, we observed that there was significant ($P \leq 5\%$) variation in aggregate stability indices among the topounits. The crest had the highest value (40.19%) of aggregated silt and clay (ASC), but this was not significantly different from the upper slope. On the contrary, the middle slope had the lowest value (30.62%), which was not significantly different from the lower slope and valley bottom. The upper slope had the highest value (82.73%) of CFI, which was not significantly different from the crest. The lower slope had the lowest value (70.47%) of CFI was observed at the lower slope, which did not vary considerably from the middle slope and valley bottom. The middle slope had the highest degree of clay dispersion with clay dispersion index (CDI) of 33.86%, which was not substantially different from the lower slope and valley bottom.

The lowest degree of clay dispersion (CDI = 15.39%) was observed at the crest, and this was not significantly different from the upper slope. The upper slope had the lowest DR (28.40%), which was not significantly different from the crest. We observed the highest DR (39.73%) at the middle slope, and this did not vary considerably from the lower slope, and valley bottom. Soils at the crest had the highest stability of macro aggregates (MWD = 6.11mm), which differed significantly from the other topounits. Conversely, the lowest MWD (4.27mm) was observed at the valley bottom, and this was statistically different from the other topounits. The better aggregation and aggregate stability of soils at the crest and upper slope compared to the descending slopes can be attributed to their increased clay content and BD.

The large surface area of clay particles increased their cohesive forces, which enhanced the flocculation of the soil, and resulted to micro aggregation and stability of micro aggregates. Also, the increase in the adhesive force of attraction due to the large charged surfaces of the clay induced the binding force between clay particles and other soil mineral particles (sand and silt), which resulted in the aggregation and stability of aggregate at the macro level (MWD); hence, the increase in aggregate stability decreased the possibility of soil dispersion by water (Amanze et al., 2024). Conversely, the relatively poor aggregation and instability of aggregates to water at the descending slope could be inferred on their relatively lower clay content (Amanze et al., 2024).

The authors also revealed that the topounits differed significantly ($P \leq 5\%$) in water retention properties such that the water retained at available water capacity (AWC) was highest (30.31%) at the crest, which differed significantly from the other topounits. The valley bottom had the highest water retained at field capacity (FC) (30.51%) and permanent wilting point (PWP) (8.16%), while the crest had the lowest values of FC (22.06%) and PWP (4.28%). These were significantly different from the other topounits. The general increase in the capacity of the soils to retain water at the lower slope could be attributed to the rise in OC content at the lower slopes (Amanze et al., 2022). Organic carbon provided large charged surfaces that attracted and held the water molecules within their matrix (Landon, 1991).

Variability in soil chemical properties among the topounits of the toposequence

Table 3 shows that the topounits varied significantly ($P \leq 5\%$) in available phosphorus (avail P) and organic carbon (OC). The valley bottom had the highest value (30.02mg/kg) of avail P, which was significantly different from the other topounits. The middle slope had the lowest value of Avail. P (19.74mg/kg), which was statistically different from the other topounits. Also, the valley bottom had the highest value of OC (1.32%), while the upper slope had the lowest (0.42%). The relatively increase in OC content and avail P at the valley bottom can be a result of the superficial translocation of different forms of phosphorus and organic materials from the upper slope to the lower slope via erosional and depositional processes. The formation of geomorphic surfaces along a slope revealed that materials are moved from the erosional surface i.e. the upper slope to the deposit surface usually the valley bottom via lateral movement (Gregorich and Anderson, 1985).

Table 3 Mean values of chemical properties of soil at the topounits

Parameters	Crest	Upper	Middle	Lower	Valley B.	LSD
Avail P (mg/kg)	20.48	25.85	19.74	21.04	30.02	0.50
OC (%)	0.84	0.42	0.59	0.65	1.32	0.02
K (cmol/kg)	0.26	0.22	0.29	0.27	0.28	0.02
Mg (cmol/kg)	1.84	2.16	2.80	3.04	2.96	0.17
Ca (cmol/kg)	7.28	5.68	9.68	10.64	13.04	0.20
Na (cmol/kg)	0.40	0.38	0.40	0.45	0.41	0.02
TEB (cmol/kg)	9.78	8.45	13.16	14.40	16.68	0.28
EA (cmol/kg)	1.36	2.40	2.20	1.52	1.68	0.16
ECEC (cmol/kg)	11.07	10.85	15.38	15.92	18.36	0.32
BS (%)	88.19	78.03	85.64	90.82	90.66	1.53

Extr Fe (mg/kg)	0.21	0.16	0.18	0.20	0.42	0.01
Extr Al (mg/kg)	0.08	0.004	0.012	0.022	0.000	0.004

KEY: Avail P = Available phosphorus, OC = Organic carbon, K = exchangeable potassium, Mg = exchangeable magnesium, Ca = exchangeable calcium, Na = exchangeable sodium, TEB = Total exchangeable bases, EA = exchangeable acidity, ECEC = effective cation exchange capacity, BS = base saturation, Extr. Fe = extractible iron, Extr. Al = extractible aluminum

Also, the topounits varied significantly ($P \leq 5\%$) in exchangeable calcium (exch Ca), and the valley bottom had the highest value (13.04 cmol/kg), while the upper slope had the lowest value (5.68 cmol/kg), which varied considerably from the other topounits. The lower slope had the highest exchangeable Mg (3.04 cmol/kg), which differed significantly from the other topounits except the valley bottom (2.96 cmol/kg), while crest had the lowest value (1.84cmol/kg), which varied significantly from the other topounits. The middle slope had the highest value of exchangeable K (0.29 cmol/kg), and this was not substantially different from the lower slope (0.27 cmol/kg) and valley bottom (0.28 cmol/kg). On the other hand, the upper slope had the lowest exchangeable K (0.22 cmol/kg). The exchangeable Na was highest (0.45 cmol/kg) at the lower slope and lowest (0.38 cml/kg) at the upper slope.

