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Hydraulic conductivity, moisture retention capacity, and chemical characteristics of soils at varying slope positions and depths; implication on crop production

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ABSTRACT

The interaction of slope positions and depths in influencing soil condition for crop production is of great concern. A 2 – factor factorial (slope positions and depths) experiment in Randomized Complete Block design was carried-out to assess hydraulic and chemical characteristics of soils at varying slope positions and depths in relation to crop production. Five slope positions (crest, upper, middle, lower slopes, valley bottom) were identified, and three (3) replicates each of disturbed and undisturbed soils were sampled from each slope position at five depths (0- 20, 20-40, 40-60, 60-80, 80-100 cm). Soil samples were processed and analyzed in a laboratory. Results showed a significant ($P \leq 0.05$) interaction effect of slope positions and depths on hydraulic and chemical characteristics of soils. Soil at valley bottom had greatest rate of water flow across depths, while soil at crest had the least. Water retention capacity of soils increased down the slope across depths with the greatest observed at valley bottom. Available phosphorus and organic carbon content varied considerably among slope positions and depths such that soil at crest had increased available phosphorus at higher depths, while soil at middle slope ranked highest at 0-20 and 20-40 cm depths. Soils at lower slope and valley bottom had highest content of organic carbon across depths. All the soils have great potentials for crop production; soils at lower slope and valley bottom can serve for all season vegetable production, while soils at the ascending slopes can sustain arable crop production with effect water and nutrient management strategies.

Keywords: slope positions, depths, crop production, hydraulic conductivity, water retention, chemical characteristics

1. INTRODUCTION

The general fertility and quality of soils in relation to crop production are predicated on their physical, chemical, and biological characteristics (Moses and Christopher, 2024). The dynamics of soil water are of great significance among other physical conditions influencing soil for crop production (Lamptey, 2022). The energy state of soil water as influenced by forces acting on it, is vital in determining the rate of water flow or movement in the soil under both saturated and unsaturated moisture conditions (hydraulic conductivity) and the amount of water retained in the soil (Kool *et al*., 2019). The relevance of the lateral and vertical flow of water in the soil, and the amount of water retained in the soil at varying depths for crop production and overall quality of soil cannot be over-emphasized; soil water plays considerable role in influencing nutrients availability and transportation within a body of soil; activates chemical processes that require hydration and hydrolysis thereby helps in chemical transformations in the soil; promotes microbial activities which results in improved decomposition of organic matters, mineralization, detoxification and chemical transformations that guarantee soil health and fertility for crop production; regulates soil temperature which influences energy states of chemical substances in the soil, seed germination, as well as root growth and ramification (Gong, 2023).

Soil chemical composition including the organic matter content, essential nutrient elements, soil reaction or pH dependent factors are very relevant in fertility and productivity of soils (Smita and Sangita, 2015). Organic matter serves to promote microbial activities, enhance soil structural stability, improves soil buffering capacity and cation exchange capacity (Smita and Sangita, 2015). The essential nutrient elements are inevitable in plant nutrition; they serve as sources of plant mineral nutrition, such that in their absence or limited supply, plants manifest deficiency symptoms including poor yield, stunted growth, crop failure or death of plants (Nkanyiso and Lembe, 2019). Soil reaction which constitutes the concentration of active hydrogen ions (pH) and other exchangeable ions which influence soil acidity including, exchangeable hydrogen ion, aluminum ion, and iron (iii) ion, has been found to bear considerable influence on varying chemical processes in the soil including nutrients availability; soil biodiversity, population and activities of soil organisms; availability toxic heavy metals and micronutrients in the soil; choice of crop as well as root growth and development (Nwawuike *et al*., 2024). Meanwhile, Amanze *et al*. (2022) noted that soil reaction could be a function of land use system, soil management practices, fertilization and manuring, drainage pattern, leaching, nature of parent material, plant uptake of nutrients, acid rain, etc.

Topography is among the factors influencing soil formation; hence, the degree of sloppiness of land as well as length and pattern of land slope substantially affects degree of surface runoff and drainage pattern within the soil both laterally and vertically (Delin *et al*., 2000). The lateral flow of water is usually from the ascending to the descending slope which gives rise to erosional and depositional surfaces, respectively, along the slope (Delin *et al*., 2000). Consequently, as materials such as colloidal particles (including nutrients and humic substances), and solid mineral particles (sand, silt and clay) are detached from the erosional surfaces and moved to the depositional surfaces by agents of erosion at varying periods and locations, there occurs differences in the physical and chemical composition of soils across the slope; a condition known as toposequence (Godspower, 2023). Therefore, there is always notable variation in soil physical and chemical conditions along a sloping land, which obviously influences the productivity of crops cultivated at these slope positions of a land (Tenagne *et al*., 2025).

Similarly, vertical flow of water across soil column brings about vertical translocation and deposition of materials across the depths, and this gives rise to variation in soil properties along the depths of soil (Amanze et al., 2023). Such changes in soil condition across depths control nutrients availability for plant uptake, root penetration and ramification, root respiration and access to water, microbial population and activities (Amanze et al., 2023).

Notwithstanding, there is dearth of information on the effect of interaction of slope positions and depths on soil physical and chemical conditions. Therefore, this study aims at assessing the effect of interaction of slope positions and depths on hydraulic conductivity, moisture retention capacity and chemical characteristics of soils formed on Coastal Plain Sands along a sloppy landscape.

