Short Research Article

Vertical Changes of Organic Carbon Storage, Structural and Hydraulic Properties of a Humid Tropical Soil under Vegetation Cover in Southeast Nigeria

ABSTRACT

Changes in organic carbon storage (OCS), structural and hydraulic properties with depth of soil are important phenomena that need to be understood per soil for effective soil management in crop production. A study was conducted in a Randomized Complete Block Design (RCBD)to assess the vertical changes in OCS, structural and hydraulic properties of soil under vegetation cover. The studyinvolved 5 levels of sampling depth replicated nine (9) times to give forty five (45) observational units. The nine points for sampling were randomly selectedand the five sampling depths were 0 – 20, 20 – 40, 40 – 60, 60 – 80 and 80 – 100 cm. Auger and core soil samples were collected at the designated depths. The samples were processed and analysed in the laboratory. The results of data analyses showed that depths varied significantly ($P \leq 0.05$) in the parameters measured. The highest OCS of 38.28 ton / ha was obtained at the 0 – 20 cm depth and the lowest (10.38 ton / ha) was obtained at80 – 100 cm depth.The highest mean weight diameter of 1.00 mm and lowest of 0.72 mm were obtained at 0 – 20 and 80 – 100 cm depths, respectively. The lowest clay dispersion index of 25.43 % and the highest clay flocculation index of 74.53 % were obtained at 80 – 100 cm depth. Clay content and bulk density (BD) increased with depth and, the highest clay content of 212.4 g / kg and highest BD of 1.65 mg / m^3 were obtained at the 80 – 100 cm depth. Saturated hydraulic conductivity (K_{sat}), total porosity (Pt) and macroporosity (Pm) decreased with depth. The highest $K_{sat}$of 3.11 cm / hr, Pt of 47.41 % and Pm of 24.13 % were obtained at 0 – 20 cm depth. The water retention characteristics increased with depth. The highest field capacity of 24.46 %, permanent wilting point of 11.16 % and available water capacity of 13.32 % were obtained at 80 – 100 cm depth. There were consistent changes in the soil properties across the depths. The reduced drainage at the higher depths should be considered in cultivating deep rooted cropswhich are sensitive to poor drainage. The top soils should be managed with good agronomic practices and minimum tillage to avertdamages to the microaggregates.

Keywords: organic carbon storage, soil depth, bulk density, hydraulic conductivity, porosity

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INTRODUCTION

Changes in physicochemical properties across the surface and down the depths of soil are inherent phenomena associated with the body of soils (Malgwi and Abu, 2011). These changes are usually conditioned by climate, land use system,pedogenic processes and soil management practices (Malgwi and Abu, 2011). Soil organic carbon (SOC) is significant in controllingbiological, physical and chemical properties in the soil and also serves in determining the overall fertility and quality of soils at varying depths (Gaudinski*et al*., 2000). Variation in SOC down the profile influences the biological activities across the depths which conditions the physicochemical properties of the soils (Gaudinski*et al*., 2000). The density and ramification of roots of plants are influenced by changes in SOC across the depths such that root density seems to be at the increase within the region of increased SOC across the depths (Richard *et al*., 1999). The report of Eleanor and Brain (2016) showed that SOC decreased with increase in depths; hence highest storage of organic carbon was observed at the top soil.

The clay content of soils is greatly influenced by parent materials (Barros et al., 2018), andclay plays significant role in influencing most physicochemical conditions of soils such as bulk density (BD), water retention characteristics, soil aggregation and aggregate stability indices (Kome *et al.*, 2019, Amanze *et al*., 2022a). Clay minerals are part of the colloidal mixture of the soil and help to control most chemical processes influencing nutrients release and availability in the soil (Kome *et al.*, 2019). In most soils, clay content increases with increase in depth, and this is attributed to the downward translocation of clay through illuviation (Adugna and Abegaz, 2015). The amount of clay at varying depths of soil is of great importance in the overall concept of soil texture because the clay content at any depth of soil influences the effectiveness of rooting in plants, moisture content, drainage and erodibility of the soil (Kome *et al.*, 2019).

