CHANGES IN SOME PHYSICAL PROPERTIES OF SOILS AND SPATIAL VARIATION OF ORGANIC CARBON STORAGE OF SOILS UNDER CONTRASTING LAND USE SYSTEMS IN SOUTHEASTERN NIGERIA.

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ABSTRACT
Organic carbon (OC) storage and distribution is greatly influenced by land use systems, and this has direct effect on the physical properties of soil. Some physical properties and the spatial variability of OC storage of soils under continuously cultivated land (CC), forest land (FL), 3 – year grass fallow land (GL3) and oil palm plantation (OP) were investigated. The experiment was laid out in a randomized complete block design (RCBD) such that each land-use type was partitioned into nine blocks (replicate) of equal area, disturbed and undisturbed soils were sampled randomly in each block at 0 – 20 cm depth. The disturbed soil samples in each block were bulked to obtain a representative sample for the block. Nine samples were obtained from each land-use type totaling thirty six disturbed and undisturbed soil samples for the four land-use types. The soils were analyzed in the laboratory. Analysis of variance (ANOVA) was performed using Genstat software package version 14, while spatial variability was measured by the use of GIS software package. Results showed that bulk density was significantly highest ($P<0.05$) at 1.55 Mg/m^3 under GL, and lowest value of 1.26 Mg/m^3 was found under OP. Saturated hydraulic conductivity (K_{sat}) was significantly highest ($P<0.05$) at 3.62 cm/h under CC, and lowest at 2.56 cm/h under GL3. Organic carbon storage was significantly highest ($P<0.05$) at 51.92 ton/ha and lowest at 22.98 ton/ha under OP and CC, respectively. Water retention at field capacity was significantly highest ($P<0.05$) at 21.24 % under OP and lowest at 9.96 % under CC. Available water holding capacity was significantly highest ($P<0.05$) at 12.16 % under OP and lowest at 8.17 % under CC. Water retained at permanent wilting point was also significantly highest ($P<0.05$) at 9.08 % under OP and lowest at 1.78 % under CC. There was spatial variability in organic carbon storage under each land use type. Regions with more organic carbon storage were northeast, southwest, northward and random for OP, FL, CC and FA, respectively. Soil water conductivity was enhanced by the pulverization of the soil via tillage at CC, but greatly decreased in the compacted soil under FA. Soil bulk density was significantly decreased with increase in organic carbon storage at OP while at CC, bulk density was decreased due to pulverization. The oil palm plantation and the cultivated land had the highest and the lowest values of the organic carbon storage, respectively.

Keywords: Soil physical properties, organic carbon storage, land use systems, spatial variation

INTRODUCTION
Soil organic carbon greatly influences aggregate stability, bulk density and total porosity. These soil structural properties affect water infiltration and retention, access to water and nutrients by plants. These properties also affect seedling emergence, root penetration, plant growth and soil erodibility. However, soil organic carbon is greatly influenced by human activities through land use and management such that its variability, both spatially and vertically, across soils follows systematic changes as a function of these influences (Amusan *et al*., 2006; Mbagwu and Auerswald, 1999). Hence, understanding the relationship between land use and soil organic carbon is paramount for effective soil management and land use allocation.
Degradation of soils due to unsustainable land use has released billions of tons of carbon into the atmosphere (Schwartz, 2014). The world cultivated soils have lost 50 – 70% of their original carbon stock (Schwartz, 2014). Holland (2004), showed how effective land restoration through bush fallow and conservation tillage could be in sequestering carbon and slowing down climate change. In order to mitigate the effects of rapid increase of atmospheric CO_2, soil carbon losses and carbon sequestration have become important issues in research. Intensive soil tillage increases soil aeration and changes the climate (temperature and moisture) of topsoil and thus, often accelerates soil organic matter decomposition rates (Balesdent *et al*., 2000). Conservation tillage is therefore considered as a measure to sequester carbon in soils as it has proven to

be effective in conserving soil organic matter at the topsoil (Holland, 2004). Blaire *et al*. (2006) revealed, in a comparative study of grassland and cropland, that there was a significant difference in the amount of carbon stored in grassland than that in cropland under similar site conditions such as climate and topography.
Soil physical properties deteriorate with changes in land use especially from forest to arable. Cropping usually results in losses of soil organic matter and soil aggregates, increase in bulk density and compaction (Chisci and Zanchi, 1981). Soil structure is greatly affected by intensity of land use which has influence on the distribution of microbial biomass as well as microbial processes that lead to soil aggregation and structural stability (Gupta and Germida, 1988). Land use significantly influenced soil physical properties especially structural parameters. Oguike and Mbagwu (2009) reported that changes in land use, such as conversion of natural forest to cropland, contributed to land degradation that manifested in losses of soil organic matter and reduced stability of soil aggregates.