2. MATERIALS AND METHODS

Study area and Site characterization

This study was conducted on soils along a toposequence at Oboro in Ikwuano Local Government Area of Abia State, Nigeria. The area lies within latitude 05^{o} 27′ N and longitude 07^{o} 32′E in the rainforest area of South-Eastern Agro-climatic zone of Nigeria. The area is characterized by a fairly uniform mean daily temperature of 27^{0} C all through the year, relative humidity of the range 51 to 87%, diurnal sunshine of 3-7 hours, and mean annual rainfall of 2200 mm. The topography of the land is gently sloped, and the vegetation is typical of the tropical rainforest zone (Amanze *et al*., 2023). The parent material of the area is the Coastal Plain Sands, and the area is dominated by the Ultisols and localized areas of Inceptisols according to the United State Department of Agriculture (USDA) soil taxonomical order (Amanze *et al*, 2016). Textural characteristics and bulk density of soils at the various slope positions are such that, at the crest; sand, silt, clay, and bulk density are 718.9 g/kg, 24.1 g/kg, 256.9 g/kg, and 1.71 mg/m^{3}, respectively. At the upper slope; sand, silt, clay and bulk density are 699.7 g/kg, 143.3 g/kg, 156.9 g/kg, and 1.57 mg/m^3, respectively. At the middle slope; sand, silt, clay, and bulk density are 666.5 g/kg, 44.4 g/kg, 288.5 g/kg, and 1.50 mg/m^3, respectively. At lower slope; sand, silt, clay, and bulk density are 680.0 g/kg, 67.5 g/kg, 252.5 g/kg, and 1.63 mg/m^3, respectively. At the valley bottom, sand, silt, clay, and bulk density are 697.3 g/kg, 102.7 g/kg, 200.0 g/kg, and 1.53 mg/m^3, respectively (Nwosu *et al.*, 2024).

Soil sampling and sample preparation

The toposequence was delineated into five (5) slope positions namely; Crest, Upper slope, Middle slope, Lower slope, and Valley bottom. Three (3) replicates each of soil core and auger samples were randomly collected at each slope position across five (5) depths of 20cm interval starting from 0 – 20, 20 – 40, 40 – 60, 60 – 80, and 80 – 100 cm depths.

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 to separate fine earth fractions, and were packed in well labeled polythene bags for laboratory analyses.

Laboratory analyses

Saturated hydraulic conductivity (K_{sat}): This was determined by the constant head method outlined in Klute (1986), while saturated hydraulic conductivity (K_{sat}) of the soil was calculated using Darcy's equation as explained in Youngs (2001) as shown below:

$$\text{Ksat} = \frac{\text{QL}}{\text{AT}\Delta\text{H}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. Eq.\ 1$$

Where Q is quantity of water discharged (cm^3), L is length of soil column (cm), A is interior cross-sectional area of the soil column (cm^3), ΔH is head pressure difference causing the flow or hydraulic gradient, and T is Time of water flow (seconds).

Soil water retention characteristics: field capacity (FC), permanent wilting point (PWP) and available water content (AWC) was determined following the procedure outlined in Mbagwu (1992). Core soil sample was put in basin containing water such that the water level was nearly four – fifth (4/5) of the height of the core sampler. The soil was allowed to saturate. The mass of the saturated soil (M_1) was recorded. The saturated soil was allowed to drain for two days and thereafter, its mass (M_2) was recorded. The same soil was allowed to drain further to 11th day and thereafter, its mass (M_3) was recorded. After the drainage, sample was oven - dried at a temperature of 105^{O}C and the oven – dry mass (M_4) was recorded.

The percentage moisture at field capacity (FC) on a dry mass basis was calculated as follows.

$$\%\ \text{FC} = \frac{\text{M2} - \text{M4}}{\text{M4}}\ X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. Eq.2$$

The percentage moisture at permanent wilting point (PWP) on a dry mass basis was calculated as:

$$\%\ \text{PWP} = \frac{\text{M3} - \text{M4}}{\text{M4}}\ X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. Eq.3$$

The available water capacity (AWC) was obtained as the difference between the moisture content at field capacity (FC) and moisture content at permanent wilting point (PWP).

% AWC = % FC - % PWP …………………………………………………………… Eq. 4

Soil Organic carbon was determined using wet oxidation method of Walkey and Black as reported in Nelson and Sommers (1982). **Available phosphorus** was determined by obtaining the supernatant solution using Bray I extraction method, then the extract was determined using a spectrophotometer as described in Bray and Kurtz (1945).

Exchangeable basic cations were extracted with normal Ammonia Acetate (NH_4OA6) at pH 7, then Calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined in the extract by ETDA titration method outlined in Udo *et al*. (2009), then potassium (K^+) and sodium (Na^+) were determined by the use of flame photometer (Udo *et al*., 2009).

Exchangeable acidity comprising of exchangeable aluminum (Al^+) and exchangeable hydrogen (H^+) was extracted with INKCL as described by Udo *et al*, (2009), and 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 expressed.