The hydraulic properties of soils including infiltration, percolation, and water retention characteristics vary across the soil surface as conditioned by geology, land use, soil management practices and soil texture (Amanze *et al*., 2022b); similarly, there occurs vertical variation in the hydraulic properties of soil resulting from changes in clay content, BD, OCS, and aggregation of soil across depths of soil profile (Jarvis *et al*., 2013). Research shows that clay content and BD were negatively related to hydraulic conductivity but had a positive relationship with water retention characteristics and this knowledge is vital in managing the drainage and availability of water across the soil profile (Jarvis *et al*., 2013). This study aims at assessing the vertical changes in soil organic carbon storage, structural and hydraulic properties of a humid tropical soil under vegetation cover.

MATERIALS AND METHODS

Location and description of study area

The study was conducted in Abia State, within the humid tropical region of Southeastern Nigeria. The area lies within latitude 5^{o}29$^{'}$N to 5^{o}31'N and longitude 7^{o}30$^{'}$E to 7^{o}32$^{'}$E with mean annual rainfall distribution of 2200 mm (NiMet, 2019). The rainy season starts from March and extends to October with bimodal peaks in July and September. There is a short spell of dry weather in August. The dry season starts in November and lasts till February. The mean annual temperature is about 28^{o}C (NiMet, 2019). The landscape is flat to gently undulating slope. Coastal plain sand is the dominant parent material in the area although there are localized portions of alluvial deposits. The soil of the area is dominated by the 1:1 clay mineral and belongs to the order "Ultisol" according to the USDA soil taxonomy (Amanze *et al*., 2016). The vegetation type is tropical rainforest.

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Land use types

The land was undisturbedsecondary vegetation growing for over three (3) years. The tree plant species that made up the vegetation include oil bean plant (*Pentaclethramacrophyllum*), African bread fruit (*Treculiaafricana*), bush mango (*Irvingiagabonensis*). Other plant species were shrubs and herbs such as "siam weed" (*Chromolaenaodorata*), sun flower (*Aspilliaafricana*), goat weed (*Sidaacuta*), elephant grass (*Panicum maximum*), mimosa plant (*Mimosa pudica*), cassava (*Manihotesculentus*), etc.

Field work

Soil sampling and sample preparation

Soil samples were collected from nine randomly selected points and each point was sampled at five depths(0 – 20. 20 – 40, 40 – 60, 60 – 80 and 80 - 100 cm). Disturbed and undisturbed soil samples were collected from each depth. The disturbed soil samples were air-dried and passed through a 2 mm mesh for laboratory analysis. The undisturbed soil samples were collected with core samplers, the core soil samples were trimmed, the bases fastened with cheese cloth and placed in a trough of water to saturate before determination of the soil physical properties.

Laboratory analyses

Particle size distribution was determined using the hydrometer method as described by Gee and Or (2000). Saturated hydraulic conductivity (K_{sat}) was determined by the constant head method explained by Klute (1986). The K_{sat} of the soil was calculated using Darcy's equation as explained by Youngs (2001) as shown below.

$$Ksat = \frac{QL}{AT\Delta H} \dots\dots\dots\dots\dots 1$$

where Q is quantity of water discharged (cm^3), L is length of soil column (cm), A is the interior cross – sectional area of the soil column (cm^2), ΔH is head pressure difference causing the flow (hydraulic gradient) and T is time of water flow (s). Bulk density (BD) was determined using the core method as described by Anderson and Ingram (1993). Field capacity (FC) was determined following the procedure outlined by Mbagwu (1991). Here, core soil sample was put in a basin and water was added 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 saturated core sample was removed from the basin of water and allowed to drain freely for 2 days and thereafter, its mass (M_1) was recorded. The drained core sample was then oven-dried at a temperature of 105°C and the oven - dry mass (M_2) was recorded.

