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Porosity and water retention characteristics of humid tropical soil at specific depths of different land use practices

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ABSTRACT

Soil porosity and water retention characteristics influence permeability and water dynamics of soils. This study examines soil porosity and water retention characteristics of different land-use practices at specific depths. The split-plot experiment under Randomized Complete Block Design had land-use as the main plot factor at four levels, and depth, the sub-plot factor at five levels. Soil samples were collected at specific depths of nine randomly selected points in each land-use. Samples were analyzed in a laboratory. Data were analyzed for variance and correlation using Statistical Analysis System (SAS) and Statistical Package for the Social Sciences (SPSS) software, respectively. Results showed that treatments varied significantly ($P \leq 5$ %); oil palm plantation (OP) had the highest water content at 0 – 20 and 20 – 40 cm depths, while continuously cultivated land (CC) had the lowest water content across depths. Also, OP had the highest total porosity at 0 – 80 cm depths, while grassland (GL) had the lowest total porosity across depths. The CC had the highest macro-porosity across depths, while forest land (FL) had the lowest accordingly. Porosity decreased with increase in depth, while water retention characteristics increased with depth. There was significant ($P \leq 5$ %) negative relationship between soil porosity and water retention characteristics at the land-use practices. The order of optimum soil porosity and water retention capacity of the land-use practices was OP > FL > GL > CC, while the strength of the relationship between porosity and water retention characteristics was greatest at the soil under CC.

Contribution/Originality: Most previous reports on related research provided generalized information on porosity and water retention characteristics of soils, but this research provides detailed information on same parameters among soils under different land-use practices at specific depths, thereby established that land-use practices influence the dynamics of these soil parameters at varying depths.

1. INTRODUCTION

The quality and productivity of agricultural soils are essential factors considered in the pursuit for food security, sustainable agriculture, and healthy environment amidst climate change [1]. Soil physical properties are significant players in the overall quality and productivity of soils because of their influence on the population and activities of soil biotic community, and chemical processes including nutrients transformation and translocation within the soil system [1]. Soil porosity as a measure of volume of voids or pores within a body of soil is a basic property of soil which controls certain physical characteristics of soil such as; soil permeability, hydraulic conductivity, soil aeration, water retention capacity, and bulk density [2]; hence, it is a significant soil parameter used in the assessment of soil quality and productivity potentials. The water retention characteristics of soil as a measure of the ability of soil to retain water at different moisture regimes has been found to have significant association with soil nutrient availability, microbial population and distribution in the soil [3]; therefore, it controls decisions on choice of crop, and schedule of cropping activities, because, plant nutrition is solely by water. Sahur, et al. [3] further noted that osmotic processes involved in plant mineral nutrition, water imbibition for seed germination, root growth and ramifications, and transpiration pull, which is the driving force for plants uptake of nutrients, are known to largely depend on soil moisture content. Also, Chang, et al. [2] highlighted that soil temperature, thermal diffusivity, water movement in soil, and aeration are influenced by soil porosity and moisture content.

The quality of soils, including the nature of soil porosity and water retention characteristics extensively depends on land use and soil management practices [4, 5] as well as differences in depths of soil [6]. The ramifying roots of trees in rainforest vegetation can promote the presence of macropores, which has impact on volume of soil pores, and water transmission and retention properties of soil [7]. Moreover, litter fall from the trees can add to the organic matter content of the forest soil, which can positively affect the macro aggregation of soil, and influence the capacity of the soil to transmit and retain water [7]. The pulverization of soil during tillage operation under intensive cultivation of soil promotes the loosening of soil, which enhances soil porosity [8]; however, in such soils, the porosity of the residing untilled layer of soil is jeopardized through the compaction of soil by tillage implements [8] the loosening of soil through tillage operation and its associated increase in porosity often weakens the water retention capacity of soil, but increases water percolation [8]. The dense fibrous root system of grasses has the ability to initiate and improve soil aggregation thereby enhances soil porosity, and promotes water retention capacity of soils [7].

The concept of vertical variation in soil properties across soil depths has been reported [9]. Changes in soil organic matter content, clay content and bulk density across soil depths has considerable influence on the porosity and moisture retention capacity of soils [10]. Notwithstanding, the changes in soil properties across depths of soil is speculated to vary with differences in land use and soil management practices; hence, there is a possible significant interaction between land use practices and depth of soils. Therefore, this study aims at assessing the effect of the interaction of land use practices and depth on the porosity and moisture retention characteristics of soils as well as the relationship between the porosity and water retention characteristics at the various land use practices.

2. MATERIALS AND METHODS

2.1. Location and Description of Study Area

The study area was Umuahia, Abia State which lies within latitude and longitude of 5^o29^IN to 5^o31^IN and 7^o30^IE to 7^o32^IE, respectively with mean annual rainfall of 2200 mm [10]. Umuahis is known for two seasons which are the rainy and dry seasons. The rain kicks off in March and continues to October with a short period of dry spell in August, while the extended dry period prevails from November till February. It has mean annual temperature 28^oC [10]. The area is characterized by plain to gently undulating terrain with Coastal plain sands as the dominant parent material. The soil of the area was classified as "Hapludult" at great group category according to the USDA soil taxonomy [11, 12].

