Discovery

Texture-related characteristics, fertility indices, and organic carbon storage of soils as influenced by lithological and depth-base variations; an agronomic implication

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ABSTRACT

The influence of parent material and depth on soil properties is a long-standing knowledge, but in the prevailing climate change, it is paramount to reassess and compare the characteristics of soils formed on varying parent materials at different depths with regards to soil management and crop production. This study aims at to assess the physicochemical properties and organic carbon storage of soils on varying parent materials and depths. It was a 2 - factor factorial experiment in a randomized complete block design (RCBD) with 3 levels of depths (0 -19, 20- 39, 40- 100 cm) and 5 levels of parent materials (Coastal Plain Sands, Shale, Imo clay Shale, Sombreiro Warri Deltaic formation, and mangrove swamp deposit. Three (3) replicates of auger and core soil samples were collected randomly at each site at the reference depths. The samples were processed and sent for laboratory determinations. Data obtained was subjected to analysis of variance, and correlation analysis. Fisher's Least Significant Difference at 5% probability level was used to separate significant means. Results obtained showed that there was a significant interaction effect ($P \leq 5\%$) of parent material and depths on organic carbon storage and physicochemical properties of soil. Soil at Shale had the highest bulk density at the various depths, while the soil on Sombreiro Deltaic Deposit had the lowest. Across all the depths, soil on Coastal Plain Sands had the greatest water conductivity, while soil on Imo Clay Shale had the lowest. The soil pH varied from moderately to strongly acidity, and it decreased with depth at soil on Coastal Plain Sands, but increased with depth at soil on Shale and Imo Clay Shale. However, the soil pH fluctuated across depths of the other soils. The soils derived from the various parent materials vary considerably in the measured parameters at the various depths. Consequently, the soils should be given specific attentions in land use allocation and management practices for crop production.

Keywords: organic carbon storage, parent materials, Soil depth, Coastal Plain Sands, Imo Clay Shale, Sombreiro

1. INTRODUCTION

The geological formation of soil often referred as parent material is a significant driving force which influences the physical and chemical characteristics of soil (Oyetola, 2014). Soil textural class, structure, bulk density, and specific surface area of mineral particles of soil are among the physical conditions of soil under the control of parent materials. These properties directly and indirectly influence the physical characteristics of soils, such as water retention and transmission properties, nutrient holding capacity, soil aeration, thermal properties, etc (Ibe, 2014). The report of Soropa et al. (2021) informed that chemical characteristics of soils, including nutrient composition, concentration of cations and mineral composition, as well as soil fertility, are greatly influenced by parent materials. Lekwa and Whiteside (1986) earlier reported that parent materials form the bedrock of soil formation. They highlighted that their weathering results in the formation of a geological material known as saprolite, which could support primitive plants, and over time, by its interaction with organic deposits, form a body of soils that is capable of supporting higher plants. Consequently, soil physical and chemical properties could vary considerably with parent materials.

Most soils of the Niger-Delta area of Nigeria are derived from sedimentary materials of alluvial deposits, such as the Coastal Plain Sands of Benin formation; Imo Clay Shale; Sandstones; Basement Complex, and unconsolidated sediments of quaternary alluvium (deltaic formation and mangrove swamp deposits) (Lekwa and Whiteside, 1986). These parent materials vary substantially in physical and chemical characteristics; hence, they impact varying characteristics on soils derived from them (Ibe, 2014). For instance, soils derived from Shale parent material often have higher mineral fertility and carbon retention due to its fine texture and mineral content (Soropa *et al.,* 2021), while sandy soils derived from Coastal Plain Sands may have lower fertility potential due to higher rates of leaching and increased loss of organic matter resulting from rapid rate of decomposition due to increased aeration and oxidation (Amanze *et al.,* 2024a). Meanwhile, soil derived from the Sombreiro Warri Deltaic deposit may be characterized by increased sand content, and may have a higher deposit of organic carbon storage. However, soils of the Mangrove Swamp may be notable for increased organic matter deposits due to their origin. They may contain cat clays commonly associated with increased acidity (very low pH) (Lekwa and Whiteside, 1986).

Variation of soil properties across depth of a body of soil is an established phenomenon especially for old soils (Amanze et al., 2024a). However, there may be notable differences in soil properties at referenced depths of soils derived from differing parent materials. This speculation is predicated on the understanding that parent materials impact the holistic influence on the body of soils within a landscape (Soropa *et al.,* 2021). Variations in porosity, permeability, texture, and structure of soils derived from contrasting parent materials can influence the transportation and transmission of materials across soil depths, which may impact differences in physicochemical properties of the soils at reference depths (Amanze *et al.,* 2024). Furthermore, the differences in the mode of formation and origin of the parent materials, such as depositional processes, may control the physicochemical properties and organic matter accumulation at varying depths of soils (Lekwa and Whiteside, 1986). These speculations underscore or mirror the need to assess soils on varying parent materials at various depths to ascertain the degree of variation among them in terms of physicochemical properties and organic carbon storage. The essence is to enhance location-based and site-specific cropping systems, and soil management practices for sustainable crop production and environmental health.

Soil organic matter is a relevant factor in soil quality assessment. The fertility, productivity, quality, and health of soil could be predicted on the organic carbon storage (Amanze et al., 2024b). Increased organic carbon (OC) content f soils often translates to improved biodiversity, which correlates significantly positive with the ability of soil to perform its ecosystem functions, including nutrient cycling and chemical transformations (Ibe, 2020). Soil OC also plays a relevant role in soil buffering capacity, improves structural parameters, such as aggregation and aggregate stability, bulk density, water retention, and transmission properties, etc (Okebalama, 2016). Therefore, the ecological significance of soils derived from varying parent materials across depths could be based on their organic carbon content and storage. Generally, the agronomic relevance of soils anchors on their fertility and productivity, which revolve around their physical and chemical characteristics. This study therefore aims to assess the organic carbon storage, and physicochemical properties of soils derived from varying parent materials at varying depths.

2. MATERIALS AND METHODS

Locations of the study areas

The study was carried out at Isieke; Okigwe; Agbala; Kpong; and Isiokolo; in Abia, Imo, Rivers and Delta States. These areas make up part of the Niger-Delta region of Nigeria, and falls within latitudes 4° N to 7° N and longitudes 5° E to 9° E. Detailed geographical information of each of the study locations is shown in Table 1.