Spatial variability refers to the variation in soil properties at varying spaces of a land in a defined geographical location on the landscape (Ojanuga, 2003). There are no two spots along a soil continuum that have exactly the same combination or interaction of factors, hence, the spatial variability of soil continuum is inherent in the concept of soil (Ojanuga, 2003). Similarly, differences in soil management practices and land utilization systems impact greatly on the pattern of spatial distribution of organic carbon storage within similar land use types and across different land use types. In order to ensure high precision agriculture and site specific soil management, the need to ascertain the spatial variability of soil organic carbon storage across and within land use types is of great research interest. Therefore, the objective of this research was to evaluate the effect of land use types on soil bulk density, moisture characteristics and spatial variability of soil organic carbon storage.

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°29'N to 5°31'N and longitude 7°30'E to 7°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°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 of the order "Ultisol" according to the USDA soil taxonomy (Soil Survey Staff, 2010). The vegetation type is tropical rainforest.

Land use types

The land use types studied were arable farmland under continuous cultivation (CC), oil palm plantation (OP), forest land (FL) and 3 - year grass fallow land (GL3). The FL and GL3 were on one toposequence while the OP and CC were on another. The FL was on the upper slope whereas the GL3 was on the mid slope. The OP and CC were both on the lower slope.

The forest land was secondary vegetation growing undisturbed for over 20 years. The common tree species found in this forest include oil bean plant (*Pentaclethra macrophyllum*), African bread fruit (*Treculia africana*), and bush mango (*Irvingia gabonensis*). Other plant species were shrubs and herbs such as "siam weed" (*Chromolaena odorata*), sun flower (*Aspillia africana*), goat weed (*Sida acuta*), etc. The grassland was a 3-year grass fallow land previously sown to cassava. The land was previously cultivated with plough, harrow and ridger attached to a tractor. The grass species was elephant grass (*Panicum maximum*). The oil palm plantation was established over 20 years ago. There were also weeds such as "siam weed" (*Chromolaena odorata*), mimosa plant (*Mimosa pudica*), etc., found in the plantation. However, the weeds were periodically cleared especially during the dry season to reduce excessive shade and competition with the oil palm trees. The continuously cultivated land was planted to cassava (*Manihot esculentus*), yam (*Dioscorea spp.*) and pumpkin (*Telferia occidentalis*). The soil fertility was managed by the application of both mineral (NPK) and organic fertilizers (poultry droppings and swine waste). Weed control was by manual method of hoeing and hand-picking.

Field work

Soil sampling and sample preparation

Soil samples were collected from nine geo-referenced observation points at 0 - 20 cm depth in each land use system using simple random sampling technic. The grid sampling method was done by using an existing pathway in the land as a baseline while nine observational points of 50 m intervals were established across the length and width of the land area through traverses created from the baseline. Soil samples were then collected from those determined points as replicates. The auger soil samples were air-dried and passed through a 2 mm mesh for laboratory analysis. The core 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^{o}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:

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

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) as shown below:

$C_T = C_F$ x D 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 four land use types. Data obtained were subjected to analysis of variance (ANOVA) to evaluate the effect of land use types on soil physical properties. Significant means were separated using Fisher's least significant difference at 5% probability level ($LSD_{0.05}$). Analysis of spatial variability of soil organic carbon storage across each land use type was done using GIS software package.

RESULTS AND DISCUSSION

Soil texture and textural classes

Variation of the texture of soils studied is shown in Table 1. Sand component varied significantly ($p\leq 0.05$) among the land use types with forest land (FL) having the highest (857 g/kg). The lowest value of 750 g/kg was observed in the 3-year grass fallow land (GL3), which was not significantly different from the oil palm plantation (OP) (756 g/kg) and continuously cultivated land (CC) (752 g/kg). The silt and clay components varied significantly ($p\leq0.05$) with GL3 having the highest value of silt (133 g/kg) and was significantly different from the other land use types. The highest value of clay component (161 g/kg) was observed under CC, which significantly ($p\leq0.05$) varied from the other land use types. The lowest clay component (74 g/kg) was observed under FL, which differed significantly from the other land use types. Thus, the textural classes of the soil was such that CC, GL3 and OP were sandy loam (SL), while FL was loamy sand.