2.2. Land use Types

The study involved four land-use practices. They were continuous cultivation arable farmland (CC), oil palm plantation (OP), forest land (FL) and grass land (GL).

The forest land was regenerated for over 20 years, though it was previously cultivated with heavy tillage implements and machineries for an extended period of time before it was allowed to regenerate into secondary vegetation [10]. The forest is characterized by diverse species of tree plants, such as oil bean plant (*Pentaclethra macrophyllum*), African bread fruit (*Treculia Africana*), and bush mango (*Irvingia gabonensis*). Other plant species were shrubs and herbs like Siam weed (*Chromoleana odorata*), goat weed (*Sida acuta*). Sun flower (*Aspillia Africana*) etc [10].

The grassland was a 3 - year grass fallow land previously cultivated to cassava. The land was previously cultivated with heavy farm machinery and tractor-mounted implements such as, plough, harrow and ridger attached to a tractor [10]. The dominant grass species was elephant grass (*Panicum maximum*), spear grass (*Imperata cylinderica*), and carpet grass (*Axonopus compressus*) [10].

Table 1. Summary of soil characterization, classification and history of sites used for the study.

Land use	Soil characterization	Soil classification	Land use history
Oil palm plantation	OC storage = 21.10 ton/ha Clay content = 143 g/kg Bulk density = 1.26 mg/m^3	Hapludult	The land was cultivated to oil palm which had grown for over 20 yrs. The alleys were not cultivated to crops but were covered by weeds which were slashed periodically and the biomass left at the ground to decay.
Continuously cultivated land	OC storage = 13.50 ton/ha Clay content = 161 g/kg Bulk density = 1.35 mg/m^3	Hapludult	The land was cultivated to arable crops (Such as cassava, maize, pumpkin, yam) in every planting season. Soil tillage was by the use of simple farm tools. The soil fertility was managed by the application of organic manure (Such as poultry droppings and pig waste) and mineral fertilizer (Such as NPK). Weeding is done periodically.
3 - year grass fallow land	OC storage = 18.80 ton/ha Clay content = 117 g/kg Bulk density = 1.55 mg/m^3	Hapludult	The land was cultivated to cassava and potato three years ago, and soil fertility was managed by application of NPK fertilizer before fallowed to grass. The previous soil tillage was with heavy machineries. Within the 3 – year fallow, the grasses were set on fire on yearly basis during the dry season and allowed to regenerate during the rainy season.
Forest land	OC storage = 18.70 ton/ha Clay content = 74 g/kg Bulk density = 1.41 mg/m^3	Hapludult	The forest land was a 20 years secondary vegetation, but previously tilled with heavy farm machineries and implements. During cropping seasons.

Source: Amanze, et al. [10].

The plantation was composed of oil palm trees grown for over 20 years. There were other plant species growing in the plantation as weeds, these include; Siam weed (*Chromoleana odorata*), mimosa plant (*Mimosa pudica*), etc [10]. There was a practice of periodic de-weeding of the plantation in which the weeds were cut down and left on the soil to decay [10].

The continuously cultivated land was an arable farmland sown to cassava (*Manihot esculentus*), yam (*Dioscorea spp.*) and pumpkin (*Telferia occidentalis*) [10]. Extraneous input of organic manure and mineral fertilizer (NPK) was carried out in managing the fertility status of the soil, and weeds were controlled by manual method [10].

Forest land and 3 – year grass fallow land were on a toposequence, and lie at the upper and mid slopes with mean altitudes of 142 and 127 m.a.s.l, respectively while oil palm plantation and continuously cultivated land were on a near level to gently undulating land with mean altitudes of 163 and 155 m.a.s.l, respectively [10].

Table 1 presents some physical properties and organic carbon storage of soils under the various land-use practices, and this shows that the soils vary in bulk density, clay content, and organic carbon storage. It further indicates that the soils are of the same soil taxonomical category, great group, according to USDA soil classification. Also, the Table 1 shows the history of the various land-use and the current management practices of soils under the land-use, and these are shown to vary across the land-uses.

2.3. Soil Sampling and Sample Preparation

Soils were sampled by digging nine representative pits of 100cm depth in each land use practice. The pits were delineated into five depths of 0 – 20 cm, 20 – 40 cm, 40 – 60 cm, 60 – 80 cm and 80 – 100 cm. Soil samples were collected from each depth of the pit with a trowel and bulked to obtain a representative sample for each depth. A total of forty - five bulked samples were collected from each land use practice. A core sample of soil was collected at the respective depths of the pits from each land use practice. Therefore, Forty - five core soil samples were collected from each land use practice; hence, total of one hundred and eighty (180) core soil samples were collected across the land use practices. The core soil samples were saturated in water at return from the field, while the disturbed soil samples were air-dried and sieved with 2 mm sieve at the laboratory before analyses.

