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# Soil structure stability and organic carbon distribution along the toposequence of Orumba North in derived savannah of the South-East, Nigeria

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**ABSTRACT**

In high-rainfall zones with severe water erosion problems, soil structure stability as promoted by soil organic carbon (SOC) should be prioritized. Landscape positions and land use influence soil properties and nutrient distribution. This study assessed soil structure stability and SOC content at top-slope, mid-slope and low-slope positions of a toposequence at Orumba North in derived savannah zone of the South-East, Nigeria. The top/mid-slope positions are situated at upland plains and the low-slope position at a lowland. A pedon was excavated and described in each topo-position, and the identified horizons tested for topo-position influence on soil texture, structure and SOC. The top/mid-slope positions show sandy, light-coloured, well-drained, friable, moist soils, whereas the low-slope soils are loamy sand but poorly drained with high water table, leading to the presence of mottles. Soil texture varied among the pedons. Clay content was higher at the top- than mid/low-slope positions; silt content was higher at the top/mid- than low-slope position. Soil aggregation indicated no regular trend, but water-stable aggregates, state of aggregation, aggregates' mean-weight diameter (MWD) were all lowest and structure stability index highest at the mid-slope position. However, the generally less compacted surface soils showed higher values of these aggregation indices at the top- than mid/low-slope positions, except MWD that tended to decrease along the toposequence. Saturated hydraulic conductivity showed the least permeable soil at the poorly drained low-slope position. The SOC content, though generally low, increased along the toposequence (2.90, 5.00 and 6.70 g kg$^{-1}$, respectively), but with top-slope < mid-slope position for surface soils only. Overall, the toposequence showed poorly developed and/or fairly unstable soil structure. The data presented highlight the somewhat inverse aggregation-SOC trends along humid tropical toposequences, serving as an indication of their possible relationship under contrasting drainage status.

## 1.0 Introduction

Topography, one of the factors that are vital for soil formation, plays important role in the nature and properties of soil, as well as nutrient distribution in soils. Rather than such other factors of soil formation as climate and parent material, large proportions of variations in soil properties within a given location are due to topography and land use (Hu *et al*., 2019; Alarima *et al.,* 2020). Ibrahim *et al*. (2020) noted that topography influences the morphological, physical and physicochemical properties of soils. Such influence leads to a sequence of soils with distinct soil properties on topographic positions, known as a toposequence. In a typical toposequence, the other soil-forming factors (climate, organisms, parent materials and time) remain constant, such that any observed differences in soil properties are defined, almost entirely, by topography. The implication is that the pattern of soil distribution over delineated landscapes depends more on topographic gradients than on the additive influence of these other four factors of soil formation.

Topography serves a major function in the variation of soil properties and nutrient distribution along a non-uniform agricultural landscape (Ibrahim *et al*., 2020), which emphasizes the need for sufficient understanding of soil variability and its impact on sustainable food production, particularly in regions with varying slope gradients. The variation in soils along topography leads to very shallow and gravelly soils on hills or steep slopes due to the minimal rate of weathering and high removal of soil by erosion, whereas soils on gentle slopes allow ample infiltration of water and develops into deep profiles (Moeslund *et al*., 2013). Thus, topography also influences soil texture, soil pH, soil organic carbon (SOC), structure, drainage, erosion, and indeed other soil properties/processes influencing soil productivity (Aweto and Enaruvbe, 2010; Atofarati *et al*., 2012; Tellen and Yerima, 2018; Omokaro, 2023).

Adequate understanding of the dynamics and distribution of soil properties, which are used in assessing land use and management (Ibrahim *et al*., 2020; Sadiq *et al*., 2021), is key to doing sustainable agriculture. Such data on soil physicochemical/fertility indices along toposequences abound in the literature. Corresponding data on soil aggregation are rarely reported (e.g., Salako *et al*., 1999), despite its interconnectedness with soil fertility (Ifeanyi-Onyishi *et al*., 2024). Soil aggregation, a measure of the extent of formation and stabilization of aggregates which relates to their ability to resist breakdown by destructive water and wind forces, is a critical process in soil functioning. Similarly, SOC is often used as one-parameter index of soil quality (Obalum *et al*., 2017). Both soil aggregation and SOC build-up are important processes that influence soil physical and physicochemical properties which in turn influence sustainable food production. For instance, soil aggregation has been reported to correlate positively with crop yields in the derived savannah agro-ecology of Nigeria (Ogunezi *et al*., 2019; Ebido *et al*., 2021), contrary to the common view that soil structure is a minor factor in tropical agriculture.