Table 1. Geographical information of sampled sites under the parent materials

Locations	Parent Material	Sampling Units	Area (ha)	Latitude	Longitude	Elevation (masl)
Isieke (Abia)	CPS	C-01	5	05°25′41″N	07°31′13″E	182
		C-02		05°25′16″N	07°31′18″E	180
		C-03		05°25′08″N	07°31′10″E	181
Okigwe(Imo)	SHL	S-01	5	05°50′28″N	07°18′35″E	186
		S-02		05°52′43″N	07°18′45″E	178
		S-03		05°52′28″N	07°18′17″E	183
Agbala (Imo)	ICS	I-01	5	05°19′55″N	07°05′17″E	97
		I-02		05°17′54″N	07°05′36″E	98
		I-03		05°18′14″N	07°05′54″E	100
Kpong (Rivers)	SDD	SD-01	5	04°41′42″N	07°24′10″E	30
		SD-02		04°40′24″N	07°24′20″E	27
		SD-03		04°40′19″N	07°24′30″E	25
Isiokolo (Delta)	MSD	M-01	5	05°29′00″N	05°59′16″E	15
		M-02		05°28′38″N	05°59′51″E	20
		M-03		05°28′10″N	06°00′02″E	18

CPS - Coastal Plain Sands, SHL - Shale, ICS - Imo Clay Shale, SDD - Sombreiro Warri Deltaic Deposit, MSD - Mangrove Swamp Deposit

Geology, topography, climate and vegetation of the study area

The soils of Coastal Plain Sands is of Benin formation (Lekwa and Whiteside, 1986; Nuga and Akinbole, 2012). Soils of shale is of Ajali formation (Ojanuga, 1977). While soils of Imo clay shale is of Imo formation of the tertiary period. The residuum of this shale formation is the parent material of the soils (Ojanuga, 1997). Soils of Sombreiro Warri Deltaic deposit is of the Deltaic Plain Sands which are connected with the sea by a large number of creeks. The general geology of the Deltaic soil essentially reflects the influence of the movement of rivers in the Niger Delta, in their search for lines of flow to the sea with consequent deposition of transported sediments (Lekwa and Whiteside, 1986; FDALR, 1990). The soils of the mangrove swamp deposit are of Deltaic clayey/silt sands (FDALR, 1990).

The topography of the five (5) locations is nearly level to gently undulating (0 -3 %), and the altitude ranged from 14 masl to 600 masl (Ibe, 2025a). The southern Nigeria has a tropical humid climate with bimodal rainfall distribution pattern but with less intensity and clear distribution between wet and dry season in the tropical rainforest (Abia and Imo States). The freshwater swamp and the tropical rainforest have average rainfall of 2,500 mm and 2,350 mm, respectively (Nwagbara and Ibe, 2015; NIMET, 2025). Air temperature in southern Nigeria is generally high all year round. Mean maximum temperature of the area is 35° C while the mean minimum is 21° C, with an average annual daily sunshine hour of 6.25 hours from 3.5 hours at the coastal area to 9.9 hours, at the continental area (NIMET, 2025). Similarly, it has an annual daily solar radiation of about 2.25 Kwh/m²/day varying between 3.5 Kwh/m²/day at the coastal areas and 7.0 Kwh/m²/day at the northern boundary. Relative humidity over the study area ranged from 65 % to 92 % at the coastal area through 82 % in the central area (NIMET, 2025; Nwagbara and Ibe, 2015). The region exhibits rich biodiversity. Mangrove forests are found along the coastal areas, while the Inland areas host tropical rainforests, characterized by dense vegetation, tall trees, and a variety of plant and animal species. The vegetation of the experimental area is typical of tropical rainforest vegetation. Some of the forest species found in the areas include: oil bean (*Pentacclenthra marcophyllum),* oil palm (*Elaesis guinensis),* plantain/banana (*Musa spp),* and raffia palm (*Raphia spp).* Grasses and broadleaf weeds that dominate the entire area include *Panicum maximum, Penisetum purpreium, Cyperus spp, Axonopus compresses, and Aspillia africana.* Meanwhile, the fallow period of soils on ICS and CPS is more extensive that those of the other soils.

Soil sampling

Stratified random sampling as modified by Smith (1976) was used in the collection of soil samples. There were three (3) mini-pits of the dimensions (0.5 m × 0.5 m × 1 m) dug at each of the various litho-contrasting locations, and soil samples were collected at depths of 0 - 19, 20- 39, 40 – 100 cm. The three (3) mini-pits at each location represent the replicates in each location.

Experimental design

The experiment was designed as a 2-factor factorial experiment in Randomized Complete Block Design (RCBD) involving five (5) levels of parent material (Coastal Plain Sands, Shale, Imo Clay Shale, Sombreiro Deltaic Deposit, and Mangrrove Swamp Deposit) and three (3) levels of depths (0 – 19, 20 – 39, and 40 – 100 cm) with three (3) replications. This gave a total of forty-five (45) observational units.

Laboratory analyses

Particle size distribution was determined by the hydrometer method as described by Gee and Or (2002). Bulk density was obtained by the cylindrical core method as described by Blake and Harige (1986), and calculated as shown in equation 1.

$$Bulk\ density = \frac{mass\ of\ oven\ dry\ soil}{volume\ of\ bulk\ soil} \quad \text{.......... Eq. 1}$$

Saturated hydraulic Conductivity (Ks) was determined through constant head method to obtain quantity of water flow, then the saturated hydraulic conductivity was calculated using Darcy's equation by Young (2001) as shown in equation 2.

$$Ks = \frac{QL}{AT\Delta H} \quad \text{.......... Eq. 2}$$

Where Q, L, A, ΔH, and T in the equation represent the quantity of water flow (cm^3), the length of the soil column (cm), the interior cross-sectional area of the soil column (cm), the head pressure difference causing the flow or hydraulic gradient, and time of water flow (s), respectively.

Soil pH was determined in distilled water and Potassium Chloride solution at ratio 1:1 and 1.2.5 soil/water suspension using pH meter (McLean, 1982). Electrical conductivity was determined by Jackson (1973). Soil organic carbon content was quantified by the Walkley and Black wet oxidation method as described by Nelson and Sommers (1982). Total nitrogen content was determined by the macro Kjeldahl digestion method using $CuSO_4$ and NaSO4 catalyst mixture (Bremmer and Mulvaney, 1982). Cation exchange capacity (CEC) was determined by the NH_4OAC (Ammonium acetate) pH method (Thomas, 1982). Available Phosphorus was determined using Bray II solution (Bray and Kurtz, 1945). Exchangeable potassium K was determined in IN NH_4OAC (Ammonium acetate) at pH 7 leachate using the flame photometer for Potassium (Thomas, 1982). The SOC pool was calculated using the equation of Lal et al., (1998):

SOC Storage (Mg C ha^{-1}) = (% C × ϱb × d × 1 ha) / 100 .... Eq. 3

Where; Mg C ha^{-1} = Megagram carbon per hetare, % C = percentage of C given by laboratory results, ϱb = Soil bulk density (Milligram per cubic meters), d = depth in meters.