2.4. Laboratory Analyses

2.4.1. Bulk Density (BD)

This was determined using the core method as described by Anderson and Ingram [13]. This involved the collection of core sample of soil using a core sampler of known volume (V) and mass (M_1). The core sample was oven – dried at a temperature of about 105°C for 24hrs. The oven – dried core sample was placed inside desiccator immediately it was brought out of the oven and allowed to cool without absorbing moisture from the atmosphere. On cooling, the oven – dried core sample was weighed to obtain the mass (M_2). The mass of the oven – dried soil (M) was computed as ($M_2 - M_1$). The bulk density (BD) of the soil was computed as shown in the equation below;

$$BD = \frac{\text{Mass of oven dried soil (M}}{\text{Bulk volume of the soil (V)}} \qquad (1)$$

Equation 1 presents the formula for calculating the soil bulk density where bulk volume of the soil was calculated as the volume of cylindrical core sampler using $\pi r^2 h$ ($\pi = 22/7$, r is the inner radius of the cylindrical core sampler, and h is its height).

2.4.2. Total Porosity (PT)

This was determined by calculation using the bulk density (BD) values assuming a particle density (PD) of 2.65 mg/m^3. The formula is shown as follows;

$$PT = 1 - \frac{\rho_b}{\rho_s} X\, 100 \qquad (2)$$

Equation 2 shows the formula used in calculating soil total porosity (PT), where ρ_b in the formula is the soil bulk density and ρ_s is the soil particle density given as 2.65 mg / m^3.

2.4.3. Macroporosity (PM)

This was computed from volumetric moisture content at field capacity (FC) as described by Mbagwu [14] using the equation shown below:

$$PM = PT - \Theta_{vf} \quad (3)$$

Equation 3 shows the formula used in calculating the soil macroporosity where PT is the soil total porosity and Θ_{vf} is the volumetric water content at field capacity.

$$\Theta_{vf} = \rho_b \Theta_{mf} \quad (4)$$

Equation 4 presents the formula used in calculating the volumetric water content at field capacity (Θ_{vf}) is volumetric water content at field capacity, Θ_{mf} is gravimetric water content at field capacity and ρ_b is the soil bulk density.

2.4.4. Soil Water Retention Characteristics

Field capacity (FC), permanent wilting point (PWP) and available water content (AWC) were determined following the procedure outlined by Mbagwu [14] and reported in Amanze, et al. [15]. Core soil samples were soaked in water to saturation point. The saturated core soil samples were allowed to drain freely for 2 days, and thereafter, each of their respective masses (M_2) was determined by weighing. The same core soil sample was allowed to drain further to the 10th day, and thereafter, the mass (M_3) was determined by weighing for each of them. After drainage, the core soil samples were oven-dried at a temperature of 105°C and the oven-dry mass (M_4) for each core soil sample was determined by weighing.

The percentage moisture content at field capacity (FC) on dry mass basis was calculated using the formula as presented in Equation 5.

$$\% FC = \frac{M2-M4}{M4} X \ 100 \quad (5)$$

The percentage moisture content at permanent wilting point (PWP) on dry mass basis was calculated using the formula shown in Equation 6.

$$\% PWP = \frac{M3-M4}{M4} X \ 100 \quad (6)$$

The percentage water content at available water capacity (AWC) was obtained as the difference between the moisture contents at field capacity (FC) and permanent wilting point (PWP) as shown in Equation 7.

$$\% AWC = \% FC - \% PWP \quad (7)$$

2.5. Experimental Design and Data Analysis

The study was a split plot experiment laid-out in Randomized Complete Block Design (RCBD) with land-use practices as main plot factor, and this was at four levels (Continuously cultivated land, Forest land, Grass land, and Oil palm plantation), while the sub-plot factor was depth at five levels (0 – 20, 20 – 40, 40 – 60, 60 – 80, and 80 – 100 cm).

A total of twenty (20) treatments combination was obtained, which were replicated nine times to give one hundred and eighty (180) observational units.

Data obtained from the laboratory analyses were analyzed for variance and correlation using SAS and SPSS version 20, respectively. Significant means were separated using Fisher's Least Significant Difference at 5 % level of confidence.

