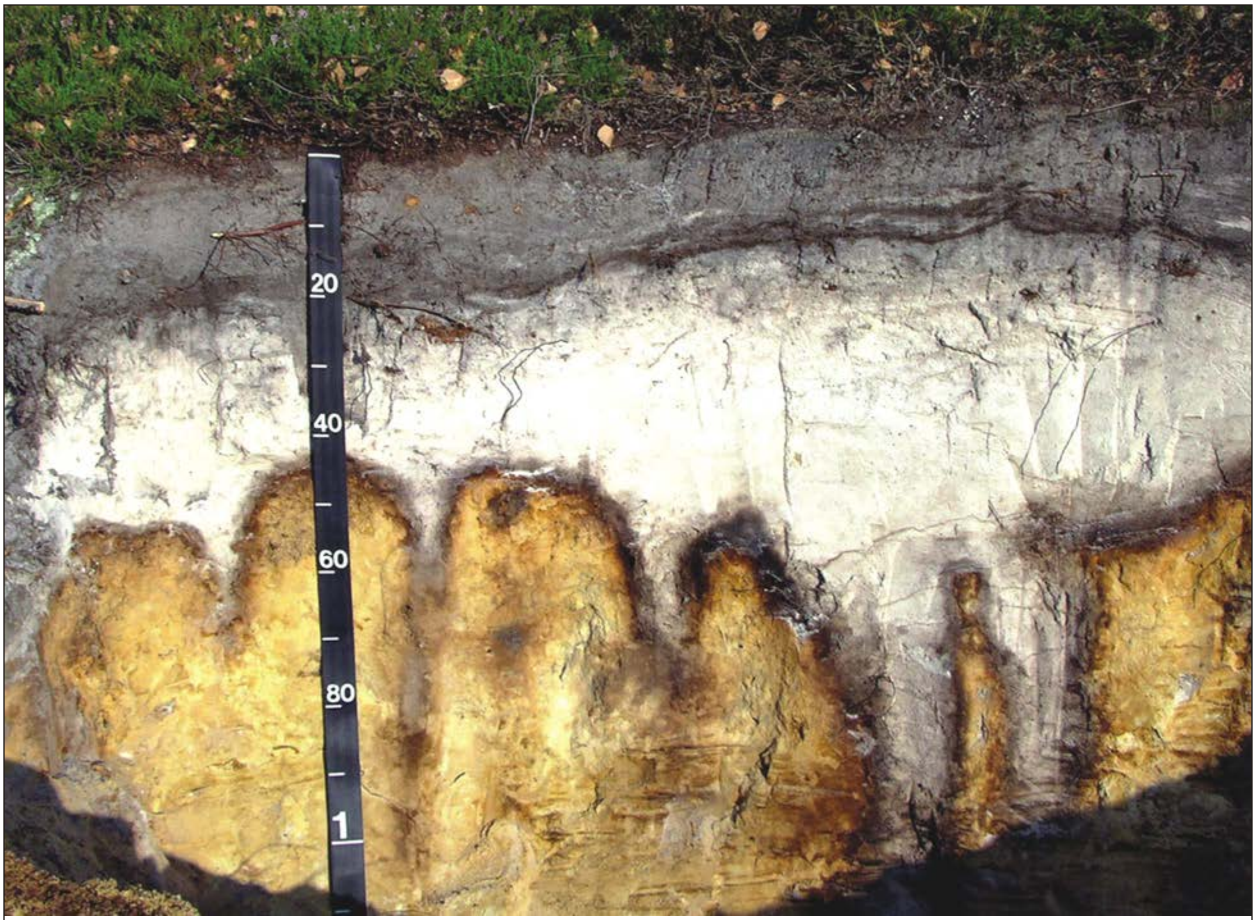

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Organic Carbon and Nitrogen Distribution in Particle-size Fractions of Soils Under Cassava, Plantain and Rubber Based Land Use