Data analyses

Data obtained from laboratory was subjected to analysis of variance (ANOVA) to compare the means of observations, while significant means were separated using the Fisher's Least Significant Difference (LSD) at 5% level of probability.

3. RESULTS AND DISCUSSION

Particle size distribution and textural class of the soils

There was significant variation ($P \leq 5\%$) of particle size distribution and texture among the litho-contrasting soils at varying depths as shown in figures 1, 2, and 3. At the 0-19 cm depth, the soil on MSD and CPS had the highest (81.0 %) and lowest (70.3 %) sand contents, respectively. Whereas the highest (13.0 %) and lowest (6.0 %) silt contents were observed at soils on SHL and MSD, respectively. The soils on CPS and SHL had the highest (23.0 %) and lowest (11.0 %) clay contents, respectively. Meanwhile, the textural class across the soils at 0 – 19 cm depth was loamy sand except the soil on Coastal Plain Sands which was sandy clay loam. At the 20-39 cm depth, soils at MSD and SHL had the highest (76.2 %) and lowest (68.0 %) sand contents, respectively. Furthermore, the silt content of the soil was highest (20.0 %) at SHL and lowest (6.33 %) at SDD, but SDD had the highest (18 %) clay content at this depth while the lowest (12.0 %) was observed at SHL. Consequently, at 20-39 cm depth, the soils were sandy loam, except soil on MSD which was loamy sand. Then, at the 40-100 cm depth, soils on CPS and ICS were sandy clay loam; SHL was sandy clay, while SDD and MSD were sandy loam.

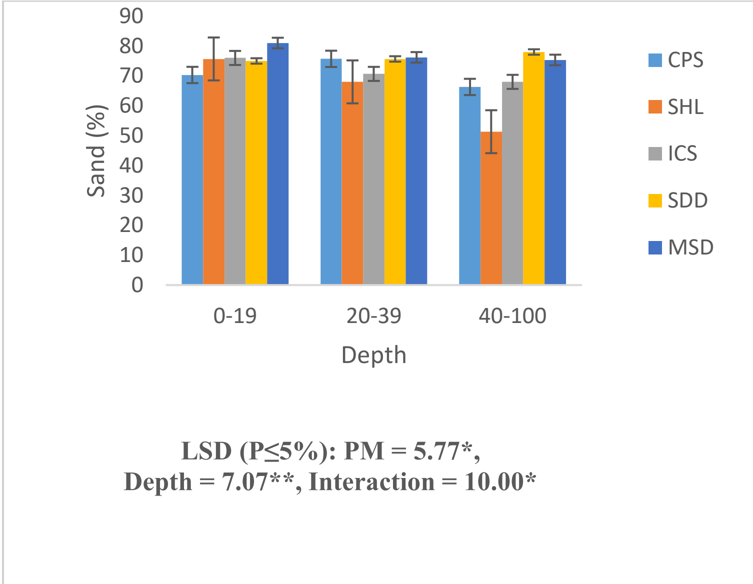

Figure 1. Sand content (%) across the soils at varying depths

CPS - Coastal Plain Sands, SHL - Shale, ICS - Imo Clay Shale, SDD - Sombreiro Warri Deltaic Deposit, MSD - Mangrove Swamp Deposit, PM – Parent Material.

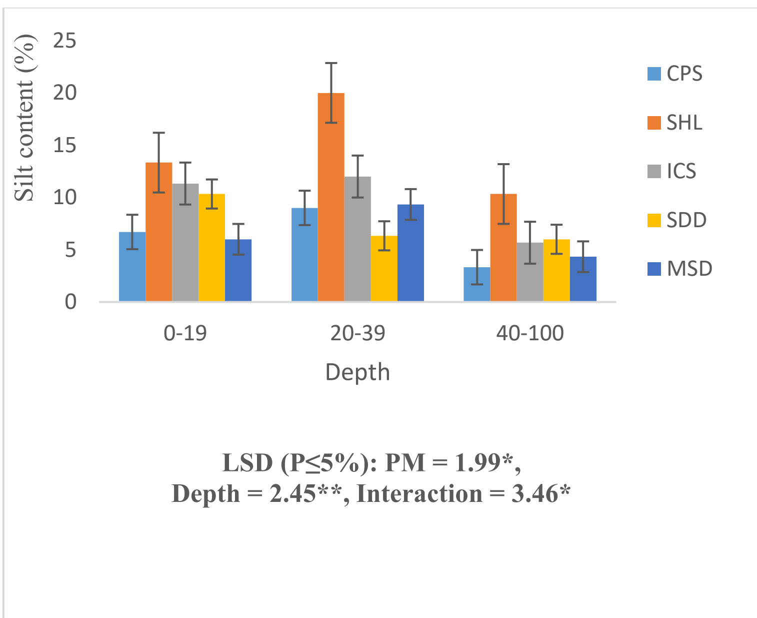

Figure 2. Silt content (%) across the soils at varying depths

CPS - Coastal Plain Sands, SHL - Shale, ICS - Imo Clay Shale, SDD - Sombreiro Warri Deltaic Deposit, MSD - Mangrove Swamp Deposit, PM – Parent Material.

The observed textural classes across the depths of soil on the CPS contradicts the report of Amanze et al., (2024) which noted that soils on CPS vary from loamy sand to sandy loam, and sandy clay loam from top layer to the residing depths. However, the considerable differences in textural class across depth of soils derived from CPS implies that the soil is well developed, which is common feature of soils associated with extensive pedogenic processes including translocation of clay particles across the depth via lessivage (Nuga and Akinbole, 2012). Conversely, the very close textural class observed across the depths of soil derived from MSD could depict that the soil is young, which is due to the periodic deposit of unconsolidated sediments dominated by sand. The increase in clay content with depth at the soils could be a result of eluviation of clay from the upper layer of soil body to the residing depth through agents of translocation such as water (Nuga and Akinbole, 2012). The variation in the textural classes of the soils, particularly at the residing depths will influence the establishment of deep-rooted crops. Moreover, permeability of water, air and roots at the residing depths of the soils will vary considerably; hence, the soils will differ in their drainage capacity, soil aeration for roots respiration, as well as roots penetration and ramification (Amanze et al., 2024a).