3. RESULTS AND DISCUSSIONS

3.1. Total Porosity of Soils Under Different Land Use Practices at Specific Depths

Figure 1 showed that there was significant (P≤5%) interaction effect of land use practices and depths on total porosity (PT), as well as significant (P≤5%) variation of PT across the depths. Oil palm plantation (OP) had the highest PT (52.14 %) at 0 – 20 cm depth, which was significantly different from the other land use practices. On the contrary, grassland (GL) had the lowest PT (41.56 %), which was also significantly different from the other land use practices. Moreover, at the 20 – 40, 40 - 60and 60 – 80 cm depths, OP had the highest PT of 48.85 %, 46.85 %, and 43.48 %, respectively, which were considerably different from the other land use practices except at the 60 – 80 cm depth where it was not significantly different from forest land (40.39 %).furthermore, at 80 – 100 cm depth, forest land (FL) had the highest PT (39.70 %), but was not substantially different from OP (39.62 %). Contrariwise, GL had the lowest PT at the various depths, such that, the values were 41. 56 %, 40.17 %, 38.24 %, 36.27 %, and 34.84 %, for 0 – 20, 20 – 40. 40 – 60, 60- 80, and 80 – 100 cm depths, respectively. The Figure 1 also shows that PT decreased significantly with increase in depth at the various land use practices. The CC, FL, GL, and OP, had highest PT of 49.09 %, 46.91 %, 41.56 %, and 52.14 %, respectively, at 0 – 20 cm, which differed significantly from their respective values obtained at the other depths. On the other hand, CC, FL, GL, and OP, had the lowest PT of 36.23 %, 39.7 %, 34.84 %, and 39.62 %, respectively, at the 80 – 100 cm depth, and these varied considerably from values obtained at the other depths of the respective land use practices.

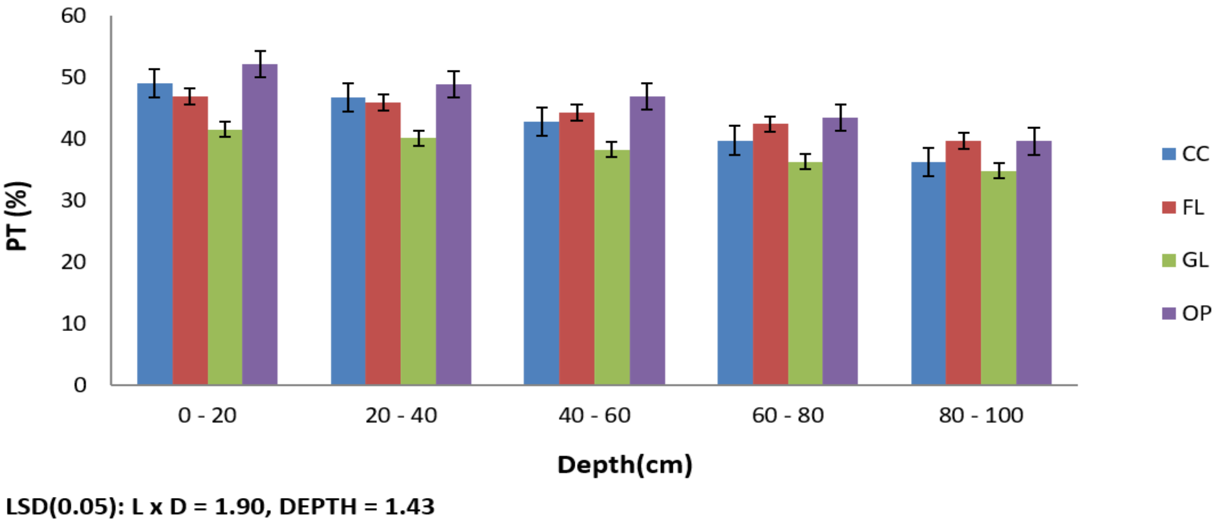


Figure 1. Interaction-effect of land use practices and depth on total porosity (%).

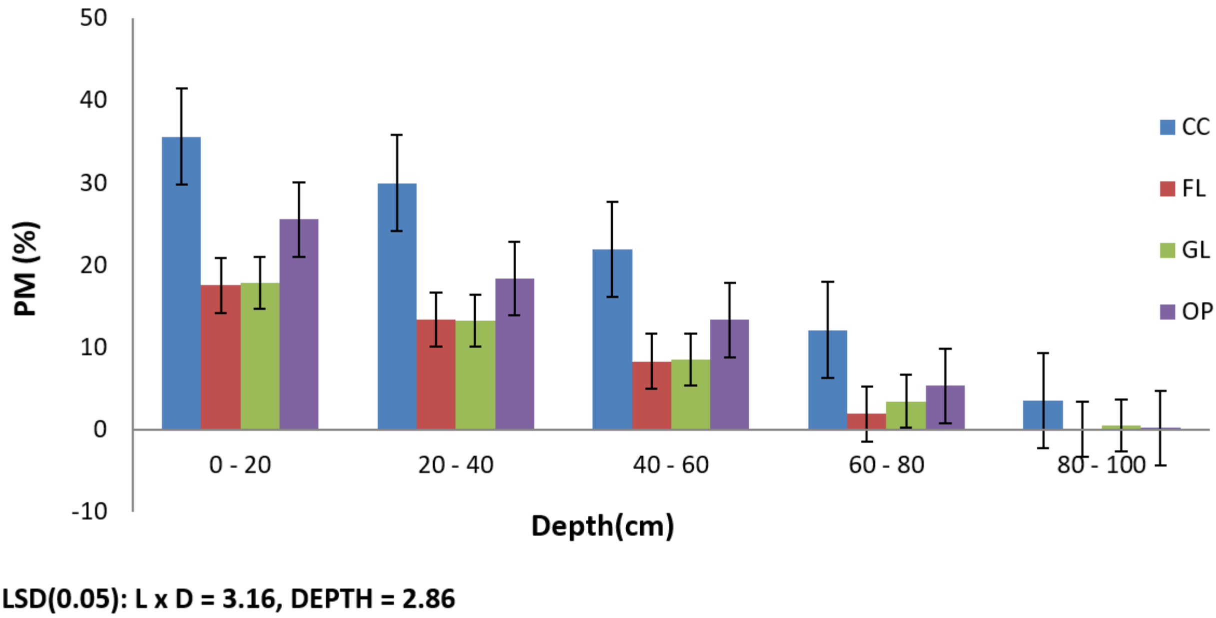
The increased total porosity at OP compared to the other land use practices implies that the soil under OP had better aggregation and improved structure, which, perhaps resulted from increased deposit of organic materials through the return of plant residues into the soil via litter fall, and the slash and compost practices at the plantation. This claim agrees with the report of Amanze, et al. [10] that organic matter deposit on the soil enhances aggregate and structural stability of soils. Conversely, the decreased PT of the soil under GL signified that the soil had limited amount of pore spaces, which possibly resulted from the compaction of the soil during the previous tillage operations.