Table 1: Variation of soil texture

Land use types	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	Texture
CC	752	87	161	SL
FL	857	69	74	LS
GL3	750	133	117	SL
OP	756	101	143	SL
LSD(P≤0.05)	8.7	10.4	5.9	-

The relatively high sand and low clay fractions in the FL and GL3 may be due to their positions at the upper and mid slopes, respectively. Therefore, it may be inferred that clay particles have been considerably moved away from soils under FL and GL3 via erosion. In contrast, the relatively high clay fractions observed in CC and OP may be attributed to their positions on the landscape (lower slope). Hence, little or no erosion may have occurred at OP and CC. This agreed with Ojanuga (2003) who reported that soils formed at the upper elevation of the landscape contained higher sand fraction and lower clay due to the lateral translocation of clay particles from the higher elevation to the lower via erosion process, while soils at the lower elevation or near level surface formed by the same parent material and on the same landscape contain higher clay. However, the lower sand fraction and relatively high clay and silt fractions in GL3 compared to FL that was on a similar elevation may be attributed to the mechanical manipulation of the soil during previous tillage operations at GL3. The tillage operations may have caused illuviation of silt and clay as well as crushing of the sand fraction into silt and clay sizes due to abrasion thereby leaving little sand fraction at the surface (Nwite, 2015).

Bulk density, hydraulic conductivity and organic carbon storage

There were significant variations ($p \leq 0.05$) in saturated hydraulic conductivity (K_{sat}) and bulk density (BD) across the soils as shown in Table 2. The fastest K_{sat} (3.62 cm/hr) was observed in CC. This was statistically similar to FL (3.38 cm/hr) but significantly different from the other land use types. The slowest K_{sat} of 2.56 cm/hr was observed in the GL3, which was not significantly different from OP (2.88 cm/hr). The highest BD (1.55 Mg/m^3) was observed in GL3, which differed significantly ($p \leq 0.05$) from the other land use types while the lowest (1.26 Mg/m^3) was observed in OP which differed significantly ($p \leq 0.05$) from the other land use types.

The Table 2 also shows that there was significant variation of soil organic carbon (SOC) storage across the land use types. Oil palm plantation (OP) had the highest value of 51.92 ton/ha, which varied significantly from the other land use types while the lowest (22.98 ton/ha) occurred in CC.

Table 2: Variability of Bulk density, hydraulic conductivity and organic carbon storage

Land use types	BD (Mg/m^3)	K_{sat} (cm/h)	OC ($tonha^{-1}$)
CC	1.35	3.62	22.98
FL	1.41	3.38	43.61
GL3	1.55	2.56	34.62
OP	1.26	2.88	51.92
LSD($P \leq 0.05$)	0.03	0.77	2.97

The low BD and rapid K_{sat} observed at CC were probably due to the pulverization of the soil during tillage operations which perhaps led to the loosening of the soil and development of macro pores confirming the report of Nwite (2015). Conversely, the relatively high BD and slow K_{sat} observed under GL3 were attributable to the compaction of the soil as a result of trafficking with heavy farm machineries during previous mechanized tillage operations. This corroborated Kutilek (2005) who reported that, long use of machinery during tillage operation caused an irreversible soil compaction resulting in high BD and reduced water transmission.

The low accumulation of organic carbon (OC) at CC may be related to the increased oxidation of the soil organic matter (SOM) stimulated by increased disturbance and aeration of the soil due to the continuous and intensive tillage operations coupled with low vegetation cover that exposed the soil surface to intense heat of the tropics. This observation was consistent with the report of Balesdent *et al.* (2000) that soil aeration increased with tillage while the climate of the topsoil, with respect to temperature and moisture, was altered leading to an increased rate of SOM decomposition and loss. Low turnover of residues to the soil due to frequent crop removal may also have contributed to the low OC storage. Contrarily, the high content of OC observed under OP may be due to the frequent return of biomass to the soil through periodic slashing of the over - grown plants and the shading provided by the canopy of the palm fronds as well as reduced soil disturbance. This confirmed the finding of Holland (2004) who reported that little or no disturbance to the soil was effective in conserving SOM at the topsoil and therefore serves as a measure to sequester carbon in the soil.