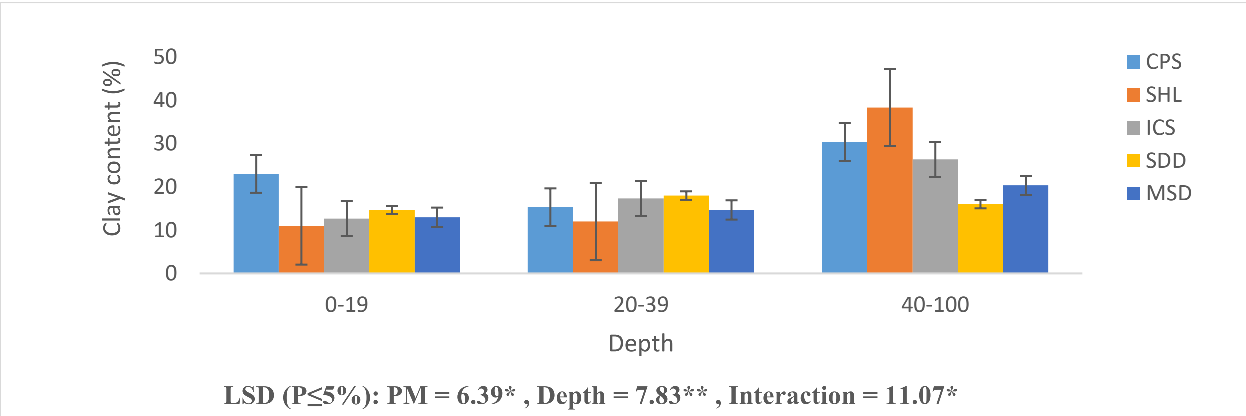

Figure 3. Clay content (%) across the soils at varying depths

CPS - Coastal Plain Sands, SHL - Shale, ICS - Imo Clay Shale, SDD - Sombreiro Warri Deltaic Deposit, MSD - Mangrove Swamp Deposit, PM – Parent Material.

Bulk density and Saturated hydraulic conductivity of the soils

Figure 4 shows that soil bulk density (BD) significantly (P≤5%) varied across the soils at varying depths. At 0-19 cm depth, the soil on SHL had the highest BD of 1.62 g/cm^3, while soils on SDD and ICS had the lowest (1.33 g/cm^3). Moreover, at 20-39 cm depth, soils on SHL and SDD had the highest (1.74 g/cm^3) and lowest (1.35 g/cm^3), while at 40-100 cm depth, soil on MSD had the highest BD (2.10 g/cm^3), and soil on SDD had the lowest. Meanwhile, BD at each soil was observed to increase with depth. The increased bulk density observed at soil derived from Shale at the first two depths could be predicted on its mineralogy, because the soil possibly contains high weighing minerals such as manganese, iron, and cobalt, which are common mineral elements associated with shale (Nwosu et al., 2024). Also, the possible increased pack volume of soil derived from Shale may have increased its mass per unit volume, leading to increased BD. Conversely, the unconsolidated nature of the soil derived from SDD may have contributed to its decreased bulk density relative to the other soils. The loosely packed nature of the soil on SDD may have created considerable large pore spaces filled with air; hence, decreased the mass per unit volume of the soil (Wang and Shao, 2013). Consequently, the soil derived from Shale may be prone to increased compaction, crusting, sealing and hardpan when tilled with heavy machineries. Consequently, it may negatively affect seed germination, root growth and ramification, as well as nutrients and water accessibility by plants (Ukabiala et al., 2025).

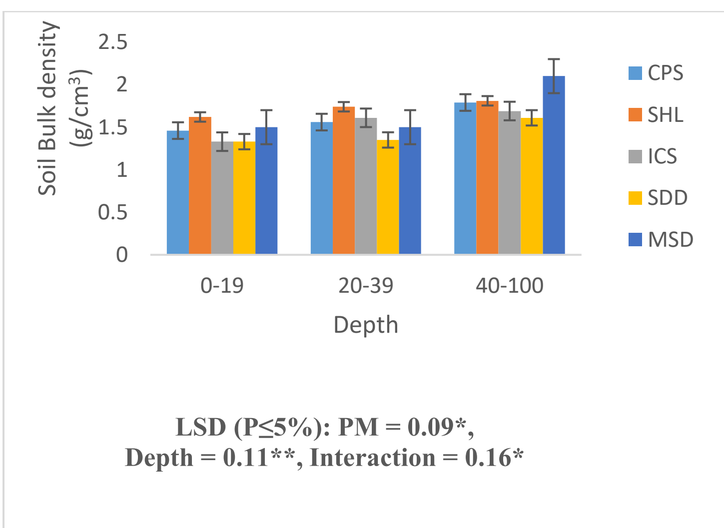

Figure 4. Bulk density of the soils (g/cm^3)

CPS - Coastal Plain Sands, SHL - Shale, ICS - Imo Clay Shale, SDD - Sombreiro Warri Deltaic Deposit, MSD - Mangrove Swamp Deposit, PM – Parent Material.

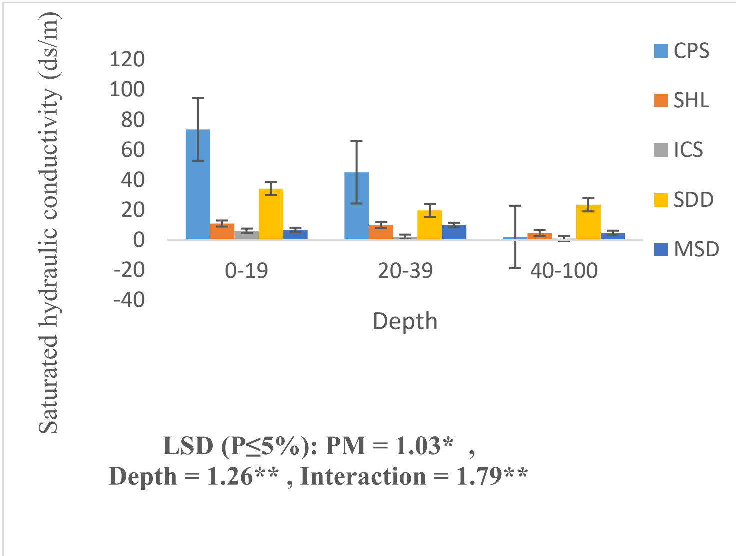

Figure 5. Saturated hydraulic conductivity of the soils (ds/m)

CPS - Coastal Plain Sands, SHL - Shale, ICS - Imo Clay Shale, SDD - Sombreiro Warri Deltaic Deposit, MSD - Mangrove Swamp Deposit, PM – Parent Material.