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

$$\text{FC \%} \quad = \frac{M1 - M2}{\text{M2}} \; X \; 100 \quad \dots\dots\dots 2$$

The permanent wilting point (PWP) was determined by growing an indicator plant (*Zea mays*) in 500 g of the soil sample in a metal can. Adequate moisture was applied to the plant until the third pair of leaves emerged. Then the top of the can was completely covered with cellophane material and kept outdoors until the plant wilted permanently. The soil moisture content at this point of permanent wilting was then determined as the permanent wilting point (Taylor and Ashcroft, 1972). The available water capacity (AWC) was obtained as the difference between the moisture contents at field capacity (FC) and permanent wilting point (PWP) thus:

AWC % = FC % - PWP % ………… 3

Organic carbon was determined by the dichromate oxidation procedure of Walkley and Black as modified by Nelson and Sommers (1982). Total carbon stored in the soil was calculated according to the procedure explained by Peter (2013) and reported in Amanze *et al.* (2022b) as shown below:

$C_T = C_F \text{ x } D \text{ x } V$ ……………….. 4

where C_T is total organic carbon for the layer (metric ton), C_F is the fraction of carbon (percentage carbon divided by 100), D is bulk density of the soil, V is the volume of the soil layer (m^3).

Experimental design and statistical analysis

The experiment was laid out in a randomized complete block design (RCBD) involving five depths replicated nine times. Data obtained were subjected to analysis of variance (ANOVA). Significant means were separated using Fisher's least significant difference at 5% probability level ($LSD_{0.05}$).

Results and Discussion

Aggregate stability

Table1 shows the variability in aggregate stability indices across the depths. It revealed that there was significant ($P\leq0.05$) decrease in DR with increase in depth. Therefore, colloidal disaggregation with respect to DR decreased with depth. The highest DR (23.78%) was observed at 0-20cm depth which was not significantly ($P\geq0.05$) different from 60 – 80cm depth. Similarly, there was a significant decrease in CDI with increase in depth. This also suggested decrease in colloidal disaggregation with increase in depth. The highest CDI (35.21%) was observed at 0 – 20cm depth while the lowest value (25.43 %) was observed at 80 – 100 cm. However, there was no significant ($P\geq0.05$) variation between 40 – 60cm (27.53%) and 60 – 80cm (27.34 %) depths. On the average, the high DR and CDI at the topsoil may be due to low clay and high OM contents at this depth. This agreed with the report that increase in OM increased the net negative charge of the colloidal mixture and therefore increased the dispersivity of the soil particles by repulsion (Nelson and Oades, 1998).Soils withclay content of 1:1 clay type and low OC content helped in improving the stability of soil aggregates against dispersion by water (Uddivira and Camps, 2006). This therefore affirmed the reason for the stability of soils at lower depths where

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there was a significant increase in clay content of 1:1 silicate clay type (Lekwa and Whiteside, 1986; Kome *et al*, 2019).

There was significant (P≤0.05) increase in CFI and ASC with increase in depth. The greatest flocculation and aggregation with respect to CFI (74.53%) and ASC (26.28%), respectively, were observed at 80 – 100cm depth, which differed significantly from other depths while the least CFI (64.79%) and ASC (16.92%) were observed at 0 – 20 cm depth.The increase in soil microaggregationwith depth was perhaps a result of the increase in clay content and decrease in OM content with depth. Increase in SOM increased the critical flocculation concentration (CFC) of soil which resulted in the dispersion of particles rather than flocculation (Goldberg and Forster, 1990). According to Goldberg and Forster (1990) critical flocculation concentration (CFC) is the minimum total exchangeable cations (TEC) at which the diffused double layer (DDL) forces of clay are reduced, allowing particles to remain together after collision to form floccules that subsequently settle. Hence, the improved microaggregation of these soils with increase in depth was most likely as a result of the decrease in SOM and increase in clay content. The large charged surface area of clay particles and the overburden effect at the residing depths increased the cohesive and adhesive forces that helped in binding the particles into stable aggregates(Barros et al., 2018). In addition, the possible higher concentration of sesquioxides (Al and Fe (III) oxides) at higher depths helped in increasing the stability of aggregates compared to the topsoil (Uddivira and Camps, 2006).