Experimental Design and Data Analysis

The research was laid-out in a 2 – factor factorial experiment under Randomized Complete Block Design (RCBD). The two factors were slope position and depth; the slope position was of five (5) levels (crest, upper slope, middle slope, lower slope, and valley bottom), and depth was also of five (5) levels (0-20, 20-40, 40-60, 60-80, 80-100 cm), and these were replicated three (3) times to give seventy-five (75) observational units. Data obtained from the experiment was analyzed for variation through Analysis of Variance (ANOVA) statistical approach using Statistical Analysis for Sciences (SAS) analytical package. Significantly different means of treatments were separated using Fisher's Least Significant Difference at 5 % level of confidence.

3. RESULTS & DISCUSSION

Effects of slope positions and depths on hydraulic conductivity (K_{sat}), field capacity (FC) and AWC

Figures 1a, b and c show that there was significant interaction (P≤5%) of slope position and depth on hydraulic conductivity (K_{sat}), field capacity (FC) and available water content (AWC).

The highest values of K_{sat} (22.78, 16.67, 19.07, 5.32, and 2.96 cm/min) were obtained at the valley bottom across all the depths from 0-20cm to 80-100cm depths, accordingly. These values differed significantly from values obtained at the other soils except at the 80-100cm depth where valley bottom was not substantially different from the lower slope. Contrariwise, the lowest values of K_{sat} (5.46, 2.33, 1.40, 0.84, and 0.62 cm/mins) were observed at the crest across all the depths from 0-20cm to 80-100cm depths. This differed significantly from values observed at other soils except at 20-40cm to 80-100cm depths where the crest was not significantly different from the upper slope.

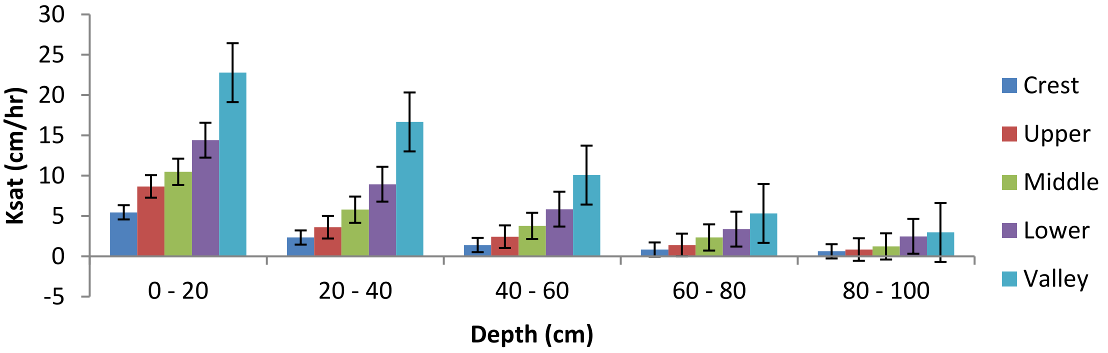

Fig. 1 a. Effect of slope position and depth on K_{sat} ($LSD_{(0.05)} = 1.56$)

The highest values of water content at field capacity (FC) (21.80, 24.70, 28.03, 29.97, and 30.77 %) were observed at the valley bottom across the respective depths from top to base. These varied significantly from those of soils at the other slope positions at the respective depths. Conversely, the lowest values of FC (10.07% and 10.84%) were obtained at the upper slope at the 0 – 20 cm and 20 – 40 cm depths, respectively. However, the value at the upper slope was not significantly different from the crest at the 0-20cm depth. At 40-60cm, 60-80cm, and 80-100cm depths, the lowest values of FC (12.93%, 16.03% and 16.24%, respectively) were obtained at soil at the crest, but not significantly different from that of the upper slope at 40-60cm and 60-80cm depths.

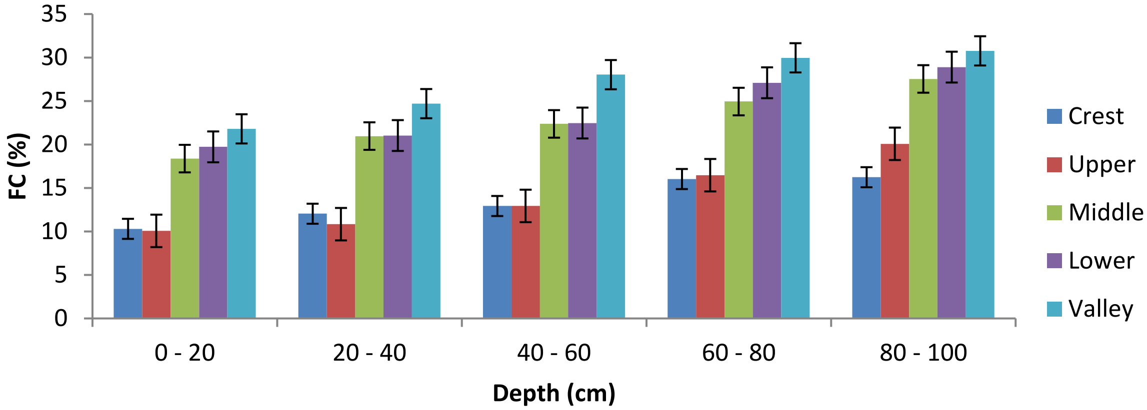

Fig. 1 b. Effect of slope position and depth on field capacity (FC) (LSD$_{(0.05)}$ = 1.15)