Soil aggregation and SOC build-up vary across landscapes not only in response to agricultural and non-agricultural land uses (Uzoh *et al*., 2020; Oguike *et al*., 2023) or soil and water management practices (Obalum *et al*., 2024a, b; Eyibio *et al*., 2025), but also along the toposequence (Salako *et al*., 1999). As the level of soil aggregation and structure stability increases, SOC content, surface area of clay minerals and cation exchange capacity of the soil also increase (Bronick and Lal, 2005; Onah *et al*., 2023). In Nigerian agro-ecosystems, however, soil aggregate stability often relates with SOC positively under well-drained soil conditions (e.g., Uzoh *et al*., 2020), but also negatively in seasonally flooded lowland soils (e.g., Obalum *et al*., 2011a). These contrasting soil aggregation-SOC relationships are logically a reflection of soil drainage status and associated variations in SOC priming.

Considering the differences in drainage status of topo-positions, the contrasting aggregation-SOC relationships are expected to prevail on diverse toposequences of the tropical region. To date, we are not aware of any research in this direction, exposing the relative trends of soil aggregation and SOC distribution along the toposequence in any location of the humid tropics. Information of this nature would guide soil and water management decision in fragile agro-ecosystems. The derived savannah zone of the South-East of Nigeria is characterized by high-intensity rainfall and consequent soil erosion menace in (Okenmuo *et al*., 2023), making the need for such information critical in the zone. The rolling topography of a truly representative toposequence in Orumba North area of this vulnerable zone offers the opportunity for studying toposequencial soil variations. This study assessed soil aggregation (indexed by soil structure stability) and SOC contents at three topo-positions along this toposequence. The aim was to highlight the extent of variations in soil aggregation and SOC and their relative distributions along the toposequences occurring in fragile agro-ecosystems of the Nigerian savannah and similar agro-ecologies of the tropical region.

## 2.0. Materials and Methods

### *2.1. Description of the study area and soil sampling*

The study was carried out along the toposequence situated at Orumba North Local Government Area of Anambra State, located between 5°56'40" N and 6°15'0" N and 7°2'40" E and 7°15'20" E (Figure 1). The area lies within the humid tropical climate and is characterized by distinct dry and rainy seasons, with bimodal rainfall pattern. The mean annual rainfall ranges from 1400 to 2500 mm, with mean temperatures in the range of 24 – 27 ºC during rainy season (Igwe and Una, 2019). About 50% of rainfall comes with intense storm events during the middle and towards the end of rainy season. Palm oil trees and cassava are the main crops found in the upland area, while rice and cassava (on well raised mounds) dominate the lowland area.

Three topo-positions were identified along the toposequence. The elevations at the top-slope, mid-slope and low-slope positions are 165.7, 102.6 and 50 m asl, respectively. Soil profile pits were dug at the topo-positions at Oko, Ndiowu and Ufuma communities in the study area. Three pedons were excavated, one in each of the identified topo-positions. After the description and morphological study of the pedons, undisturbed soil samples were collected from observed horizons of each pedon, using core samplers of 7 cm × 5 cm in dimension. Disturbed soil samples were also collected from each horizon using a trowel. A total of 14 soil samples were collected from the three pedons; 6, 5 and 3