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Comment [Ma5]: diffuse

The mean weight diameter(MWD) decreased with increasing depth as shown in Table 1. Therefore, aggregation at the macrolevel decreased with depth. The highest value of MWD (1.00 mm) was observed at 0 – 20 cm depth while the lowest (0.72 mm) was observed at 80 – 100cm, and these varied significantly from the other depths. The reason for high MWD at 0 – 20 cm depth may be due to high OC content from high roots density, roots exudate and litter fall at the topsoil which helped in binding the microaggregates into water stable macroaggregates(Richard *et al*., 1999). The exudates from the densely populated roots at the 0 – 20cm depth may have also served as glues in binding and stabilizing the soil aggregates (Eleaner and Brain, 2016). The general decrease in MWD down the depth may be attributed to the decrease in polysaccharides (passive Organic matter), root density and fungi hyphae down the depths (Golchin *et al*., 1995).

Comment [Ma6]: macro level

The root hairs of plants at the 0 – 20cm depth may have also helped to enmesh the soil particles into water stable aggregates.

Table 1: Variability in aggregate stability indices across the depths

DEPTHS (cm)	DR (%)	CDI (%)	ASC (%)	CFI (%)	MWD (mm)
0 - 20	23.78	35.21	16.92	64.79	1.00
20 - 40	21.64	31.01	20.01	69.21	0.89
40 - 60	21.23	27.53	22.14	72.45	0.83
60 - 80	23.23	27.34	23.28	72.40	0.76
80 - 100	22.53	25.43	26.28	74.53	0.72
LSD (0.05)	1.08	1.50	0.59	1.54	0.04

DR – dispersion ratio, CDI – clay dispersion index, ASC – aggregated silt and clay, CFI – clay flocculation index, MWD – mean weight diameter

Clay content, bulk density, saturated hydraulic conductivity, total and macro porosities

Variability in clay content, bulk density, saturated hydraulic conductivity, total and macro porosities across the depths was shown in Table 2. It revealed that there was a significant ($P \leq 0.05$) increase in clay content with increase in depth. The highest value of 212.4 g/kg was observed at 80 – 100 cm depth while the lowest value (122.7 g/kg) was observed at 0 – 20cm depth, and these varied significantly from the other depths. The reason for the increase in clay content with depth could be a result of the downward translocation of clay particles via eluviation and illuviation processes (Ojanuga, 2003; Adugna and Abegaz, 2015).

Bulk density increased significantly ($P \leq 0.05$)with depth. The highest BD of 1.65 Mg/m^3 was observed at 80 – 100cm while the lowest (1.39 Mg/m^3) was observed at 0 -20cm. The lowest BD at the topsoil may be due to the relatively higher OC content at the topsoil which resulted from increased litter fall, roots exudates, and low clay content at the topsoil (Amanze *et al*, 2022a) as well as the loss of clayby translocation from topsoil to subsoil via lessivage (Ojanuga, 2003). Conversely, the high BD at higher depths was possibly due to the decreased OCcontent and increase in clay content. This corroborates the report of Oguike and Mbagwu (2009) that decrease in OCsignificantly increased soil BD. Also,Ojanuga (2003) revealed that soils with high clay content had higher BD, hence the general increase in BD with depth was possibly a result of increase in clay content, low organic carbon content and the overburden or compressive force exerted by the overlaying layers to the underlying soil (Schaetzi*et al.*, (2005).