The highest values of water content at available water capacity (AWC) (16.83%, 18.86%, 21.37%, and 22.23%) across the depths of 0-20cm, 20 – 40cm, 40 – 60 cm, and 60-80cm, respectively were obtained at the valley bottom while at 80-100cm depth, the highest value (22.32%) was observed at the lower slope though was not significantly different from the valley bottom. On the other hand, at 0-20cm and 20-40cm depths, soil at the upper slope had the lowest values of AWC (6.26% and 6.53%, respectively), but were not considerably different from those observed at soil on crest. At 40-60cm, 60-80cm, and 80-100cm depths, the lowest values of AWC (8.15 %, 10.94 %, and 10.78 %, respectively) were observed at the crest, but were not significantly different from soils at the upper slope at 40-60cm and 60-80cm depths.

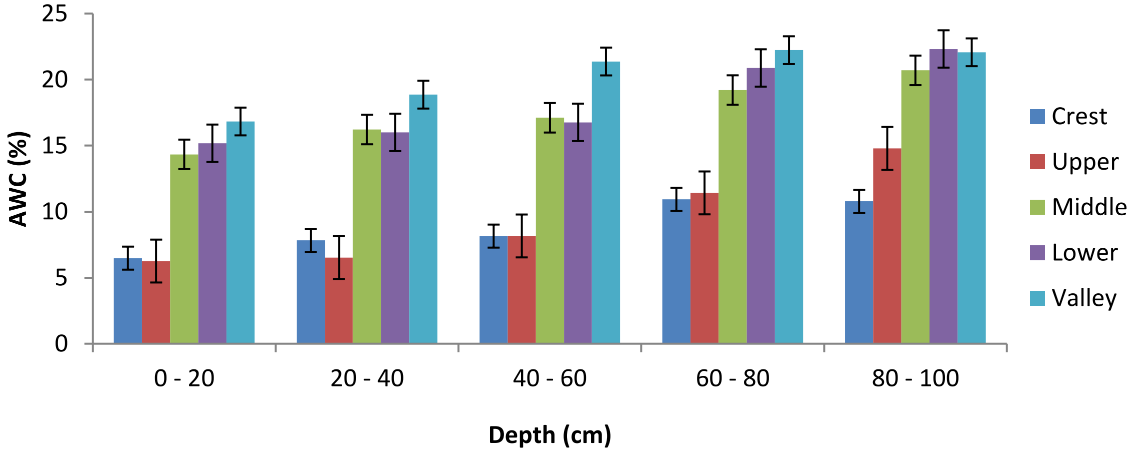

Fig. 1 c. Effect of topounit and depth on available water capacity (AWC) (LSD$_{(0.05)}$ = 1.06)

The most rapid rate of water flow in soil under saturated condition (saturated hydraulic conductivity) at the valley bottom across the various depths could be attributed to the unconsolidated nature of its particles, which possibly gave rise to increased number of macropores which enhanced the permeability of the soil (Amanze et al., 2023). Conversely, the reduced rate of water flow across depths of soil at the crest may have resulted from its increased bulk density arising from increased sand and reduced organic carbon (OC) contents; also, the increased bulk density that hampered water flow at soil on the crest and upper slope may have resulted from increased soil compaction by human activities and raindrop impacts considering the slope position of the area (Amanze et al., 2023). The increased capacity of soils at the descending slopes to retain water at field capacity (FC) and available water capacity (AWC) could be associated with their relatively higher OC and clay contents, which corroborates the report of Amanze *et al*. (2024) that soils moisture retention characteristics correlated significantly positive with clay; hence, higher clay content increases water retention capacity of soils.

Effect of slope positions and depths on available phosphorus (Avail P) and organic carbon (OC) in the soils

Figures 2 a and b, show significant interaction (P≤5%) of slope positions and depths in influencing available phosphorus (avail P) and organic carbon (OC) The highest value (16.40 mg/kg) of avail P at 0-20cm depth was observed at the middle slope, while the lowest (11.50 mg/kg) was observed at the lower slope, and these values were significantly different (P≤5%) from values observed at soils on the other slope positions at this depth. At 20-40cm depth, the highest value (25.80 mg/kg) was observed at the crest, while the lowest value (14.20 mg/kg) was obtained at the middle and lower slopes. These slope positions varied significantly (P≤5%) from the others at this depth, accordingly. The middle slope had the highest value (24.70 mg/kg), while the lowest (14.20 mg/kg) was observed at the crest and valley bottom within 40-60cm depth. These slope positions were significantly different from the other slope positions, accordingly. The upper slope was highest (32.90 mg/kg) in avail P at 60-80cm depth while the lower slope was lowest (10.40 mg/kg). These were significantly different from the other slope positions, accordingly. Also, the lowest (12.00 mg/kg) was obtained at the valley bottom within the 80-100cm depth.