This assertion corroborates the reports of Kutilek [16] and Amanze, et al. [9] that use of heavy machinery during tillage operation causes irreversible compaction of soil, which results in increased bulk density, and decreased total porosity. Consequently, the soil under GL would be characterized with poor drainage, limited water storage, increased surface run-off and its resultant effect on soil erosion, poor aeration, and restricted root growth and ramification [1].

3.2. Macro Porosity of Soils Under Different Land Use Practices at Specific Depths

Figure 2 showed that there was significant (P≤5%) interaction effect of land use practices and depths on macro porosity (PM), as well as significant (P≤5%) variation of PM across the depths. Continuously cultivated land (CC) had the highest values of 35.60 %, 29.96 %, 21.89 %, 12.08 %, and 3.53 %, at 0 – 20, 20 – 40, 40 – 60, 60 – 80, and 80 – 100 cm depths, respectively, which differed considerably from the respective values obtained at the other land use practices. On the contrary, GL had the PM (13.25 %) at 20 – 40 cm. Meanwhile, at 0 – 20, 40 – 60, 60 – 80, and 80 – 100 cm depths, FL had the lowest PM of 17.52 %, 8.28 %, 1.89 %, and 0.00 %, respectively, but GL and FL were not substantially different in macro porosity.

The Figure 2 further showed that there was substantial decrease in PM with increase in soil depth, such that CC, FL, GL, and OP had the highest PM of 35.60 %, 17.52 %, 17.83 %, and 25.56 %, respectively at 0 – 20 cm depth. Contrariwise, CC, FL, GL, and OP had the lowest PM of 3.58 %, 0.00 %, 0.46 %, and 0.21 %, respectively at 80 – 100 cm depth, and these varied substantially from the values obtained at the other depths of the respective land use practices.



LSD(0.05): L x D = 3.16, DEPTH = 2.86

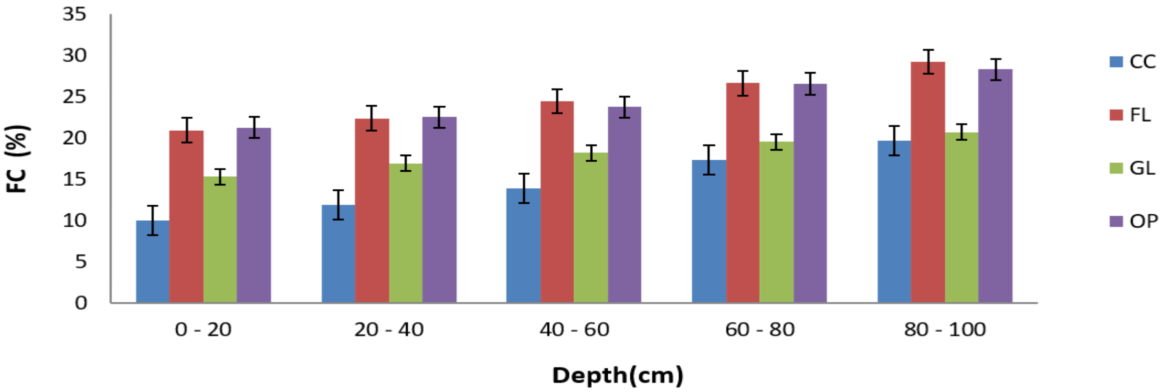
Figure 2. Interaction-effect of land use type and depth on macroporosity (%).