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ABSTRACT

Protection of Soil Organic Carbon (SOC) and nitrogen (N) from losses is important in evaluation and maintenance of soil fertility and environmental quality. Uncertainties exist concerning the distribution of SOC pool and N in primary particle size fractions under land use types. A study was carried out to determine the distributions of SOC and N in sand, silt and clay fractions of a sandy soil under cassava, plantain and rubber land use types in southern Nigeria. Results showed that cassava had the highest amounts of SOC in whole soil and the particle size fractions. Clay particles had significantly higher SOC across all the land use types at 0-15 cm soils ($p>0.05$). Total N was significantly higher in silt and clay particles of cassava and plantain soils. Coarse sands showed low amounts of SOC and total N in all the soils. Bulk densities ranged from 1.38 g cm^{-3} in cassava soil to 1.5 g cm^{-3} in rubber soil at the 0-15 cm depth. Total porosity was inconsistent in all the soils. Macro-aggregate fractions were more stable in cassava and plantain soils. Therefore, land use practices that lead to loss of clay and silt particles in large amount may deplete large reserve of the soil organic carbon and nitrogen.

Key words: Carbon pool, nitrogen pool, sand, silt, clay, land use

INTRODUCTION

The fractionation of soil based on physically defined particle-size fractions is used increasingly to interpret the dynamics of Soil Organic Carbon (SOC). This method can provide useful information on SOC dynamics under natural conditions or short-term management practices (Shrestha *et al*., 2007). Previous research has indicated that changes in land use (or management practices) have a marked impact on the amount of Organic Carbon (OC) in particle-size fractions, which could serve as an early indicator to identify the impact of land-use change on SOC storage (Leifeld and Kogel-Knabner, 2005; Udom and Ogunwole, 2015).

Agricultural land use and cropping systems can affect soil organic carbon storage and sequestration. It is well reported that SOC affects the soil physical, chemical and biological properties (Craswell and Lefroy, 2001) and plays crucial role in sustenance of soil quality, agricultural production and environmental quality (Zhang *et al*., 2006). The amount of OC in primary particle size fractions of soil is related to the amount of organic manure added into the soil and land use pattern (Bonde *et al*., 1992; Hassink, 1995; Liao *et al*., 2006). This indicates that there is tendency that storage capacity of SOC will vary in the primary soil particle fractions in land use types. Earlier studies showed that coarse textured soils have lower SOC concentrations when compared to silt and clay soils (Borchers and Perry, 1992). The amounts of OC that may be associated to clay and silt size fractions are affected by many factors including soil texture

(Hassink, 1995; Christensen, 2001), the dominant type of clay mineral (Parfitt *et al*., 2003) and the use to which the land is put. In arable soils most of the SOC was found in the clay and silt fractions, whereas in forest and grassland soils the contribution of sand size organic matter to total SOC was greater (Hassink and Whitmore, 1997; Christensen, 1992). Soils dominated by clays with a high specific surface area and numerous reaction sites probably adsorb more humic substances than soils dominated by sand with low specific surface area (Parfitt *et al*., 2003).

Inappropriate cropping practices and land use can induce SOC losses and significant degradation in soil quality (Six *et al*., 2002). Rational cropping involving farm land fallow (Paustian *et al*., 1997), conservation tillage (Gale and Cambardella, 2000), crop-residue recycling (Beare *et al*., 1994) and application of organic matter (Hao *et al*., 2011) can significantly affect SOC storage in primary soil particle fractions. Primary soil particles and their SOC contents affect soil fertility. Previous study by Aweto (2001), revealed that increase in age of plantation was an important factor in determining soil nutrient balance and fertility status. Jobbagy and Jackson (2000) also observed that older plantation led to increased SOC.

Soil texture provides an insight into the properties of soils influencing the hydrological processes and the capacity of soils to store organic carbon. Numerous authors have described the relationship between clay (or clay+silt) content and SOC (Parton *et al*., 1993; Feller and Beare, 1997). The linear increase between clay content and organic carbon was only valid up to a certain amount of clay depending on the type of soil, climatic conditions and mean annual temperature (Feller and Beare, 1997). Therefore, clay (or clay+silt) content is a relatively important determinant of SOC levels in soils and appears to apply to both cultivated soils and soils under natural vegetation. The formation of passive organic carbon pools with low turn-over rates can be facilitated by clay rich soils as clay particles can physically and chemically protect SOC in organo-mineral complexes (Von Lutzow *et al*., 2006). Increasing concentrations of carbon levels in soils may occur in clay rich soils as carbon can be captured within the small pores of clay particles (Feller and Beare, 1997).