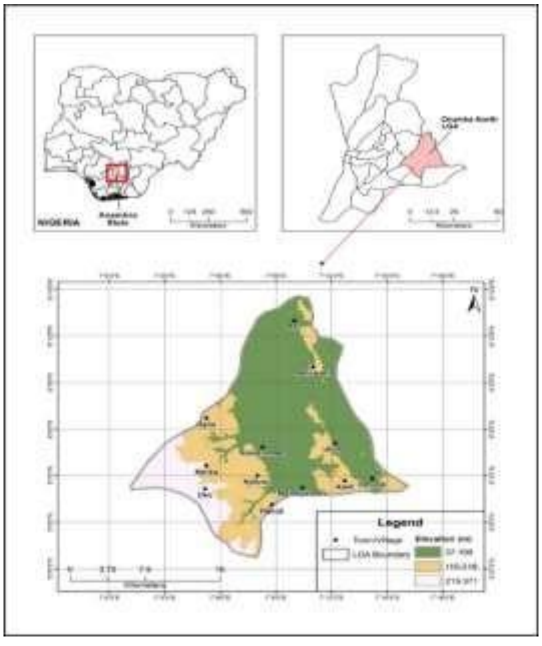

Fig. 1: Topo-map of the study area in Anambra State, Nigeria

for the ones at the top-slope, mid-slope and low-slope positions, respectively. The undisturbed soil samples (soil cores) were used to determine saturated hydraulic conductivity ($K_s$) of the soils and water retention at 60-cm tension, while the disturbed soil samples were used to determine soil texture, structure stability, and SOC.

### 2.2. Laboratory study

The soil samples from the pedons were labeled, bagged and sent to the laboratory where the disturbed ones were air-dried, ground, sieved with a <-2 mm sieve, before analyses. The $K_s$ was determined by the constant head method, and computed using the transposed Darcy's equation as outlined by Youngs (2000):

$$Ks = \frac{\mathrm{QL}}{\Delta \mathrm{HAT}} \quad (1);$$

where $Q$ is steady-state volume of water outflow from the entire soil column (cm$^3$), $L$ is the length of soil column being the soil core sampler (cm), $A$ is the cross-sectional area of the soil column (cm$^2$), ΔH is the change in hydraulic head or the head pressure difference causing the flow (cm), and $T$ is the time of flow (h). Thereafter, the soil cores were re-saturated and subjected to 60-cm tension for 24 h before oven-drying at 105 °C for another 24 h.

Particle size analysis was done by the hydrometer method, following the procedure described by Gee and Or (2002). The SOC content of the soils was determined by the Walkley-Black wet dichromate oxidation method (Nelson and Sommers, 1996).

Soil aggregates 4.75-2 mm were separated by wet sieving as described by Kemper and Rosenau (1986), into water-unstable and water-stable aggregates. This was done using nested four (2.0, 1.0, 0.5 and 0.25 mm) sieves. Aggregates passing through the last 0.25-mm sieve were regarded as water-unstable, while those retained on the four sieves were regarded as water-stable aggregates. These water-stable aggregates were weighed and used to calculate the percent water-stable aggregates as follows:

$$\%\ \mathrm{WSA} = \frac{WR-WSF}{TSW-WSF}\ x\ 100 \quad (2);$$

where WSA is water-stable aggregates as corrected for sand in the agggregates, WR is weight retained on all the sieves as summed up, WSF is weight of sand fraction in the aggregates, and TSW is total sample weight before the wet-sieving.

Mean-weight diameter (MWD) of the wet-sieved soil aggregates was calculated using the formula:

$$\mathrm{MWD}\ (mm) = \sum_{i=1}^{n} wimi \quad (3);$$

where $w_i$ is the mean diameter of a given aggregate size class (mm), $m_i$ is the fractional mass of a given size class (g g$^{-1}$), and $n$ is the number of sieves used in the separation of aggregates.

Structure stability index (SSI) of the soils, an indicator of the risk of soil structure deformation associated with SOC depletion (Pieri, 1992), was also calculated as follows:

$$SSI = [\frac{1.72\ x\ SOC}{Si+Cl}]\ 100 \quad (4);$$

where Si is total silt (%) and Cl is total clay (%) in the soils.

### 2.3. Data presentation

Descriptive statistical tools (means and coefficient of variation) were used to present the soil data from the profile pits as varying within each pedon. This was done using the Microsoft Excel software. The means for the pedons were used to show the trends of soil aggregate stability and SOC among the topo-positions.