The highest PM at CC entails that the soil would be associated with increased filtration and percolation, reduces surface run-off, low water and nutrient holding capacity, increased permeability with its positive effect on soil aeration, root growth and ramification [1]. The increased PM observed at CC could be inferred on the regular pulverization of the soil via continuous cultivation of crops; this loosened the soil, and caused an increase in the size or volume of soil pores [8]. Conversely, the reduced PM observed at the various depths of FL and GL is attributable to the effect of the previous tillage operation in which heavy machineries and tractor-mounted implements were deployed in the cultivation of the soils before the lands fallowed to secondary rainforest vegetation and grass land, respectively; this affirmation is in consonance with the reports of Noemi, et al. [17] and Amanze, et al. [9] that use of heavy machineries in soil cultivation compacts the soil, which leads to substantial decrease in pore size and volume. Consequently, the reduces PM at soils under FL and GL indicated that the soils would have drainage problems, poor aeration, limited root growth and ramification, increased bulk density with its negative implication on roots access to water and nutrients [18].

The general decrease in porosity with depth can be blamed on the compaction of the underlying layers of soils by the overburden effect, compressional force and pressure from the overlying layers of the soils; this claim agrees with the report of Nathalie [1] that increase in pressure and compression force on the soil increases soil compaction leading to notable decrease in pore size and volume. Consequently, soil aeration, water movement, root growth and ramification and biological activities may significantly decrease with depth, which would negatively affect soil quality and fertility for crop production. However, there will be increase in water and nutrient retention at the residing depths as a result of the decreased porosity [3].

3.3. Soil Moisture Content at Field Capacity Under Different Land Use Practices at Specific Depths

Figure 3 shows that there was significant (P≤5%) interaction-effect of land use practices and depth on field capacity (FC). At 0 – 20, and 20 – 40 cm depths, OP had the highest water content at FC with values as 21.24 %, and 22.48 %, respectively, which were not significantly (P≤5%) different from values obtained under FL at those depths. However, at 40 – 60, 60 – 80, and 80 – 100 cm depths, FL had the highest water content at FC with mean values of 24.41 %, 26.59%, and 29.20%, respectively, which were not considerably different from values obtained under OP at those depths, accordingly. Contrarily, CC had the lowest water content at FC with mean values of 9.96 %, 13.86 %, 17.30 %, and 19.70 %, at 0 – 20, 20 – 40, 40 – 60, 60 – 80, and 80 – 100 cm depths, respectively, and these substantially differed from the values obtained from soils under the other land use practices, accordingly. The Figure 3 further reveals that there was significant increase in water content at FC with increase in depth of soils at the various land use practices. The 0 – 20 cm depth had the lowest water content at FC at all the land use practices, such that the FC mean values at 0 – 20 cm depth for CC, FL, GL, and OP were 9.96 %, 20.90 %, 15.21 %, and 21.24 %, respectively. On the contrary, 80 – 100 cm depth had the highest water content at field capacity for the various land use practices, such that CC, FL, GL, and OP had their highest values at this depth as, 19.70 %, 29.20 %, 20.61 %, and 28.25 %, accordingly, which varied significantly from the values obtained at the other depths.

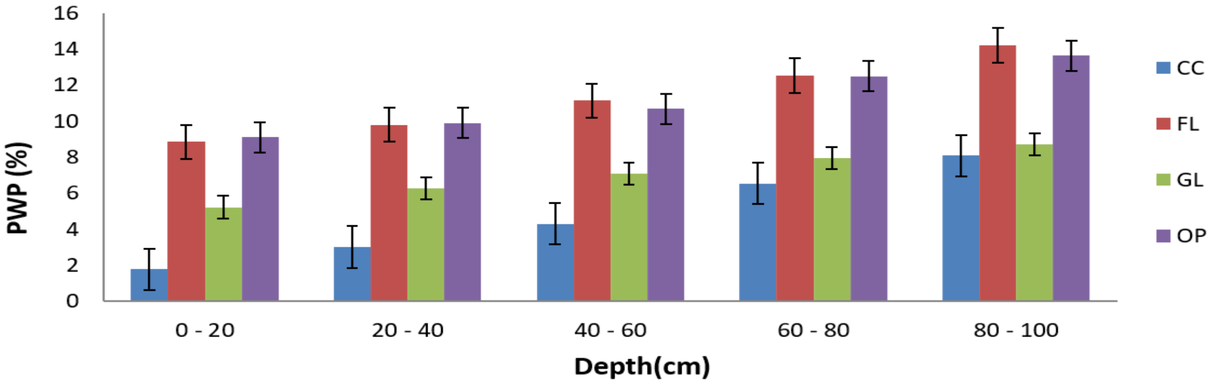


LSD(0.05): L x D = 0.94, DEPTH = 0.76

Figure 3. Interaction effect of land use practices and depth on field capacity (%).