Improved management of SOC in arable land is essential to sustain agricultural lands and natural ecosystems with which they interact (Wander and Nissen, 2004). The physical and chemical properties of soil are related to particle size distribution, bulk density and pore size distribution (Robert *et al*., 2012). Soil organic carbon content will form a key component of any integrative parameters relating to soil physical quality and one of the most important parameters indicating the degree of soil aeration. Concentration of SOC in primary particle fraction of soil is a good indicator of soil productivity due to their positive effects on physio-chemical and biological properties of the soil.

Understanding the extent which SOC are stored in primary soil particle fractions is not extensively studied under certain land use types especially in some of the indigenous tropical soils. Cropping pattern and the integration of anthropogenic disturbances on farm lands can significantly affect agricultural soil carbon pool. Results from many studies showed that rubber plantation decreased soil organic carbon (Yang *et al*., 2004; Udom and Ogunwole, 2015). In contrast, studies by Wang and Li (2003) and Yang *et al*. (2007) have demonstrated that rubber plantation could potentially enhance SOC sequestration. Most researches in the past compared total soil organic carbon pools only between mature plantations and native forest or immature plantations (Wang and Li, 2003; Zhang *et al*., 2006). Increasing knowledge in the SOC sequestration capacity can benefit the sustainability of agricultural development, agricultural carbon pool improvement, global food security and climate change mitigation. The objectives of this study were to quantify organic carbon distribution and storage in primary particle size fractions of soil in cassava, plantain and rubber based land use and their effects in the modification of soil hydrological properties.

MATERIALS AND METHODS

The study area and sampling: The study was carried out during the 2014 and 2015 planting seasons in three land use types occupying 950 ha in Choba, Port Harcourt, Nigeria (04°15'N and 07°30'E). The selected land use types were: (1) Cassava plots under 10 year continuous cultivation, (2) 10 year plantain plantation with *imperata cylindrical* as under growths and (3) Rubber plantation dominated by slam weed (*Chronoleanaodoraty*), goat weed (*Ageratum canyzoides*) and guinea grass (*Panicum maximum*). The soil in the area is from the coastal plain sand and is dominantly an Ultisol (USDA., 2008). Each land use area was divided into 4 replicates. Four disturbed and undisturbed core soil samples were randomly collected each at 0-15 and 15-30 cm depths from each replicate with the aid of a soil auger and a metal cores mechanically driven into the soil. A total of 96 representative soil samples were collected and transferred to the laboratory for analysis.

Laboratory analyses

Separation of primary particle size fractions: Soil samples were air-dried at room temperatures, crushed with wooden rollers and sieved through 4 nest of sieves of sizes: 2, 0.5, 0.05 and 0.002 mm to separate the soil particles into their spherical diameter size classes viz: coarse sand (2-0.50 mm), fine sand (0.50-0.05 mm), silt (0.05-0.002 mm) and clay (<0.002 mm) using the USDA groupings. The samples were stored in plastic bottles for analysis.

Determination of organic carbon and nitrogen in whole soil and particle size fractions: Total organic carbon in whole soils and each particle size fraction obtained through dry-sieving was measured by the wet oxidation dichromate method described by Nelson and Sommers (1996). Total nitrogen was determined by the modified macro-Kjeldhahl method of Bremner and Mulvancy (1982).

Determination of saturated hydraulic conductivity: Undisturbed soil cores measuring 6.5×5.5 cm (h×d) were saturated for measurement of saturated hydraulic conductivity using the constant head soil core method (Reynolds *et al*., 2002). Volume of water drained out was measured over a period of time until flow was constant, at each time, the flow rate was determined from the Eq. 1:

$$\text{Ksat} = \frac{Q}{AT} \times \frac{L}{\Delta H} \tag{1}$$

where, Q is the volume of water (cm^3) that flows through a cross-sectional area A (cm^2) in time T (sec) and ΔH is the hydraulic head difference imposed across the core sample of length L (cm).