## 3.0. Results and Discussion

### 3.1. Morphological properties of the soil along the toposequence of Orumba North

The morphological properties of the soil at the different topo-positions are presented in Table 1. The results indicated that the soils were deep (> 200 cm), without concretions or impenetrable layer, especially at the top-slope and mid-slope positions. At the low-slope position, which is used extensively for rice cultivation in the study area, the pedon depth was expectedly restricted by high level groundwater table encountered at 30 cm depth. This (high level of ground water table) explains the few soil horizons observed in the pedon and the abundance of olive-coloured (5Y 5/1) and red-coloured mottles (10R 4/8) in the pedon at the low-slope position (LUN). Idoga *et al.* (2006) in a study of the morphology and properties of a toposequence in Samaru area of Nigeria reported that the higher mottled areas observed in the foot-slope are indicative of poor drainage. Soils on higher elevation are usually well drained while those on the lower slope are usually poorly drained and of fine texture (Ibrahim *et al.*, 2020). The pedons at the top-slope (TON) and mid-slope (MON) positions, located at the upland areas exhibited five and six distinct horizons, respectively. The two pedons had Ap and Bt (argillic B-horizons), whereas the pedon at the low-slope (LUN) had Apg, Bg and C-horizons. The horizon boundaries of the pedon at the top-slope varied from gradual wavy to diffuse smooth; those of the mid-slope position varied from clear wavy to diffuse smooth. The pedon at the low-slope area had clear smooth horizon boundaries both at the surface and subsurface soils.

The pedons varied greatly in relation to surface soil colour pattern. Soil colour varied from dark reddish brown (5YR 3/4) at top-slope to dull yellowish brown (10YR 4/3) at low-slope, indicating the influence of topography on soil colour pattern through its effect on the rates of surface runoff, erosion and deposition. The highest soil erodibility is usually found on the upper slope positions (top-slope) (Mulugeta and Sheleme, 2010; Sheleme, 2011), which may be the cause of the observed soil colour. When erosion takes soil from the shoulder or back-slope sections of hillslope, thinner and lighter-colored soils remain.

The soils of the upper layers of the pedons are mostly coarse textured, while those of the lower layers are mostly indicating that there was prominent translocation of clay down the profiles forming argillic horizons. The moist consistence of the soils ranged from friable, loose, non-sticky and non-plastic to very sticky and very plastic. Although the soils were very sticky and very plastic, they were still very friable. This observation could be probably because of the type of clay mineral present. Many red-coloured tropical soils have clay particles composed

Table 1. Morphological properties of the soils along the toposequences at Orumba North Area, Anambra State

| Depth (cm) | Horizon | Boundary | Colour (Moist) | Texture Class (Feel Method) | Structure | Consistency (Moist) | Roots | Pores | Mottles | Concretion |
|---|---|---|---|---|---|---|---|---|---|---|
| **Top-slope (TON)** | | | | | | | | | | |
| 0-20 | Ap1 | GW | 5YR 3/4 | Sandy Loam | MMG | NS, NP, | MF, Me | MIFi, | No | No |
| 20-38 | Ap2 | GS | 5YR 3/6 | Loamy Sand | MMC | NS, NP, VFr | MF, Me | MIFi | No | No |
| 38-95 | Bt1 | DS | 10R 3/6 | Clay | MMSB | S, P | Fe Fi | MIFi | No | No |
| 95-140 | Bt2 | DS | 10R 3/6 | Clay | MMSB | S, P, | Fe, Fi | MIFi | No | No |
| 140-200 | Bt3 | | 10R 4/8 | Clay | MMC | VS, VP | Fi, Me | CIVFi | No | No |
| **Mid-slope (MON)** | | | | | | | | | | |
| 0-16 | A1 | CW | 7.5YR 3/3 | Sandy Loam | WFG | NS, NP, LO | VFi, Fi | MIFi | No | No |
| 16-36 | A2 | GS | 5YR 3/4 | Loamy Sand | MMG | NS, NP, VFr | Fe Fi | MIFeFi | No | No |
| 36-58 | AB | CS | 2.5YR 3/4 | Loamy Sand | WFC | NS, NP, VFr | Fe Fi | MIFi | No | No |
| 58-80 | Bt1 | DW | 2.5YR 4/6 | Sandy Clay Loam | MMS | SS, SP, Fr | Fe M | CIFi | No | No |
| 80-125 | Bt2 | DS | 2.5YR 4/8 | Clay | MMC | S, P | VFi Fe | CIVFi | No | No |
| 125-200 | Bt3 | | 2.5YR 4/8 | Clay | MMS | S, P | No | VFeIVFi | No | No |
| **Low-slope (LUN)** | | | | | | | | | | |
| 0-8 | Apg | CS | 10YR 4/3 | Loam | MMC | SS, SP, Fr | VFi, Fi | MI Fi | 5Y 5/1 | 10R 7/1 |
| 8-20 | Bg | CS | 7.5YR 5/6 | Sandy Clay Loam | MMC | S, P | VFi, Fi | MIFi | 10R 4/8 | 10R 7/1 |
| 20-30 | Cg | | 10YR 4/4 | Sandy Clay Loam | MMC | VS, VP, Fr | No | FeIVFi | No | No |