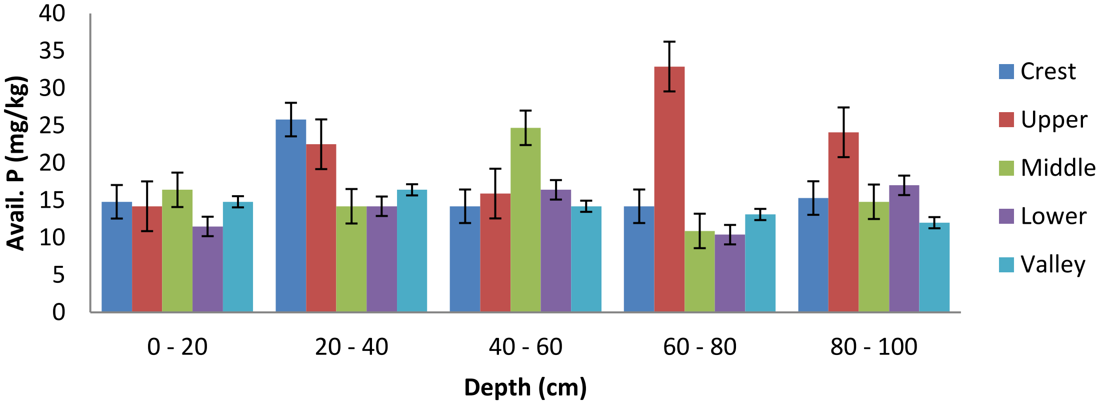

Fig. 2a Interaction effect of topounits and depth on avail P ($LSD_{(0.05)} = 0.23$)

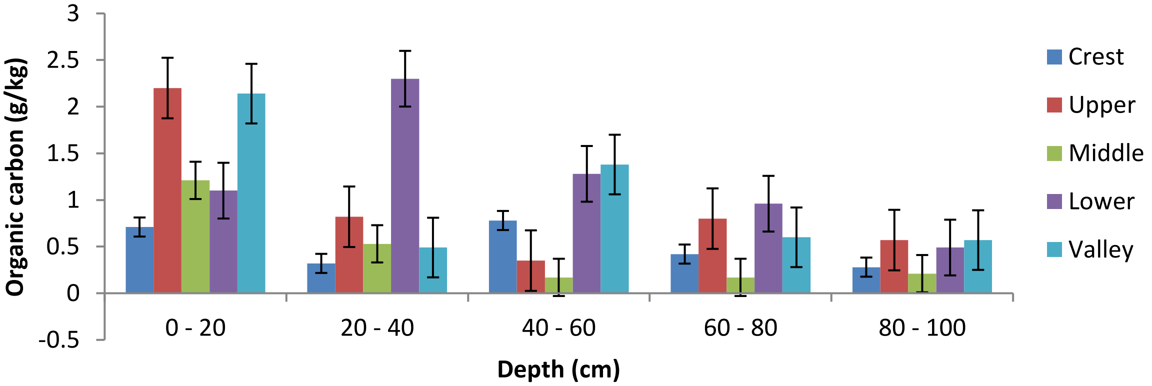

Fig. 2 b. Effect of slope position and depth on organic carbon ($LSD_{(0.05)} = 0.08$)

Organic carbon within 0-20cm depth was highest (2.20 %) in the soil at the upper slope, but was not significantly different from that of the valley bottom (2.12 %), while the lowest (0.71 %) was obtained at the crest. At the 20-40cm depth, soil at the lower slope had the highest organic carbon (2.30%), while the lowest (0.32%) was obtained at the crest, and these varied significantly (P≤5%) from the others, accordingly. At 40-60cm depth, the highest value (1.38%) was obtained at the valley bottom, while the lowest (0.17%) was at the middle slope. The lower slope had the highest (0.96%), while the lowest (0.17%) was observed at the middle slope within the 60-80cm depth. These varied significantly (P≤5%) from the other slope positions in OC. At 80-100cm depth, the highest (0.57%) was obtained at the valley bottom and upper slope, while the lowest (0.21%) was obtained at the middle slope, and this was not significantly different from the crest.

The considerable variation of available phosphorus across the slope positions and depths may be a result of differences in the degree of translocation of phosphorus along the slope and down the depths of soil with time. This may have resulted from the gently undulating nature of the topography of the landscape (Delin *et al.*, 2000) and probable increased immobilization of phosphorus at the ascending slopes due to increased fixation of phosphorus arising from the likely increase in the acidity of soils at that region. The significant increase in organic carbon (OC) content at the descending slope (lower slope and valley bottom) than the ascending slope (middle slope, upper slope and crest) with depths could be attributed to the ease at which organic materials are transported across the topography via surface run-off and internal lateral drainage from the erosional surface (ascending slope) to the depositional surface (descending slope) (Delin *et al.*, 2000).

Effects of slope positions and depths on the exchangeable Calcium, Magnesium, and Potassium

Figures 3a, b and c, show that the interaction of slope position and depth was significant (P≤5%) in influencing exchangeable calcium (Ca), magnesium (Mg), and potassium (K), respectively. The highest value of Ca (6.00 cmol/kg) at 0-20cm depth was observed at the crest, while the lowest (4.40cmol/kg) was observed at the middle and lower slopes. Also, the crest had the highest value (5.20 cmol/kg) at the 20-40cm depth, while the lowest (3.60 cmol/kg) at this depth was obtained at the lower slope. At 40-60cm depth, the crest also had the highest (6.00 cmol/kg), while the middle slope had the lowest (4.00 cmol/kg). These slope positions varied significantly from the others at the respective depths. Furthermore, at 60-80cm depth, the highest value of 4.40 cmol/kg and lowest value of 3.00 cml/kg were obtained at the upper slope and crest, respectively. At the 80-100cm depth, the highest (6.00 cmol/kg) was observed at the valley bottom, while the lowest (3.60cmol/kg) was obtained at the upper and middle slopes.