The topounits also varied significantly ($P \leq 5\%$) in total exchangeable bases (TEB) with the highest value (16.68cmol/kg) observed at the valley bottom. In contrast, the upper slope had the lowest value (8.45cmol/kg). These values differed significantly from the values at the other topounits. The upper slope had the highest values (2.40 cmol/kg) of the exchangeable acidity, while crest had the lowest (1.36cmol/kg) was observed. These values varied significantly from the values at the other topounits. The general increase in the TEB, and basic cations (Ca, Mg, K and Na) at the lower part of the slope compared to the upper part was possibly a consequence of the superficial washing away of these soluble basic cations from the higher slope to the descending slope (lower slope and valley bottom) via water erosion (Amanze, et al., 2017).

Conversely, we can attribute the higher concentration of EA at the upper and middle slopes to the considerable loss of the basic cations by water erosion, which resulted in the accumulation of Al^{3+} and H^+ at the exchange site of the soil (Amanze, et al., 2017). The Table 3 further showed that topounits varied significantly ($P \leq 5\%$) in base saturation (BS). The lower slope had the highest value (90.82%), which differed significantly from the other topounits except valley bottom (90.66%). In contrast, the upper slope had the lowest value (78.03%), which was significantly different from the other topounits. The topounits varied significantly in ECEC; the valley bottom had the highest (18.36 cmol/kg), while the upper slope had the lowest value (10.85 cmol/kg). The decrease in cations exchange capacity of the soil at the upper slope could be inferred on its lower OC content.

In contrast, the relatively higher OC content at the valley bottom could account for its higher capacity for cations exchange (Amanze et al., 2017). Soil OC increases the capacity of soils to effectively allow for cation exchange within the exchange site of the soil colloid. This possibility could be due to the increased net negatively charged surfaces at the colloidal mixture caused by the organic materials (Amanze et al., 2017). The higher accumulation of cations which increased the TEB of the soils at the valley bottom and lower slope, and the reduced EA at these regions accounted for the higher saturation of basic cations (%BS) in the soils at these regions. This explanation corroborates the report of that an increase in the concentration of basic cations increased the base saturation.

The Table 3 also shows that the topounits differed significantly ($P \leq 5\%$) in the exchangeable Fe and exchangeable Al (sesquioxides). The highest value (0.42mg/kg) of extractable Fe was observed at the valley bottom, while the upper slope had the lowest (0.16mg/kg). These were significantly different from the other topounits. The crest was highest (0.08mg/kg) in extractable Al, while the valley bottom was the lowest (traced) in extractible Al; and these differed significantly from the other topounits. The presence of increased concentration of exchangeable Fe at the valley bottom negates the expectation at the crest, despite the presence of iron-containing minerals present at the crest. This observation was due to the possible formation of soluble organo-iron complexes at the crest and their subsequent translocation to the depositional surface of the slope (valley bottom) via water erosion.

Consequently, the relatively lower concentration of Fe at the upper slope was perhaps a result of higher rate of loss of materials from this region due to the higher slope gradient. The insignificant amount of extractable Al at the valley bottom was probably because of the limited translocation of Al from the upper slope to the lower slope. Most aluminum compounds are almost insoluble in water, and are therefore relatively immobile.

Contribution of the study

Land users are increasingly utilizing tropical soils on topographic areas without adequate knowledge of the variability in soil quality at varying positions of topography. This study will help to increase the awareness on the differences in soil properties at various positions along the slope of a landscape; and this aims to guide land users to take informed decisions on land use planning and soil management for sustainable agriculture.

4. CONCLUSION

Soils along the toposequence of shale derived parent material have same mineral composition and concentration, but with slight variation at the crest where additional low concentration of a few deposits of iron – containing minerals. Generally, soils at the topounits varied in physicochemical properties, such that soil structural stability decreased down the slope while the chemical qualities of the soils increased down the slope. Therefore, the ascending part of the slope would require improved soil chemical properties through the use of soil amendments and good agronomic/cultural practices. At the same time, efforts must be made to improve and manage the structural properties of soils at the descending slope or depositional surface, such as the valley bottom to sustain its productivity over time.

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Authors' Contributions

Nwosu, Ogochukwu Comfort and Eneje, Roseta Chizoba developed the concept and design of the research, and executed it, while Nwosu, Ogochukwu Comfort and Amanze, Chikamnele Tochukwu did the writing of reports on the research findings. Eneje, Roseta Chizoba contributed in supervising the research and reporting of the findings; while Amanze, Chikamnele Tochukwu analysed the data, interpreted the results and prepared the manuscript for publication.

Informed consent

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

Ethical approval

Not applicable.

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Data and materials availability

All data associated with this study are present in the paper.

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