TC - textural class; CW - clear wavy; GS - gradual smooth; CS - clear smooth; DW - diffuse wavy; DS - diffuse smooth; GW - gradual wavy; WFG - weak fine granular; MMG - moderate medium granular; WFC - weak fine crumb; MMS - moderate medium sub-blocky; MMC - moderate medium crumb; MMSB - moderate medium sub-angular blocky; NS - non-sticky; NP - non-plastic; LO - loose; VFr - very friable; Fr - friable, SS - slightly sticky; SP - slightly plastic; S - sticky; P - plastic; VS - very sticky; VP - very plastic; V - very; Fi - fine; Fe - few; M - many; Me - medium, I - irregular; C - common of mainly kaoilinite and oxides of iron and aluminum, which have little capacity to develop stickiness and to expand and contract on wetting and drying (Foth, 1990).

### *3.2 Physical and physico-hydraulic properties of the pedons along the toposequence of Orumba North*

There was distinct variation in the proportion of sand, clay and silt contents of the three pedons down the slope (Table 2). The primary soil particles of the pedons were highly dominated by sand fraction, followed by clay and silt fractions, in decreasing order. The mean values of sand, clay and silt in the top-slope (TON) were 76%, 22% and 2%, respectively. A similar trend was observed in the mid-slope (MON) and low-slope (LUN). Similar high levels of sand were noted in a toposequence in Abia State of Nigeria by Nuga *et al.* (2006). Clay fraction increased with depth in all the pedons. Earlier, Chadwick and Grahm (2000) opined that synthesis of secondary clays *in-situ*, weathering of primary minerals in the B-horizon, or residual concentration of clays from the selective dissolution of more soluble minerals in the B-horizon could result to accumulation of clays in subsoil horizons. Obalum *et al.* (2013) attributed higher clay content of subsoils than topsoils of the derived savannah to pedogenic eluviation–illuviation processes. Also, Mulugeta and Sheleme (2010) attributed changes in clay percentages down the soil profile to pedogenic eluviation–illuviation processes, particularly in the upper as well as middle slope profiles. In Zaria, Kaduna State of Nigeria, Ibrahim *et al*. (2020) attributed general increases in clay content with depth, along a toposequence, to translocation of clay from surface soil to subsurface soil. The increase in clay content with soil depth could, therefore be attributed to eluviations and translocation of clay from surface soil to sub-surface soil.

Soil texture varied down the slope, thus indicating the impact of topography on the textural classes. While the texture of the surface soil at TON was Sandy, the subsurface soil varied from Loamy Sand to Sandy Clay Loam. At MON the soil texture was predominantly sandy at the surface soil and subsurface soil, except from the soil depth of 80 – 200 cm which exhibited Sandy Clay Loam texture. The LUN was Loamy Sand at the surface soil and Sandy Loam at the subsurface soil.

Soil water retention at the 60-cm tension was rather uninfluenced by topo-position, suggesting a similarity in sand content and hence permeability of these low-SOC soils (Obalum and Obi, 2013). The saturated hydraulic conductivity ($K_s$) showed no regular pattern as the values varied within the soil profile. However, the lowest $K_s$ (10 cm h$^{-1}$) was obtained at the low-slope, while the highest value (26.10 cm h$^{-1}$) was recorded at the mid-slope. Low $K_s$ at the low-slope resulted to wet condition in the soil and abundance of mottles in the pedon. Startsev *et al*. (2009) remarked that mottles and grey colours are primarily indicators of poor soil aeration resulting from high soil moisture filling the pore space until water blocks the air paths of diffusion. Hewitt (2004) also reported that the presence of rust-cloured mottles indicate saturation with water by an intermittent water table.