Comment [Ma7]: overlying

There was significant(P≤0.05) decrease in K_{sat} with depth. The most rapid K_{sat} (3.11cm/min) was observed at 0 – 20cm while the slowest (0.44cm/min) was observed at 80 – 100 cm depth. There was also a significant decrease in total porosity (Pt) and macroporosity (Pm) with depth. The highest values of (47.41 %) and (24.13%) for Pt and Pm, respectively, were observed at 0 – 20 cm depth while the lowest values of (37.60%) and (1.05%) for Pt and Pm, respectively, were observed at 80 – 100cm depth. The increase in clay content at the residing depth increased the micropores resulting to decrease in water transmissiondown the depths (Amanze *et al*., 2022a). The bettersoil macroaggregation and stability of macroaggregates resulting from increased organic carbon content together with the relatively lower clay content at the top soil may have improved the total volume of macropores thereby enhancedthe rate of water transmission at the top soil. This confirmed the report of Jarvis *et al*., (2013) that increase in macroaggregationand reduced clay content improved the water conduction property of soils. On the contrary, the decrease in K_{sat}, Pt and Pm with increasing depth was possibly the resultant effect of the increase in clay content and high BD with depth. This agreedwith the report of Schaetzi*et al.* (2005) that clay particles have large charged surface area with tiny pore spaces which results in increased micropores hence limit the ease at which water flows down the depths.

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Table2: Variability in clay content, bulk density, saturated hydraulic conductivity, total and macro porosities across the depths

DEPTHS (Cm)	CLAY (g / kg)	BD (mg / m^3)	K_{sat} (Cm / hr)	PT (%)	PM (%)
0 – 20	122.7	1.39	3.11	47.41	24.13
20 – 40	140.5	1.45	2.20	45.35	18.74
40 – 60	160.2	1.51	1.41	43.06	13.01
60 – 80	180.8	1.58	0.76	40.47	5.68
80 – 100	212.4	1.65	0.44	37.60	1.05
LSD (0.05)	6.2	0.02	0.11	0.72	1.43

BD – bulk density, K_{sat}– saturated hydraulic conductivity, PT – total porosity, PM - macroporosity

Water retention characteristics and organic carbon storage

Table 3 shows the variability in water retention characteristics and organic carbon storage across the depths. The water retention characteristics of the soils increased significantly (P≤0.05)with depth. The highest values of FC (24.46%), PWP (11.16%) and AWC (13.32 %) were observed at 80 – 100cm depth. The lowest values of FC (16.84%),PWP (6.24%) and AWC (10.60 %) were observed at 0 – 20cm depth which varied significantly (P≤0.05) from other depths. The increase in water retention capacity of the soils with depth may possibly be due to the progressive increase in clay content, microporosity and BD with depth. This confirmed the observation of Schaetzi*et al.* (2005) who reported a positive linear relationship between water retention characteristics of soils with BD, microporosity and clay content.

There wassignificant(P≤0.05) decrease in OC down the depth. The highest value of 38.28ton / ha was observed at 0 – 20cm depth which differed significantly from the other depths while the lowest value of 10.38 ton /ha was observed at 80 – 100cm depth. Theincrease in OC storage at the top soil was probably a result of high residue concentration at the top soil by litter falls, roots exudates, root density and increased population of soil micobes. Contrariwise, the reduced OC storageat the higher depths was possibly a result of poor root density, poor organic carbon translocation down the depth and decreased microbial population. The reports of Richard *et al.*, (1999) andBalesdent*et al.*, (2000) confirmed that soil organic carbon storage was highest at the top soil and decreased significantly with depth, stating that the rate of residue .

Comment [Ma14]: was a significant

Comment [Ma15]: microbes

Table 3: Variability in soil water retention characteristics and organic carbon storage

DEPTHS (cm)	FC (%)	PWP (%)	AWC (%)	OC (ton / ha)
0 - 20	16.84	6.24	10.60	38.28
20 - 40	18.39	7.24	11.07	25.78
40 - 60	20.03	8.30	11.75	18.79
60 - 80	22.48	9.88	12.65	12.18
80 - 100	24.46	11.16	13.32	10.38
LSD (0.05)	0.38	0.25	0.14	1.39

Conclusion

There were consistent changes in the soil properties across the depths. Organic carbon storage, water conductivity properties, and macro aggregation decreased down the depths while stability of micro-aggregates, water retention characteristics, bulk density and clay content increased down the depths. The reduced drainage at the higher depths should be considered in cultivating deep rooted crops which are sensitive to poor drainage. The top soils should be managed with good agronomic practices and minimum tillage to avert damages to the macro and microsoil aggregates.

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