Saturated hydraulic conductivity (Ks) significantly (P ≤ 5%) varied among the soils of varying lithology across depths as shown in fig. 5. The fastest and slowest vertical water flow across soil depths were observed on soil derived from CPS and ICS, respectively. The highest Ks values of 73.52 ds/m and 45.01 ds/m at 0-19 and 20-39 cm depths, respectively, were observed at soil derived from CPS, while soil on ICS had the lowest Ks of 5.91, 1.89, and 0.82 ds/m for 0-19, 20-39, and 40-100 cm depths, respectively. Next to soil on ICS in decreased water transmission was soil on MSD. The increased rate of vertical water flow at soil on CPS could be inferred on the possible presence of increased number of macropores within the soil (Oyetola, 2014). Conversely, the reduced rate of water transmission within the soil on ICS could be associated with the possible presence of an increased number of micropores, which limited the ease of water flow by increasing the adhesion of water molecules to the surface of fine solid mineral particles of the soil (Oyetola, 2014).

Consequently, soil on CPS may not be associated with waterlogging, and would be well aerated, such that it may promote biodiversity survival, which will enhance nutrient cycling and transformation, and reduce buildup of chemical contaminants and toxins across the depths; hence, it ensures good soil condition for crop production. Contrariwise, the very slow rate of water flow across depths of soil on ICS may ultimately lead to waterlogging, poor soil aeration, accumulation of chemical contaminants, thereby limits biodiversity, and hamper nutrient cycling and transformation (Wang and Shao, 2013). Meanwhile, Ks was found to decrease significantly with depth at each of the soils. This may have resulted from the increased BD of the soils with depth. The report of Amanze et al. (2024) shows that BD correlates significantly negatively with Ks.

Fertility indices of the soils

Figure 6 shows that there was a significant difference (P ≤ 5%) in the pH of the soils on varying parent materials across the depths. The pH (H_2O) shows that at 0 – 19 cm depth, the soil on CPS (5.30) was strongly acidic, soils on SHL and SDD were very strongly acidic, while soils on ICS and MSD (4.32) were extremely acidic. At the 20 – 39 cm and 40 – 100 cm depths, the soil on SHL was strongly acidic with pH of 5.10 and 5.27 at 20-39 and 40-100 cm depths, respectively, while soils on the other parent materials were very strongly acidic with the lowest pH of 4.80 and 4.57 observed at soil on CPS at 20-39 and 40-100 cm depths, respectively. The pH of soil on CPS decreases with depth, while that of soil on SHL increases with depth, but fluctuates across soil depths on the other parent materials. Generally, at the higher depths, soil on CPS had the lowest pH (increased acidity).

The increased acidity observed in the soil on CPS could be associated with the nature of the parent material, which is notable for its acidic characteristics (Amanze et al., 2022). On the contrary, the increased pH (reduced acidity) observed down the depth of soil on SHL could also be attributed to its nature of increased content of basic cations, which served to increase the soil pH (Amanze et al., 2022). The increased acidity at the top layer of soils could hamper arable crop production considering that such pH range is below the critical pH range (5.5-6.5) for productive cultivation of most arable crops. This increased acidity at the top layer of those soils contradicts the expected pH particularly for soils on SHL and ICS, which were expected to have higher pH values with regards to their nature of increased content of basic cations, including calcium (Amanze et al., 2022). Therefore, the increased acidity at the top layer of those soils could be a result of other natural influences, including vegetation type, degree of land cover, and nature of deposited sediments, which may have influenced the nature of soil organic matter content, leaching, and chemical composition (including pH-dependent chemicals) (Amanze et al., 2017).

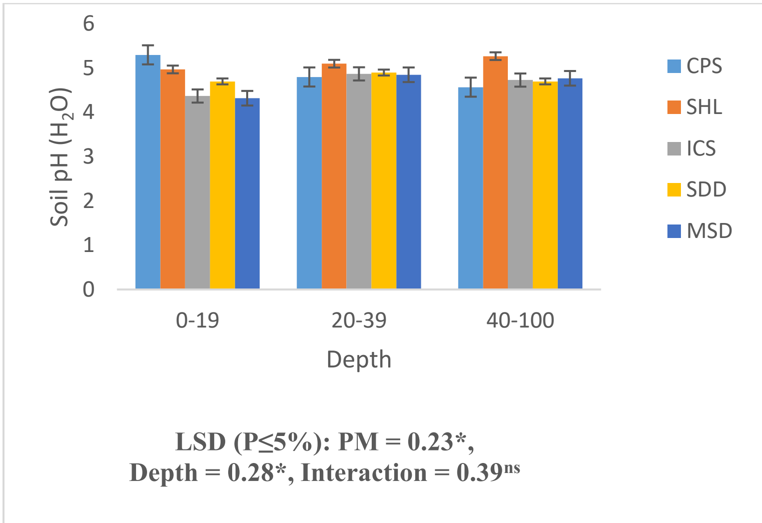

Figure 6. pH (H_2O) of the soils

CPS - Coastal Plain Sands, SHL - Shale, ICS - Imo Clay Shale, SDD - Sombreiro Warri Deltaic Deposit, MSD - Mangrove Swamp Deposit, PM – Parent Material.

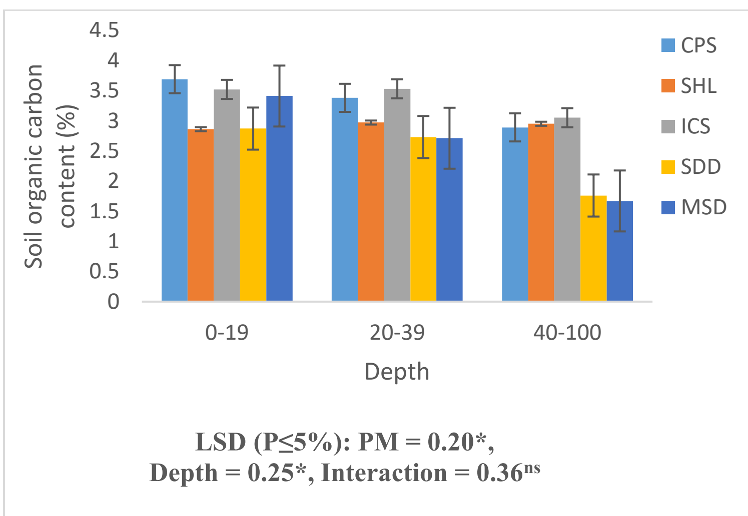

Figure 7. Organic carbon content (%) of the soils

CPS - Coastal Plain Sands, SHL - Shale, ICS - Imo Clay Shale, SDD - Sombreiro Warri Deltaic Deposit, MSD - Mangrove Swamp Deposit, PM – Parent Material.