### *3.3 Soil aggregate formation and stabilization in the soils along the toposequence of Orumba North*

Soil structure indices as presented in Table 2 showed that the pedon at the mid-slope was most susceptible to structural deformation when exposed to external forces, relative to pedons at the top-slope and low-slope. The average values of percent water-stable aggregates at the top-slope, mid-slope and low-slope were 29.69%, 7.04% and 31.49%, respectively, while the mean values of mean weight diameter (MWD) was 0.41 mm at the top-slope, 0.24 mm at the mid-slope and 1.18 mm at the low-slope. The lowest values of percent water-stable aggregates and MWD were observed at the mid-slope. The values of percent water-stable aggregates were considered very low when related to aggregate stability rating by Mukherjee and Lal (2014) and Pulido-Moncad *et al*. (2015), where < 50.0%, 50 – 70%, and > 70.0% are rated as low, medium and high aggregate stability, respectively. The low values of percent water-stable aggregates indicated that the soil structure along the toposequence are susceptible to deformation when exposed to erosion, rain drop impacts, shrinking and swelling processes and tillage. As posited by Ogban (2021), soil aggregate stability relates to soil resistance to raindrop impact, erosion and runoff, as well as its ability to accept, store and transmit water for crop growth.

The mean values of soil structure stability index (SSI) varied at the different slope positions (Table 2). While the mean value of SSI was 3.81% at the top-slope position, the values at the mid- and low-slope positions were 5.34% and 4.56%, respectively. The results, which resemble those for soil aggregate stability, indicated that the soils' capacity to resist structure deformation when exposed to external forces such as raindrop impact and tillage operations is generally low. The SSI values were generally below rating by Mukherjee and Lal (2014) and Pulido-Moncad *et al*. (2015) where < 5% was rated as structurally degraded soil, 5 – 7% as soil with high degradation risk, and > 9% as soil with sufficient carbon. Therefore, the low SSI highlights the need for adequate soil management practices aimed at boosting SOC to improve aggregation and maintain soil functions.

### *3.4 Soil organic carbon (SOC) distribution in the pedons of the toposequence of Orumba North*

The SOC content increased down the toposequence (Table 3), thus indicating the possible influence of topo-position on SOC concentration along the toposequence. The value was 25.4% higher in low-slope than in mid-slope, and 54.7% higher in low-slope than in top-slope. Soils on foot-/toe-slopes generally show a higher organic matter content (Mulugeta and Sheleme, 2010). The increase in SOC content down the slope could be attributed to depositions of fine particle organic materials by runoff down the slope. The higher SOC in the low-slope position, relative to the mid-slope position, agrees with the findings by Hu *et al.* (2019) and Seifu *et al.* (2020), who attributed the observation to the erosion process of runoff that transported humus and fine particles from the upper slope and had them accumulated at the

Table 2: Physical and structure-related properties of the soils along the toposequence at Orumba North area in the derived savannah zone of the South-East, Nigeria

| **Horizon** | **Depth (cm)** | **% Clay** | **% Silt** | **% Sand** | **Texture Class** | **% WSA** | **% SOA** | **MWD (mm)** | **% SSI** | **% $WR_{60cm}$** | **$K_s$ (cm $h^{-1}$)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Top-slope (TON)** | | | | | | |
| Ap1 | 0-20 | 5 | 3 | 92 | Sand | 32.34 | 26.00 | 0.94 | 11.73 | 21.81 | 14.83 |
| Ap2 | 20-38 | 13 | 1 | 86 | Loamy Sand | 12.32 | 10.40 | 0.13 | 4.51 | 16.24 | 16.57 |
| Bt1 | 38-95 | 31 | 3 | 66 | Sandy Clay Loam | 41.55 | 34.40 | 0.48 | 1.4 | 14.08 | 16.43 |
| Bt2 | 95-140 | 31 | 1 | 68 | Sandy Clay Loam | 33.04 | 30.40 | 0.23 | 0.69 | 13.13 | 16.03 |
| Bt3 | 140-200 | 29 | 1 | 70 | Sandy Clay Loam | 29.22 | 25.60 | 0.27 | 0.73 | 16.46 | 12.19 |
| | **Mean** | **22** | **2** | **76** | | **29.69** | **25.36** | **0.41** | **3.81** | **16.34** | **15.21** |
| | *% CV* | *48.99* | *43.75* | *13.88* | | *32.32* | *32.10* | *70.16* | *123.19* | *18.42* | *11.98* |
| | | | | | **Mid-slope (MON)** | | | | | | |
| A1 | 0-16 | 7 | 1 | 92 | Sand | 23.43 | 16.40 | 1.10 | 4.46 | 16.58 | 37.34 |
| A2 | 16-36 | 9 | 1 | 90 | Sand | 6.28 | 5.60 | 0.13 | 8.53 | 17.08 | 32.87 |
| AB | 36-58 | 7 | 1 | 92 | Sand | 6.28 | 6.00 | 0.13 | 4.46 | 16.26 | 43.82 |
| Bt1 | 58-80 | 15 | 1 | 84 | Sand | 2.58 | 2.40 | 0.02 | 0.63 | 16.81 | 3.28 |
| Bt2 | 80-125 | 21 | 3 | 76 | Sandy Clay Loam | 1.70 | 1.60 | 0.01 | 8.22 | 16.70 | 17.94 |
| Bt3 | 125-200 | 20 | 3 | 77 | Sandy Clay Loam | 1.70 | 1.60 | 0.02 | 5.73 | 17.11 | 21.36 |
| | **Mean** | **13** | **2** | **85** | | **7.04** | **5.60** | **0.24** | **5.34** | **16.76** | **26.10** |
| | *% CV* | *43.71* | *47.81* | *7.66* | | *119.04* | *100.71* | *181.87* | *54.55* | *1.91* | *56.72* |
| | | | | | **Low-slope (LUN)** | | | | | | |
| Apg | 0-8 | 11 | 13 | 76 | Loamy Sand | 22.60 | 16.00 | 1.16 | 7.52 | 18.08 | 21.91 |
| Bg | 8-20 | 15 | 9 | 76 | Sandy Loam | 44.20 | 32.00 | 1.15 | 4.00 | 15.08 | 3.29 |
| Cg | 20-30 | 17 | 13 | 70 | Sandy Loam | 27.68 | 19.60 | 1.24 | 2.14 | 14.24 | 4.81 |
| | **Mean** | **14** | **12** | **74** | | **31.49** | **22.53** | **1.18** | **4.56** | **15.80** | **9.70** |
| | *% CV* | *17.16* | *15.78* | *3.85* | | *29.28* | *30.41* | *3.34* | *59.9* | *10.41* | *7.95* |