3.4. Soil Moisture Content at Permanent Wilting Point Under Different Land Use Practices at Specific Depths

Figure 4 shows that there was significant (P≤5%) interaction-effect of land use practices and depths on soil water content at permanent wilting point (PWP). At 0-20 and 20-40 cm depths, OP had the highest water content of 9.10 %, and 9.89 %, correspondingly, but these were not considerably different from the respective values obtained at the soil under FL. Nevertheless, the soil under FL had the highest amount of water retained at PWP at 40-60, 60-80, and 80-100 cm depths with the respective values of 11.13 %, 12.53 %, and 14.21 %, which was not considerably different from the respective values obtained from the soil under OP. On the opposite, soil under CC had the lowest water content PWP across the depths with values of 1.79 %, 3.02 %, 4.31 %, 6.54 %, and 8.08 % for 0-20, 20-40, 40-60, 60-80, and 80-100 cm depths, respectively. The Figure 4 further reveals that there was considerable increase in water retained at PWP with increase in depth of soils at the various land use practices, such that, the soils had the lowest water content at 0-20 cm depth with the respective values of 1.79 %, 8.85 %, 5.23 %, and 9.15 % for soils under CC, FL, GL, and OP. On the other hand, the soils had the highest water retained at PWP at 80-100 cm depth with the respective values of 8.08 %, 14.21 %, 8.72 %, and 13.65 % for CC, FL, GL, and OP, respectively.

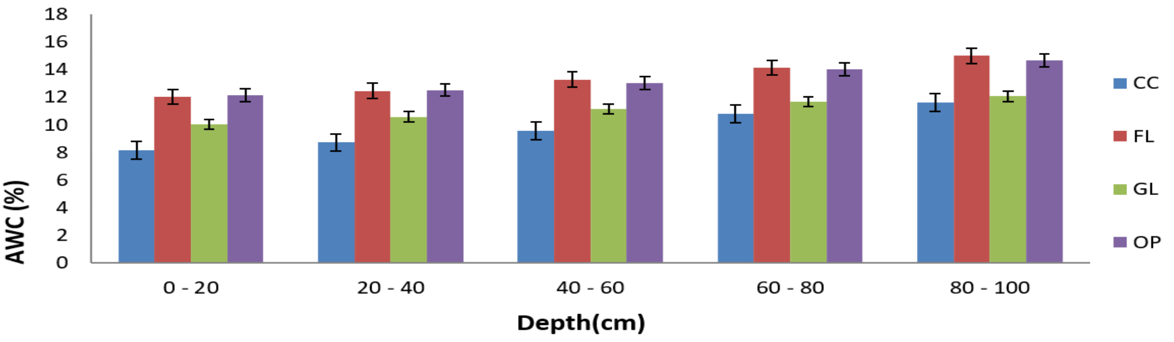


LSD(0.05): L x D = 0.61, DEPTH = 0.49

Figure 4. Interaction-effect of land use practices and depth on permanent wilting point (%).

3.5. Soil Moisture Content at Available Water Capacity Under Different Land Use Practices at Specific Depths

Figure 5 shows that there was a significant (P≤5%) interaction-effect of land use and depth on water content at available water capacity (AWC) of the soils. Soil under oil palm plantation had the highest water content at AWC (12.16 % and 12.52 %) at 0 – 20 and 20 – 40 cm depths, respectively, but these values were not substantially different from values obtained at soil under FL accordingly. Meanwhile, at 40 – 60, 60 – 80, and 80 – 100 cm depths, FL had the highest moisture content at AWC of 13.28 %, 14.14 %, and 14.99 %, respectively, but these values were not considerably different from the values obtained at the soil under OP at the respective depths. Contrariwise, the soil under CC had the lowest water content at AWC for all the depths, such that at 0-20, 20-40, 40-60, 60-80, and 80-100 cm depths, its respective water content at AWC were 8.16 %, 8.17 %, 9.54 %, 10.77 %, and 11.62 %, and these varied considerably from the values obtained at the respective depths of the soils under the other land use practices. Moreover, the Figure 5 shows that soil moisture content at AWC varied significantly (P≤5%) across the depths at the various land use practices. There was a notable increase in soil water content at AWC with increase in depth of soils under the various land use practices, such that each land use practice had its lowest value of available water content at 0-20 cm depth; hence, at 0-20 cm depth, soils under CC, FL, GL, and OP had available water content of 8.16 %, 12.04 %, 10.06 %, and 12.16 %, correspondingly, and these values differed substantially from the values obtained at the other depths, respectively. Consequently, the soils under the various land use practices had their highest available water content at 80-100 cm depth, such that, CC, FL, GL, and OP had available water content of 11.62 %, 14.99 %, 12.06 %, and 14.64 %, respectively, and these values differed substantially from values obtained at the other depths of the soils under the respective land use practices.



LSD(0.05): L x D = 0.34, DEPTH = 0.29

Figure 5. Interaction-effect of land use practices and depth on available water capacity (%).