It could further be explained that the higher storage of OC under OP and FL than CC and GL3 could be attributed to high biomass production in the OP and FL and their subsequent return to the soil. The low rate of decomposition of these residues due to the favourable micro climate prompted by the plants cover may have also contributed to high organic carbon deposit under these land use types. This observation confirmed the findings of Holland (2004), who reported that the return of biomass as plant residues to the soil as well as moderation of soil temperature by countering the penetration of solar radiation, helped in reducing the oxidation rate of organic matter (OM) and loss of soil organic carbon (SOC).

Variation of water retention characteristics

Table 2 also revealed that the moisture retention characteristics of the soils varied significantly ($p \leq 0.05$). The highest values of 21.24 %, 9.08 % and 12.16 % for field capacity (FC), permanent wilting point (PWP) and available water capacity (AWC), respectively, were observed in OP. These varied significantly ($p \leq 0.05$) from the other land use types. The lowest values of 9.96 %, 1.78 % and 8.17 % for FC, PWP and AWC, respectively, were observed in CC and these also varied significantly from the other land use types.

Table 2: Variability of water retention characteristics

Land use types	FC (%)	PWP (%)	AWC (%)
CC	9.96	1.78	8.17
FL	20.9	8.86	12.04
GL3	15.28	5.23	10.05
OP	21.24	9.08	12.16
LSD(P≤0.05)	1.25	0.81	0.44

The higher water retention capacity of soil under OP may be connected to its relatively high clay and OC accumulation. The large charged surfaces of the OC and clay attracted and retained charged surfaces of water molecules. Under FL, with relatively low clay fraction, the moisture retention characteristics may have been improved by its relatively high OC storage (Fig.1) which provided large charged surfaces for the attraction and retention of water molecules (Malgwi and Abu, 2011).

Spatial variability of organic carbon storage across the land use types

There was spatial variability of SOC storage under each land-use type (fig. 2). The lowest SOC concentration of 32.44 ton/ha was obtained at the southward, southeastward and close to the extreme northern region of the FA while the highest SOC concentration of 36.58 ton/ha under FA occurred at the extreme northern region and western region. The highest SOC accumulation of 66.15 ton/ha was obtained within the northeastern and the extreme southeastern regions of the oil palm plantation (OP), and the lowest SOC storage of 42.00 ton/ha was obtained at two localized spots of the central and northwestern regions of the land.

The highest SOC accumulation of 26.46 ton/ha was obtained at the extreme north and northwestern regions of the cultivated land, and the lowest SOC accumulation of 19.71 ton/ha was obtained at extreme southeastern region of the land. The highest SOC storage of 49.00 ton/ha was obtained within the southwestern extending to the central area of the forested land (FL), and the lowest accumulation of 38.92 ton/ha occurred at the extreme northwest of the land, while the other portions within the land had low accumulation of OC. The degree of variability of OC with space across the land use types was greatest at GL3 and least at CC.