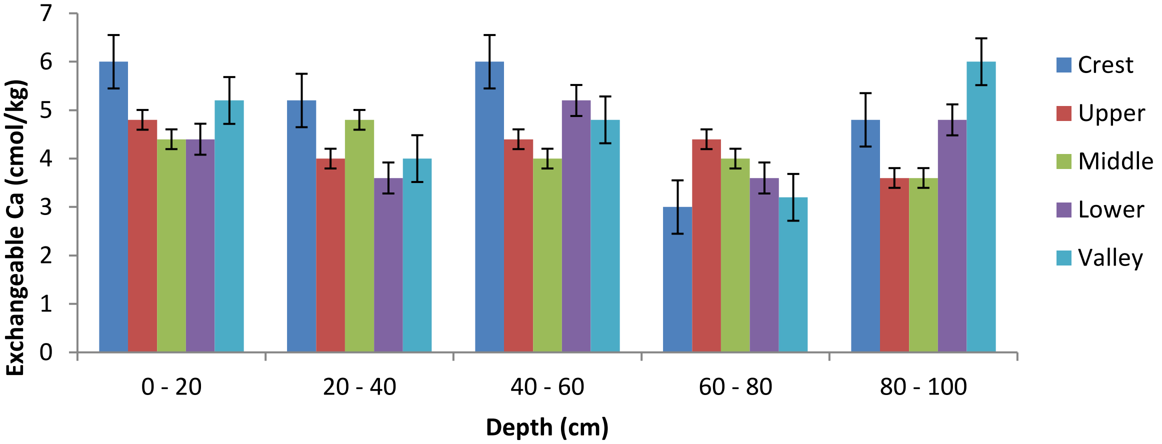

Fig. 3 a. Effect of slope position and depth on exchangeble Ca ($LSD_{(0.05)} = 0.25$)

Across the depths, crest had the highest value of exch. Mg except at the 40-60 cm depth where it had the lowest value (2.00 cmol/kg), which were not considerably different from the lower slope and valley bottom, while the middle slope had the highest (2.80 cmol/kg). The lower slope had the lowest values of exchangeable Mg across the depths, but it was not numerically different from the valley bottom (2.40 cmol/kg) at 0-20cm depth, valley bottom, and crest at 40-60cm (2.00cmol/kg) and 60-80cm (2.40 cmol/kg) depths. Again, at 80-100cm depth, it had the value (2.40cmol/kg), which varied significantly from soils at the other slope positions.

The exchangeable potassium (exch K) at 0-20cm depth was highest (0.19 cmol/kg) at the crest and lowest (0.14 cmol/kg) at the upper slope and valley bottom, though the upper slope and valley bottom were not significantly different from the middle slope. At 20-40cm depth, the highest (0.36 cmol/kg) was observed at the valley bottom, while the lowest (0.12 cmol/kg) was observed at the upper slope, and they differed significantly from soils at the other slope positions. Soil at the crest had the highest (0.18 cmol/kg) at the 40-60cm depth, while the lowest (0.10 cmol/kg) was the upper slope but was not substantially different from the middle slope and valley bottom. Also, at 60-80cm depth, the soil at the crest had the highest (0.18 cmol/kg), while the upper slope had the lowest value (0.10 cmol/kg) but was not significantly different from soils at the other slope positions except the crest. At 80-100cm depth, the highest value

(0.20 cmol/kg) was observed at soil on the crest, while the lowest (0.13 cmol/kg) was observed at the upper, middle, and lower slope positions.

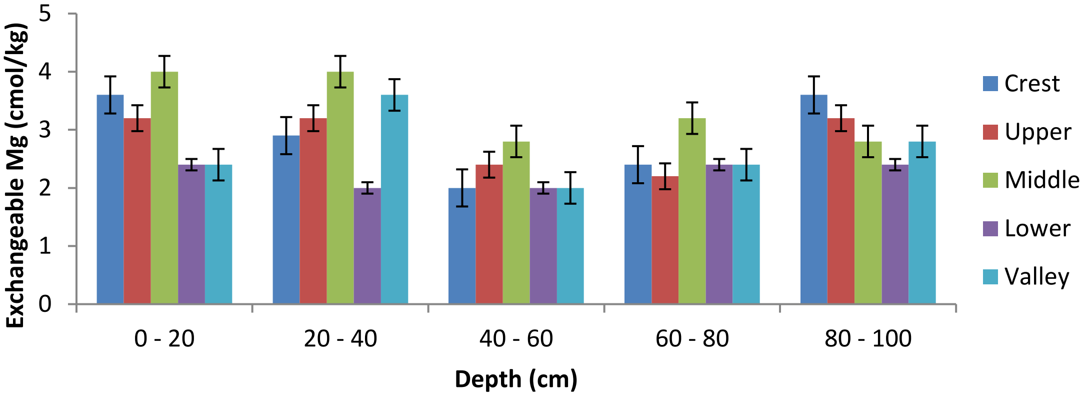

Fig. 3 b. Effect of slope position and depth on exchangeable Mg ($LSD_{(0.05)}$ = 0.27)