The soils also varied considerably in OC with depth as shown in fig. 7. Generally, the soils on the various parent materials were very high in OC content at the various depths except at 40 – 100 cm depth where soils on SDD and MSD where high in OC content. Among the soils, the soil on ICS had the highest OC content except at the 0 – 19 cm depth, where soil on the CPS recorded the highest (3.69 %), but was not significantly different from soil on ICS. The OC content of soils on ICS and SHL increased with depth up to 39 cm depth, then decreased gradually at 40 – 100 cm depth, while that of soils on CPS, SDD, and MSD decreased considerably with depth. The high OC rating of the soils could be attributed to the increased vegetation cover of the land areas, which translated to increased biomass and organic matter return to the soil through litterfall. Moreover, the less disturbance on the soil due to fallowing of the land may have helped conserve organic matter by reducing OC loss by oxidation (Amanze et al., 2024b).

Meanwhile, the greatest OC content of soil on ICS followed by soil on the CPS compared to the other soils could be associated with their prolonged period of fallowing, which supported the accumulation of organic matter over such period. This assertion corroborates the report of Amanze et al. (2024) that prolonged vegetation cover on undisturbed soil enhanced OC accumulation. The high OC content of the soils could imply that the soils, especially the soil on ICS, would be characterized with good agronomic properties for productive cultivation of crops, including high buffering capacity, enhanced biodiversity and microbial activities, effective nutrient cycling, nutrients transformation, nutrients availability, and good soil quality (Akpa et al., 2016).

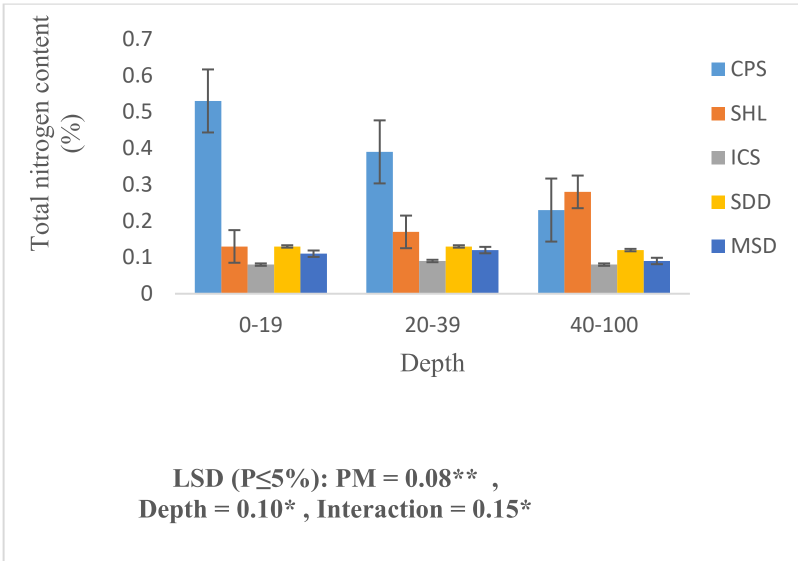

Figure 8. Total Nitrogen content (%) of the soils

CPS - Coastal Plain Sands, SHL - Shale, ICS - Imo Clay Shale, SDD - Sombreiro Warri Deltaic Deposit, MSD - Mangrove Swamp Deposit, PM – Parent Material.

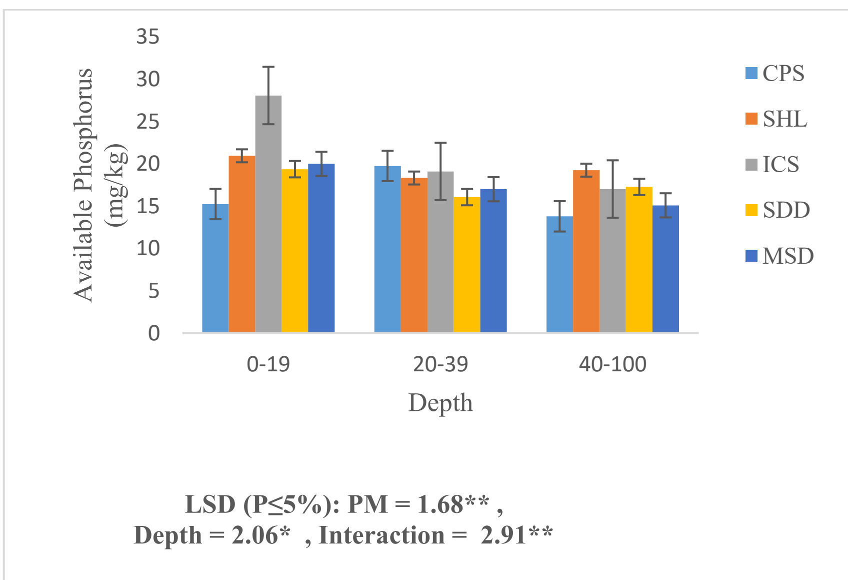

Figure 9. Available phosphorus of the soils

CPS - Coastal Plain Sands, SHL - Shale, ICS - Imo Clay Shale, SDD - Sombreiro Warri Deltaic Deposit, MSD - Mangrove Swamp Deposit, PM – Parent Material.

Figure 8 shows that there was significant variation ($P \leq 5\%$) of TN among the soils and across the depths of each soil. Also, there was a significant interaction effect ($P \leq 5\%$) of parent material and depth on TN. At the 0-19 cm and 20-39 cm depths, the soils on CPS and ICS had the highest and lowest TN content, respectively, while at 40-100 cm depth, the soil on SHL had the highest TN content, but was not considerably different from TN content of soil on CPS. At 0-19 cm and 20-39 cm depths, the soils on SDD, MSD, and SHL were moderate in TN content, while the TN at soils on CPS and ICS was very high and low, respectively. At 40-100 cm depth, the soil on SHL was high in TN, but was not significantly higher than soil on CPS which was moderately high in TN. The TN content of the soil on CPS decreased considerably with depth, and that of soil on SHL increased considerably with depth; however, there was no notable variation of TN across the depths of soils on MSD and ICS. The increased TN content of the soil on CPS could be predicted from its increased content of decomposable organic materials of high nitrogen content. The decomposition and mineralization of the organic materials may have enhanced the release of nitrogen from nitrogenous organic compounds to the soil. Consequently, the expected increased TN content of soil on ICS, considering its increased OC content, was dashed by the observed low TN content; hence, it could be inferred that the organic materials in the soil on ICS were recalcitrant organic matter left after the initial decomposition of the fresh organic materials or organic deposits of low nitrogen composition (Ibe et al., 2023).