The general order of water retention capacity of soils under the land use practices was such that, OP>FL>GL>CC at 0-20, and 20-40 cm depths, while at the other depths, FL>OP>GL>CC. The increased water retention capacity of the soil under OP compared to the other soils was attributable to its increased soil organic carbon, and clay contents relative to the soils under the other land use practices. This corroborates the report that large charged surface area of organic carbon and clay particles enhanced the attraction and adhesion force of soil to water molecules, thereby promote the water retention capacity of soils [19]. Consequently, soil under OP can adequately sustain the growth of crops at dry spell period by providing the water need of the crops compared to soils under the other land use practices [3]. Conversely, the poor water-holding capacity of soil under CC was perhaps a resultant effect of its low content of organic carbon and increased porosity. Amanze, et al. [10] reported that continuous cultivation of soils decreases the ability of the soil to retain moisture due to increased loss of organic carbon by oxidation, while Nwite [8] explained that the pulverization of soil during tillage operations increases the size and volume of soil pores, which considerably decreases the water retention capacity and moisture content of soils. Therefore, the soil under CC will be characterized with increased moisture tension during dry spell period, and this will have grave consequence on crop productivity which may manifest in poor yield or crop failure [3].

3.6. Relationship Between Soil Porosity and Water Retention Characteristics at the Various Land use Practices

Table 2 shows the relationship between soil porosity and water retention characteristics at the various land use practices. There was significant (P≤5 %) negative relationship between soil porosity and water retention characteristics at all the land use practices. The coefficient of correlation between macro porosity of soil at CC and FC, PWP, and AWC was -0.999**. This indicates a highly significant negative relationship, which is attributable to the increased macro porosity at the soil under CC compared to the soils under the other land use practices. Macro pores are characterized by large volume, which enhanced rapid and free flow of water by enhancing gravitational potential of soil water; consequently, it decreased the adhesion and retention of water within the soil by decreasing the degree at which water made contact with the soil solid particles, thereby, weakened the soil matrix force [9].

Table 2. Relationship between soil porosity and water retention characteristics.

Soil parameters	CC		OP		GL		FL	
	PT	**PM**	**PT**	**PM**	**PT**	**PM**	**PT**	**PM**
FC	-0927*	-0.999**	-0.991**	-0.990**	-0.995**	-0.998**	-0.937*	-0.937*
PWP	-0.927*	-0.999**	-0.991**	-0.990**	-0.996**	-0.998**	-0.937*	-0.937*
AWC	-0.930*	-0.999**	-0.998**	-0.988**	-0.998**	-0.100**	-0.993**	-0.993**

Note: FC = Field capacity, PWP = Permanent wilting point, AWC = available water capacity, PT = Total porosity, PM = Macro porosity, CC = Continuously cultivated land, OP = Oil palm plantation, GL = Grassland, FL = Forest land, n = 45, * = Significant at 5 % level of confidence, ** = Significant at 1 % level of confidence (2 – tailed).

The implication is that the soil under CC will be faced with poor moisture content to sustain crop production especially during dry spell periods [2]. There was a highly significant negative relationship between porosity and water retention characteristics of soil under GL, with the coefficient of correlation of -1.00** observed between macro porosity and AWC, which explained that the macro pores of soil under GL had 100 % absence of water retained at AWC. Consequently, the available form of water to sustain the growth and productivity of crops for substantial period of time at the soil under GL was absent at the macro pores, but may be present at the meso and micro pores of the soil, which may not be adequate to support the productivity of the crops without extraneous application of water via irrigation or rainfall. Lipiec, et al. [18] noted that soil available water at the micro pores does not effectively cater for the water need of many plants because it is often held at high water tension which requires greater suction force from the plants to absorb compared to available water at the macro pores. At the soil under OP, both PT and PM had highly significant negative relationship with the water retention characteristics. However, very notable was the negative relationship between total porosity and AWC with correlation coefficient of -0.998**. This implies that the micro and macro pores of the soil under OP jointly contributed to the decrease in its water content at AWC. This observation may be a result of the increased total porosity observed at the soil under OP compared to the other land use practices. This assertion corroborates with the report of Szabolcs, et al. [19] that increase in total porosity significantly decreases the availability of water for plant use. Total and macro porosity had highly significant negative relationship with AWC (correlation coefficient = -0.993**) at the soil under FL. This indicates that total or macro porosity of the soil under FL had similar effect on the amount of soil water retained at AWC. Consequently, the soil pores which may be considered as macro pores were relatively as small as the micro pores, such that, their effect on water content was just the same as the micro pores. This observation may have resulted from the notable decrease in the macro porosity of the soil under FL compared to the other land use practices; which implies that the soil was dominated by the micro pores.

4. CONCLUSION

There was significant interaction-effect of land use practices and depth on porosity and water retention characteristics of the soils, as well as considerable decrease in porosity, and increase in water retention capacity of the soils with increase in depth. The order of improved condition of soil porosity and water retention capacity at the land use practices is such that, oil palm plantation > forest land > glass land > continuously cultivated land. However, the soils at the various land use practices are prone to increased water loss by drainage, but this is greatest at the continuously cultivated soil. Efforts should be made to adopt adequate agronomic practices such as, application of organic manure, minimum tillage, mulching, and cover cropping, which will serve to improve the porosity and water retention capacity of the soils, thereby enhancing soil quality and crop productivity.

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