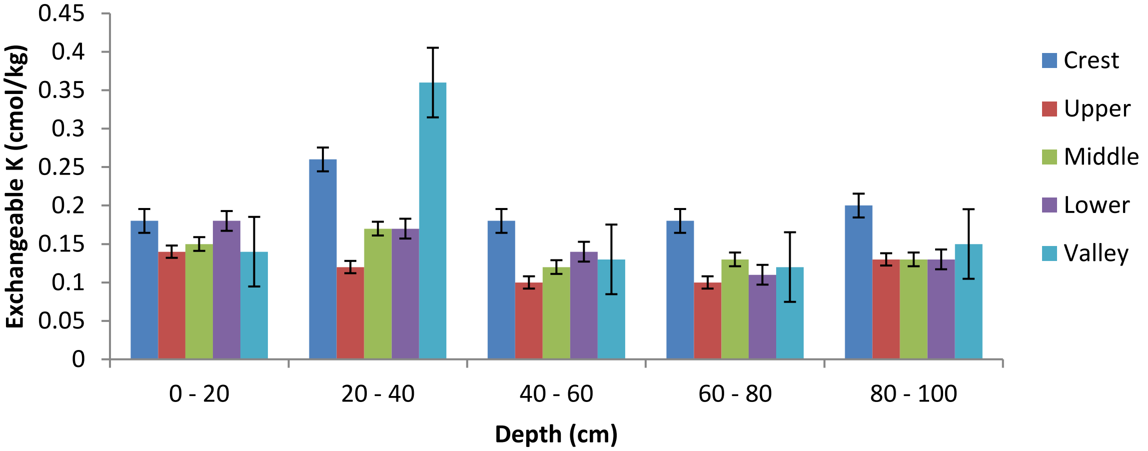

Fig. 3 c. Effect of slope position and depth on exchangeable K ($LSD_{(0.05)}$ = 0.02)

The notable increased concentration of exchangeable calcium (exch. Ca) at the crest compared to the other slope positions at the various depths could be attributed to its inherent property as the oldest soil and the primary recipient of the product of weathering of the parent material, which includes release of basic cations. Meanwhile, the appreciable concentration of exchangeable Ca at soil on the valley bottom was possibly a result of lateral translocation of exchangeable Ca along the toposequence from the ascending to the descending slopes leading to appreciable deposition of exchangeable Ca at the valley bottom (Godspower, 2023). The significant higher exchangeable Mg at the middle slope relative to the other slope positions across the depths could be a resultant action of considerable mobility of exchangeable Mg from the crest to the middle slope. Also, the gentle sloppiness of the geomorphic surfaces may have decreased the translocation of exchangeable Mg from the middle slope to the descending slope positions, hence the accumulation of exchangeable Mg at the middle slope across the depths. The highest exchangeable potassium (exch K) content across the depths at the crest suggests that K translocation along the slope positions from the crest was minimal due the possible increased fixation of K at the crest and the gently slope nature of the toposequence, which retarded the rate of flow of material through lateral drainage (Welte and Nlederbudde, 1965). Hence, the degree of soil erodibility and materials translocations via runoff and subsurface lateral drainage were not significant to deplete the K content at the crest. This effect therefore, could not considerably increase K accumulation at the lower slope and valley bottom (Delin *et al*., 2000). Generally, it could be noted that soils at the lower slope and valley bottom are young soils resulting from the accumulation of unconsolidated eroded materials (alluvial deposits) from the older soils, that is, soils at the crest and upper slope positions; hence is characterized by lesser chemical composition compared to their parent soils (Onweremadu et al., 2007).

Effects of slope positions and depths on exchangeable acidity (EA)

Figure 4 shows that there was a significant interaction (P≤5%) effect of slope position and depth on EA. The lower slope had the highest values (5.20, 4.80, 4.40, and 5.6 cmol/kg) of EA across the depths, respectively, except at 20-40cm depth where the highest value (2.56 cmol/kg) was observed at the crest, and this was not significantly different (P≥5%) from the lower slope and valley bottom. The lowest values of EA (1.04, 0.92, 1.72, and 0.80 cmol/kg) were obtained at the upper slope across the depths, accordingly, except at the 0-20cm depth where the lowest value (1.60cmol/kg) was obtained at the valley bottom, though was not significantly different from the upper slope.

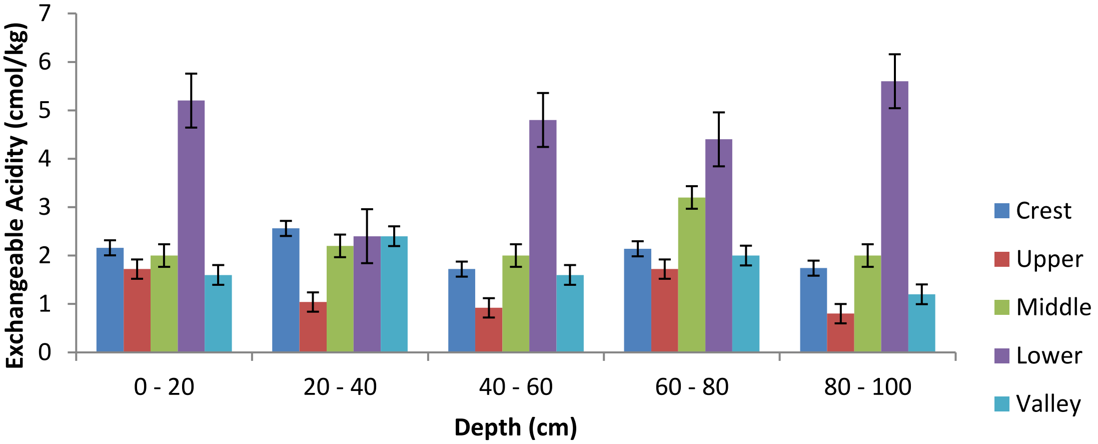

Fig. 4. Effect of topounit and depth on exchangeable acidity ($LSD_{(0.05)} = 0.21$)