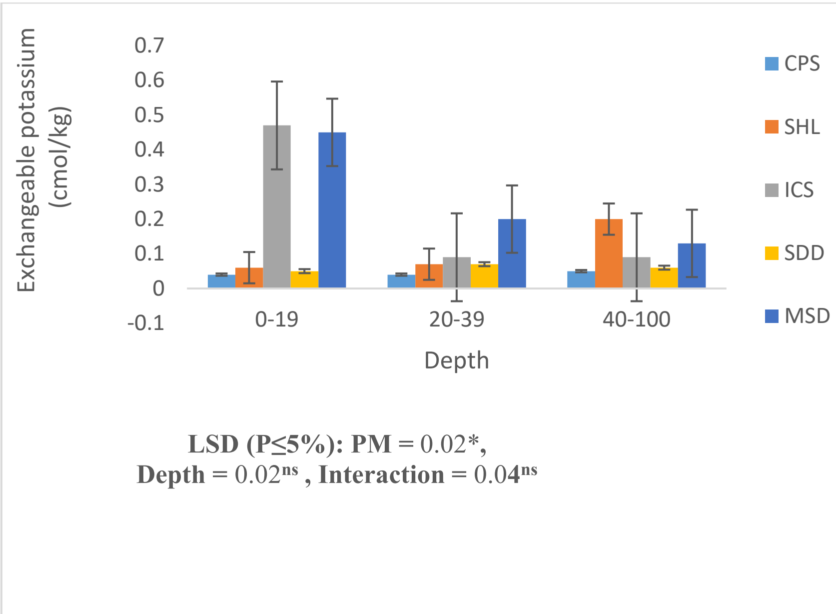

Figure 10. Exchangeable potassium content of the soils (cmol/kg)

CPS - Coastal Plain Sands, SHL - Shale, ICS - Imo Clay Shale, SDD - Sombreiro Warri Deltaic Deposit, MSD - Mangrove Swamp Deposit, PM – Parent Material.

The soils on differing lithologic materials varied significantly ($P \leq 5\%$) in Av.P across the depths as shown in fig. 9. At 0-19 cm depth, the highest and lowest concentration of Av.P were observed at soils on ICS and CPS, respectively. Meanwhile, at 20-39 cm depth the soil on CPS had the highest Av.P, which was significantly greater than the concentration at its top layer. Then, at 40-100 cm depth, soil on SHL has the highest Av.P which differed considerably from the other soils, while soil on the CPS had the lowest. The Av.P of the soil on ICS and MSD decreased considerably with depth, while at the other soils, Av.P concentration fluctuates across the depths. The Av.P rating at 0-19 cm depth was moderate at soil on CPS, SDD, and MSD, but high at ICS, and moderate to high at SHL. The increased concentration of Av.P at the top layer of soil on ICS could be attributed to the possible increased release of phosphorus via organic matter decomposition as well as the increased concentration of basic cations like K, which may have served to alleviate the P-fixing capacity of the soil; hence, enhanced availability of phosphorus (Amanze et al., 2017). The decreased AvP concentration at 0-19 cm depth of soil on the CPS could be inferred from the possible increased leaching of phosphorus to its residing depth, and the possible increase in P-fixation common with soils on CPS (Ano, 2000). Consequently, the considerable increase in Av.P at the 20-39 cm depth of soil on CPS may have resulted from the translocation of phosphorus from the top layer to the residing depth via leaching. This confirms the report of (Ano, 2000) that phosphorus is a very mobile element, and could be lost from the soil via leaching and erosional processes. It implies that the soil on ICS would readily support root development and ramification, flowering, fruiting and seed production in shallow-rooted arable crops, while soil on CPS would offer similar advantage to deep-rooted arable crops.

There was significant variation ($P \leq 5\%$) of exchangeable K (exch. K) and cation exchange capacity (CEC) among the soils on the varying parent materials as shown in figures 10 and 11, respectively. Meanwhile, the interaction of parent material and depth had no significant influence on exch. K and CEC. Moreover, there was no considerable variation of exch. K and CEC across the depths. At the top layer, the soil on ICS had the highest contents of exch. K and CEC, which were not significantly different from the soil on MSD in exch. K, but varied significantly from the other soils in CEC. Also, the soils on ICS and MSD had moderate concentration of exch. K, while the other soils were very low in exch. K. This implies that the soils under the other parent materials except ICS and MSD will scarcely support the productive cultivation of arable crops without extraneous input of potassium-containing fertilizers. Meanwhile, the soils on SHL and ICS rated high in CEC, while the other soils were moderate. The increased CEC of soils on SHL and ICS could be inferred on the nature of the parent material notable for dominance of clay. Clay is characterized by increased negatively charged large surfaces, which enhance the attraction and accumulation of exchangeable cations at the exchange site of soils (Amanze et al., 2017); consequently, the soils on ICS and SHL are likely to show good response to fertilizer application for improved crop production and food security. However, there could be possibility of increased attraction and accumulation of poisonous heavy metals, including Pb, As, Cr, and Cd at soils on SHL and ICS due to their increased CEC (Nwawuike et al. 2024). Conversely, the soil on the CPS had the lowest exch. K across the depths, and least CEC at the top layer of soils. These observations could be associated with the nature of CPS, notable for low percentage base saturation, and low to moderate CEC (Lekwa and Whiteside, 1986).

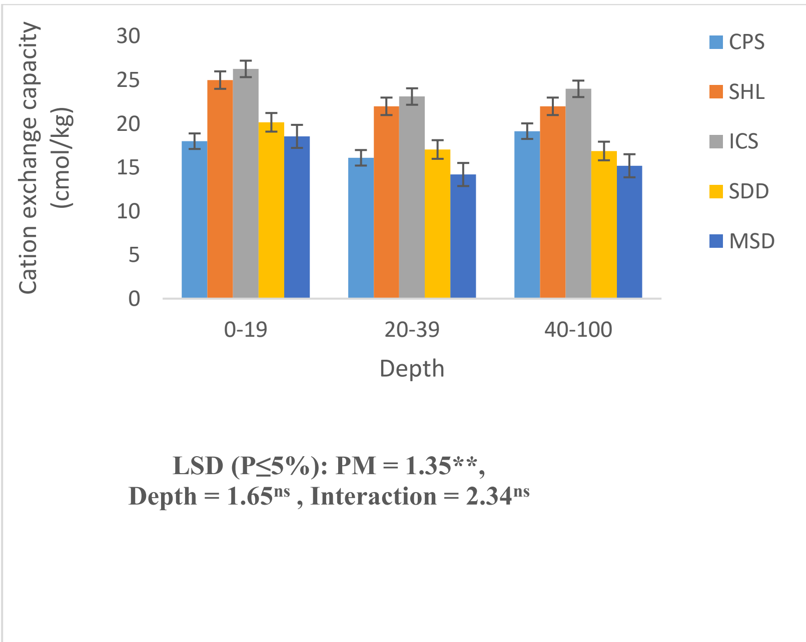

Figure 11. Cation exchange capacity of the soil (cmol/kg)

CPS - Coastal Plain Sands, SHL - Shale, ICS - Imo Clay Shale, SDD - Sombreiro Warri Deltaic Deposit, MSD - Mangrove Swamp Deposit, PM – Parent Material.