WSA - Water-stable aggregates after correction for sand in the aggregates; SOA - State of aggregation; MWD - Mean-weight diameter of aggregates; SSI - Structure stability index; $WR_{60cm}$ - Water retention at the 60-cm tension; $K_s$ - Saturated hydraulic conductivity

Table 3: Soil organic carbon distribution along the toposequence at Orumba North area, derived savannah of the South-East, Nigeria

| **Topo-Position** | | **Depth (cm)** | **SOC (g kg$^{-1}$)** |
|---|---|---|---|
| Top-slope | Ap1 | 0-20 | 5.40 |
| | Ap2 | 20-38 | 3.80 |
| | Bt1 | 38-95 | 2.80 |
| | Bt2 | 95-140 | 1.30 |
| | Bt3 | 140-200 | 1.30 |
| | | **Mean** | **2.90** |
| | | *% CV* | *53.87* |
| Mid-slope | A1 | 0-16 | 2.20 |
| | A2 | 16-36 | 5.20 |
| | AB | 36-58 | 2.20 |
| | Bt1 | 58-80 | 0.60 |
| | Bt2 | 80-125 | 11.70 |
| | Bt3 | 125-200 | 7.80 |
| | | **Mean** | **5.00** |
| | | *% CV* | *76.85* |
| Low-slope | Apg | 0-8 | 10.70 |
| | Bg | 8-20 | 5.70 |
| | Cg | 20-30 | 3.80 |
| | | **Mean** | **6.70** |
| | | *% CV* | *43.53* |

lower slope position. The hydromorphic nature of the soils at the low-slope position also contributed to organic matter build-up due to reduced rate of organic matter decomposition. Overall, having the highest SOC in the rather hydromorphic low-slope position could be attributed to its expected capacity to retain more water under field conditions due to its highest silt content (Obalum *et al*., 2011b; Ukabiala *et al*., 2021). A recent review by Omokaro (2023) threw more light on the mechanisms by which foot slope positions accumulate organic matter. This situation can benefit availability of micronutrients especially zinc and nickel for lowland rice production (Alarima *et al.,* 2023), which the low-slope position could be good for (Ukaegbu *et al.,* 2023).