The highest exchangeable acidity (EA) at the lower slope could be attributed to its low content of exchangeable bases; hence, aluminum and hydrogen ions saturated and dominated the exchange sites (Jiayi *et al*., 2025). Conversely, the low EA at the upper slope was probably due to the considerable concentration of basic cations that saturated the exchange site thereby displacing the Al^{3+} and H^{+}.

Implications of hydraulic and chemical characteristics of the soils on crop production

The increased permeability of water across depths of soil at the valley bottom implies that there is a possibility of increased leaching of mobile nutrient elements, including nitrogen, phosphorus, potassium, and calcium, which may impoverish soils at the rooting zones of crops and limit the amount of nutrients available for plant uptake (Addiscott and Whitmore, 1991). Consequently, shallow-rooted crops planted on soils at the valley bottom are likely to suffer deficiency symptoms including poor yield if not remedied. Meanwhile, the soil may sustain the cultivation of deep-rooted crops, considering the possible increased concentration of leached nutrient elements at the residing depths (Nkanyiso and Lembe, 2019). However, the increased capacity of soil at the valley bottom to retain water at varying depths implies that the soil can provide the water needs of crops in all season; hence, can sustain year-round cropping which would enhance food security. This assertions agree with the reports of (Lamptey, 2022) that water is the major limiting factor in crop production because it significantly regulates plant nutrition. Conversely, the poor permeability of soil at the crest may result in increased surface runoff and the resultant increase in soil erosion; a situation that may negatively impact crop production due to the possible washing away of planted seeds, rooting out of growing crops, and loss of topsoil, which may limits the growing of crops in such regions (Nwosu *et al*., 2024). Also, the poor water-holding capacity of soil at the crest suggests that the soil may not adequately support crop production during a dry season or dry spell period without irrigation, and this may limit the use of the area for crop production during such period or increase the cost of crop production if an irrigation programme is to be introduced. This confirms the report that water stress in plants resulting from limited available water content in soils leads to crop failure or poor yield (Lamptey, 2022).

The increased exchangeable acidity of soil at the lower slope positions may have brought about a possible increase in phosphorus fixation, which was probably the reason for decreased concentration of available phosphorus at its various depths compared to soils at the other slope positions, and this may limit plants' access to phosphorus for their nutrition. This claim is in concord with the report of Amanze *et al*. (2022) that exchangeable acidity has a negative influence on phosphorus availability because of increased phosphorus fixation by exchangeable Al. Contrariwise, the decreased exchangeable acidity and increased organic carbon content across depths of soil at the valley bottom may have enhanced phosphorus availability and ease of its access by crops across depths of the soil. Consequently, crops at the ascending slope may manifest phosphorus deficiency symptoms if there is no extraneous input of phosphorus, irrespective of their increased content of available phosphorus compared to soils at the descending slope positions (Nkanyiso and Lembe, 2019).

4. CONCLUSION

Slope positions and depths greatly influence hydraulic conductivity, moisture retention capacity, and chemical characteristics of coarse-texture soils formed on Coastal Plain Sands. Soils at the descending slope positions especially the valley bottom are considerably permeable with adequate water retention capacity at the various depths, while soils at the ascending slope positions especially at the crest are poorly permeable with least capacity to retain water at all the depths. Soils at the valley bottom are rich in organic matter content, total exchangeable bases, and percentage base saturation at all the depths, but are poor in available phosphorus. In contrast, soils at the ascending slope positions and mid slope are better in some chemical characteristics except for their poor organic matter content at all the depths. Therefore, soils at the valley bottom can effectively support year – round vegetable crop production, cultivation of maize and low land rice, but with effective soil nutrient management strategies such as regulated application of phosphorus - containing mineral fertilizers. Similarly, for sustainable crop production, soils at the ascending slope positions especially the crest require extraneous input of organic matter through manuring to improve its permeability, water retention capacity, and soil reaction across the depths.

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Author's Contribution

Amanze, C. T. participated in designing the research and preparation of the manuscript for publication, Nwosu, O. C., assisted in conducting the field work and data collection, Ukabiala, M. E., and Ibo, O. K. aided in data analysis and interpretation, while Onyechere, A. U., Okereafo, D., and Eluagu, K. F. independently contributed in reviewing and proofreading the manuscript for correctness.

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Conflict of interest

The authors declare that they have no conflicts of interests, competing financial interests or personal relationships that could have influenced the work reported in this paper.

Ethical approval

Not applicable. This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent

Not applicable.

Data availability

All data associated with this study will be available based on the reasonable request to the corresponding author.

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