Soil organic carbon pool

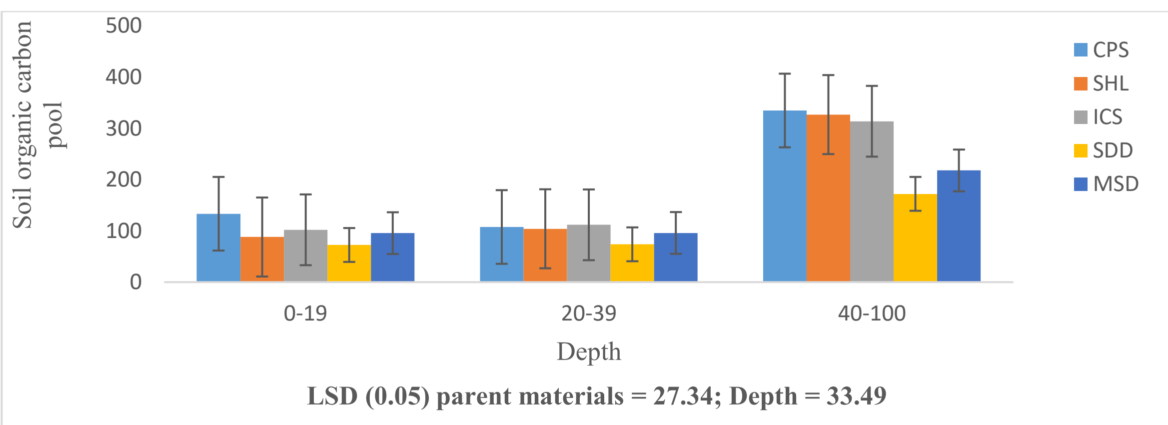

Figure 12. Organic carbon pool of the soils (mgC/ha)

CPS - Coastal Plain Sands, SHL - Shale, ICS - Imo Clay Shale, SDD - Sombreiro Warri Deltaic Deposit, MSD - Mangrove Swamp Deposit, PM – Parent Material.

Figure 12 shows the variation of soil organic carbon (SOC) storage among the soils on the varying parent materials and across depths. It indicates a significant (P≤5%) interaction effect of parent material and depth on SOC storage. The soil on CPS had the highest storage of SOC at the various depths, while the soil on SDD had the lowest storage at those depths. Meanwhile, the SOC storage of soil on CPS differed substantially from the other soils except soils on SHL and ICS at the 40-100 cm depth. Moreover, at 20-39 cm depth, the soils were not considerably different in SOC, although the highest and lowest storage of SOC at this depth were observed at soils on CPS and SDD, respectively. Then, at 0-19 cm depth, the soil on CPS with the highest SOC accumulation differed significantly from the other soils except the soil on SHL.

The increased accumulation of SOC at the various depths of soils on CPS, SHL, and ICS could be attributed to their relatively fine texture characterized by increased clay content compared to the other soils. The fine texture of those soils may have enhanced the dominance of micropores, which served to protect recalcitrant and residual organic materials from loss to oxidation and translocation (Anikwe, 2010; Ibe et al., 2025b). There was expectation that soils on SDD and MSD would have had increased organic carbon deposit relative to the other soils considering the frequency of organic deposits in them. Meanwhile, the observed decrease in SOC storage of the soils on SDD and MSD could be predicted on the limited rate of organic residues incorporation into the soil fabrics due to the possible inhibition of organic matter decomposition caused by poor soil aeration. This assertion corroborates the report of Lal (2005) that adequate soil aeration promotes soil biodiversity, which aids the decomposition of organic materials, and enhances their incorporation into the soil through the activities of biological species in the soil.

4. CONCLUSION

There is considerable variation of texture-related characteristics, fertility indices, and organic carbon storage of soils derived from contrasting parent materials at varying depths. Soils formed on Shale (SHL) have considerable clay content at the sub-soil layer. In contrast, soils derived from Mangrove Swamp Deposit (MSD) and Sombriero Deltaic Deposit (SDD) are relatively young soils characterized with little or no variation in texture across the depths. Meanwhile, soils derived from the Coastal Plain Sands, (CPS) SHL, and Imo Clay Shale (ICS) are old soils with notable variation in soil texture across the depths. Clay content in each soil tends to increase with depth. Soils derived from Shale have increased bulk density (BD), while soils formed on SDD have decreased BD.; however, BD increases with depth at the various soils. Coarse textured soils, such as soils derived from CPS are characterized with increased capacity for water transmission, while fine textured soils, such as soils on ICS are notable for decreased water transmission capacity. Meanwhile, water transmission capacity decreases with an increase in depth. Soils derived from Deltaic deposits are more saline than soils on the other parent materials; however, the soils are generally free from salt problems. Soils derived from these parent materials within the Niger-Delta ecological zone are generally acidic. However, soils derived from CPS are more acidic, while soils on Shale are less acidic at the various depth, and the acidity increases with depths in the soils. Soils derived from ICS are richer in Available P and Exchangeable K, while soils on CPS are deficient of these nutrient elements. Soils at the SDD and MSD had the least capacity to store organic carbon, compared to soils derived from CPS, SHL, and ICS. Consequently, efforts must be made to consider the uniqueness of the soils during land use allocation and soil management practices for crop production.

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Author Contributions

Ibe, O. K. develop the research concept and conducted the reseach, Nnaji, G,Uzoma, K. supervised and guided the conduct of the research, Amanze, C. T. supported in designing the research methodology, analyzed data, and prepared the manuscript; Nwosu, O. C. assisted in data collection and review of the manuscript; Eluagu, K. F. assisted in data visualization; Ukabiala, M. E.; Onyechere, A. U, and Okereafor, D. O. independently reviewed the manuscript for correctness before submission.

Informed consent

Not applicable.

Conflicts of interests

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

Ethical approval & declaration

Not applicable. This work is mainly on soil and soil resources and does not involve any information on humans or animals; thus, an ethical statement is not applicable to the context of the manuscript.

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Data and materials availability

All data associated with this study will be available at reasonable request to the corresponding Author.

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