Though SOC was observed to increase along the toposequence at the study location, the values were generally very low when compared to Pulido-Moncada *et al*.'s (2015) rating; < 11.6 g kg$^{-1}$ as low, 11.6-23.2 g kg$^{-1}$ as medium, and > 23.2 g kg$^{-1}$ as high. Also, when compared with Enwezor *et al*.'s (1990) rating for soils of southeastern Nigeria, where < 11.6 g kg$^{-1}$ was rated as low, 11.6-17.4 g kg$^{-1}$ as medium, and > 17.4 g kg$^{-1}$ as high, the values were remarkably very low. Enwezor *et al*. (1981) attributed the low SOC content in this region to high moisture and temperature conditions that favour organic matter decomposition. The generally low SOC in this study could be explained by the prevailing warm temperatures, high rainfall and continuous cultivation, all of which lead to SOC losses by facilitated organic matter mineralization and increases in runoff volume and associated selective removal of organic matter and organic colloidal complexes. This situation adversely affects plant-available nutrient and water reserve.

Soil organic carbon (SOC) also decreased with increase in soil depth, except at the mid-slope that exhibited no regular pattern (Table 3). Decreases in SOC with soil depth could be due to the deposition of organic materials on the surface soil with more biological activities (Onah *et al.,* 2021). The results showed no trend in the SOC relationship to soil aggregate stability with pedon depth. However, the low SOC corroborated with the low aggregated stability of the soil along the toposequence, thus highlighting the need for farmers to adopt agronomic practices that incorporate organic matter to the soil. The retention of crop residues and application of animal manures would, by improving SOC content, enhance macro-structure stability of these soils (Ogban, 2021; Onah *et al*., 2023; Obalum *et al*., 2024a, b).

The SOC plays vital roles in the maintenance and improvement of soil properties and functions, such as soil water retention and transmission, aggregate formation and stabilization against erosion and other degradative processes (Lal and Shukla, 2004). Verchot *et al*. (2011) also reported that organic matter in the soil promotes the formation of soil aggregates and thus influences soil structure and stability, through mechanisms such as promoting the binding of soil mineral particles.

Erosion-transport process plays a key role in nutrient and SOC distribution along a toposequence. Wang *et al*. (2023) reported that soil erosion-transport process is the process of SOC transport, and that SOC accumulated on the soil surface is easily lost with the migration of the surface soil. Thus, the higher values of SOC at the low-slope when compared with the values at the top-slope and mid-slope, did not only inform the concentration of farming activity at the low-slope, but also explained the relatively higher soil structure stability observed at the low-slope. The SOC is dynamic and sensitive to management practices (Ogban, 2021), and therefore can be used as an indicator of degradation of soil physical quality and diminishing agronomic function (Obalum *et al*., 2017). Sustainable farming activity at the study location requires the use of plant residues, manures and rotational fallow to improve SOC storage. Soil management must therefore prioritize organic matter in order to prevent the breakdown of macro aggregates into micro aggregates, and protect the soil from erosion and loss of nutrient-rich surface soil.

## 4.0. Conclusions

The study of soil aggregate stability and soil organic carbon (SOC) distribution at three topo-positions along toposequence of Orumba North in the South-East of Nigeria was carried out with the main objective of assessing the influence of topography on soil structure and SOC content. Topography was found to play a role in the transport and deposition of fine organic materials along the toposequence as well as translocation and deposition of particulate constituents in the soil within the pedons. The extent of soil aggregation was generally low at all topo-positions and across the pedon in each topo-position. This translates into poor level of soil structure development and low resistance to soil structure deformation by natural and anthropogenic factors.

Saturated hydraulic conductivity ($K_s$) showed no regular pattern, with the lowest values at the low-slope position impairing drainage, leading to pronounced mottling in the pedon at this topo-position. The SOC contents along the toposequence were typically low, especially below the plough layer and in the surface horizon of top- and mid-slope positions, respectively.

There was an overall tendency for decreasing soil aggregation with increasing SOC content along the toposequence, even with the generally low aggregation and SOC levels in the soils. These somewhat inverse trends of soil aggregation and SOC content along toposequences of the humid tropics provide an indication of the nature of their possible relationship under the likely differences in drainage status of soils occurring on such toposequences.

The low level of aggregation of the toposequencial soils has implications not only for their structure stability and hence resistance to erosion but also for availability of soil water and plant nutrients. Therefore, soil management and conservation efforts should aim at restoring soil quality via practices that promote organic matter addition and build-up in the soils. For a given topo-position and soil depth, such efforts would be deemed adequate when they promote soil structure by leading to formation of large-sized aggregates while reducing aggregate degradation and the associated water erosion.

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