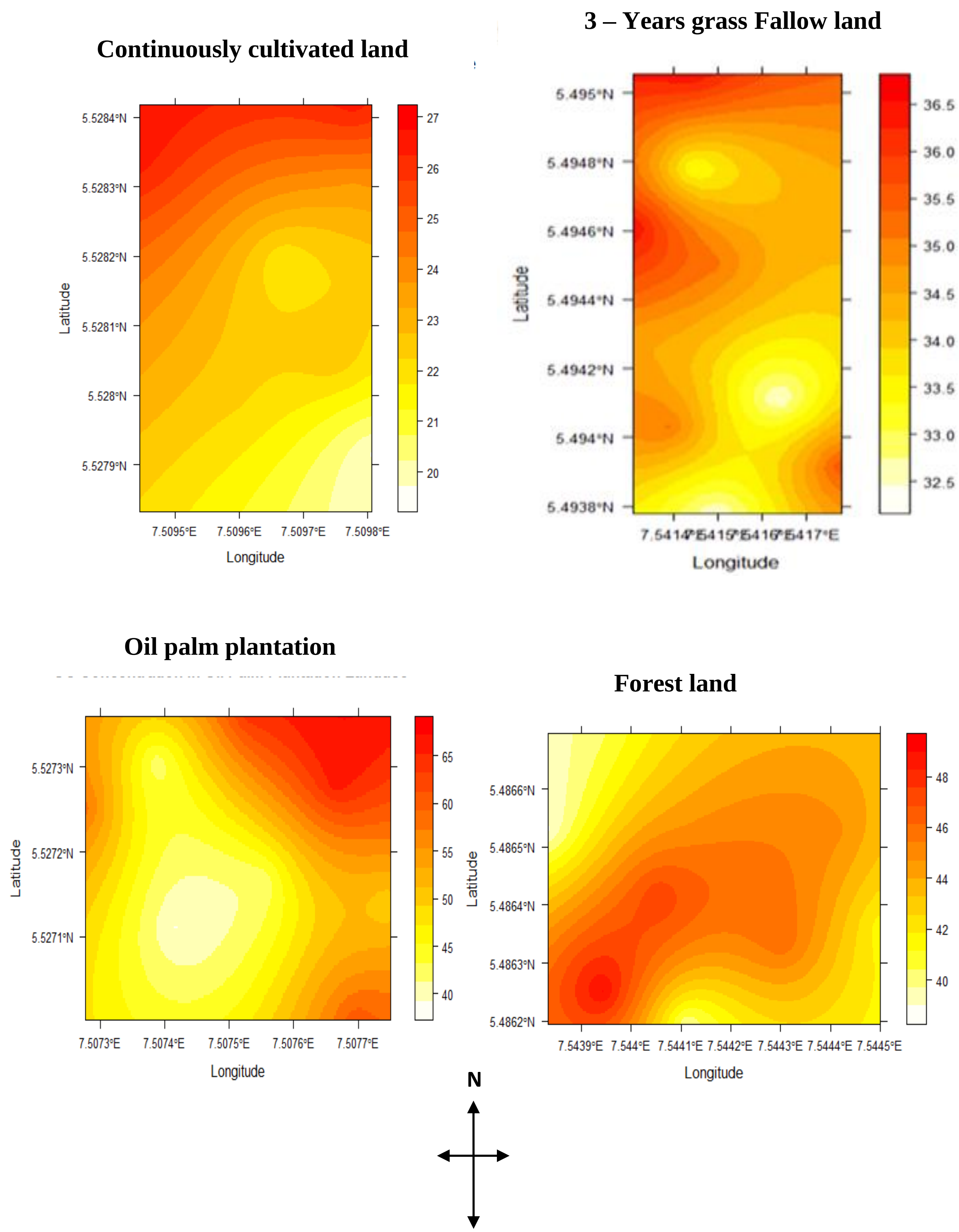

Figure 1: Spatial variability of soil organic carbon storage (ton/ha) under the various land-use types

The reason for the variability of OC within each land use was probably due to the relief which may have influenced erosion and deposition processes leading to the accumulation and reduction of SOC at the deposition and erosion surfaces, respectively. This confirmed the report of Ojanuga (2003). Also, the variation in plant density and rate of residue accumulation by litter fall across each land use must have contributed to this variability in space and may be inferred from the report of Holland (2004). Under CC, variation in residue management as well as differences in the intensity of tillage operations across the land may have contributed to this effect. The high concentration of OC within the central region than the borders under FL may be as a result of higher plant density which translated into high residue return at the central region than the borders (Holland, 2004). The implication of these findings was that the spaces within each land use type that had relatively low accumulation of OC may have low microbial activities and this may negatively affect processes of nutrient transformation. The spaces of low OC accumulation may become prone to the build - up of toxic elements (such as aluminum) through precipitation, probably because such areas may have low microbial activities that would have helped in detoxifying such toxic elements. Hence, practices that encourage organic matter accumulation (manure application, minimum tillage and mulching) should be incorporated into the overall soil management for such spaces of low accumulation while conserving OC in spaces of high accumulation.

CONCLUSION

There was significant variation of the physical properties of the soils under the four land use types. Soil under the oil palm plantation showed the best quality in water retention characteristics while the continuously cultivated land showed the worst quality to this property. Soil water conductivity was enhanced by the pulverization of the soil via tillage at CC, but greatly decreased in the compacted soil under GL3. Soil bulk density was significantly decreased with increase in organic carbon storage at OP while at CC, bulk density was decreased due to pulverization. Regarding the organic carbon storage, the oil palm plantation and the continuously cultivated land had the highest and the lowest values, respectively. There was a spatial variability in organic carbon distribution across each land use type though the degree of variability varies with the land use types. The greatest variability was observed under GL3 and least under CC. The spatial variability in organic carbon storage of soils require that attention be giving to areas with critical conditions of soil organic carbon, so as to effectively manage the soils.

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