Determination of total porosity and bulk density: Total porosity was calculated using the Flint and Flint (2002) formula as in Eq. 2:

$$\text{Total porosity (\%)} = \frac{\text{Volume of water saturation (cm}^3\text{)}}{\text{Volume of bulk soil (cm}^3\text{)}} \times \frac{100}{1} \tag{2}$$

Soil cores were oven-dried at 105°C to determine bulk density in Eq. 3 (Grossman and Reinsch, 2002):

$$\text{Bulk density} = \frac{\text{Mass of oven-dried soil (g)}}{\text{Volume of bulk soil (cm}^3\text{)}} \tag{3}$$

Measurement of aggregate stability: Water Stable Aggregates (WSA) were measured using wet sieving procedure described by Nimmo and Perkins (2002). In this procedure, 50 g of 4.75 mm dry aggregates were placed in top most of a nest of sieves to form a single layer of 4 classes 2.0, 1.0, 0.5 and 0.25 mm. The aggregates were pre-soaked in deionized water for 5 min and oscillated vertically in water 20 times. Aggregates that remained in each sieve were oven-dried at 50°C for 24 h and weighed. The mass of aggregate <0.25 mm was obtained by the difference between the initial sample weight and the sum of sample weight collected on the 2.0, 1.0, 0.5 and 0.25 mm nest of sieves. Water stable aggregates were measured by the Mean-Weight Diameter (MWD) by the following Eq. 4 (Hillel, 2004):

$$\text{MWD} = \sum\nolimits_{n=1}^{n} X_i W_i \tag{4}$$

where, X_i is mean diameter of any particular size range of aggregates separated by sieving, W_i is weight of aggregates in that size range as a fraction of the total dry weight of the sample analyzed.

Data analysis: Analyses of variance were carried out using the SAS software (SAS Institute Inc., 2001). Means within land use types were separated according to the least significant difference using Fisher's protected test (Gomez and Gomez, 1984) at 5% probability.

RESULTS

Texture, bulk density, total porosity and saturated hydraulic conductivity: Some physical properties of the soils under the land use types are shown in Table 1. The soil is sandy clay loam to loam at 0-15 cm and sandy loam to loam at 15-30 cm depth. The sand, silt and clay contents at the top soil ranged from 540-640, 140-240 and 200-220 g kg^{-1}, respectively. The land use types did not impact significant differences on the soil texture, except for plantain soil which is predominantly loam. Bulk density was lower (1.38 g cm^{-3}) in the cassava and showed highest value of 1.5 g cm^{-3} in rubber soils at the top 0-15 cm depth. The low bulk density in cassava soil suggests increased Soil Organic Matter (SOM) deposit from the cassava, especially on the top soil. Total porosity was significantly higher ($p<0.05$) in cassava and plantain soils than in rubber soil at the

Table 1: Some physical properties of the soils under the land use types

Land use	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	Textural class	Bulk density (g cm^{-3})	Total porosity (%)	Ksat (cm h^{-1})
0-15 cm							
Cassava	640^a	160^a	200^a	SCL	1.38^a	52.7^a	29.8^a
Plantain	640^a	140^a	220^a	SCL	1.45^a	40.9^b	23.7^b
Rubber	540^b	240^b	220^a	L	1.50^b	35.9^a	19.5^b
15-30 cm							
Cassava	660^a	160^a	180^b	SL	1.42^a	41.76^a	19.1^a
Plantain	525^b	240^b	230^a	SCL	1.50^b	31.30^b	12.6^b
Rubber	440^c	340^a	220^a	L	1.53^b	30.43^b	12.2^b

Means followed by the same letters are not significantly different at p>0.05, Ksat: Saturated hydraulic conductivity, SCL: Sandy clay loam, SL: Sandy loam, L: Loam top and subsoil (Table 1). Saturated hydraulic conductivity was rapid (29.8 and 23.7 cm h^{-1}) in cassava and rubber soils, respectively at the 0-15 cm depth. This trend was also found in the subsoil, with cassava soil having the highest amount. Generally, rubber soils were associated with higher bulk density, lower porosity and slow to moderately slow permeability.

Organic carbon and nitrogen in particle size fractions

Organic carbon: Organic carbon and nitrogen storage in sand, silt and clay fractions and whole soils at 0-15 and 15-30 cm soils are shown in Fig. 1-4. Results showed that SOC in whole soil was higher in cassava than plantain and rubber soils ($p>0.05$). There was indication storage in soil was higher in topsoil probably due to the presence of plant liters on the top soil. Soil organic carbon was significantly higher in the clay and silt size fractions at 0-15 cm depth, in cassava than in plantain and rubber soils Fig. 1.

Soil organic carbon in clay particles at the top 0-15 cm soil were 26.45, 20.4 and 16 g kg^{-1}, respectively, for cassava, plantain and rubber (Fig. 2). The coarse and fine sand fraction stored less

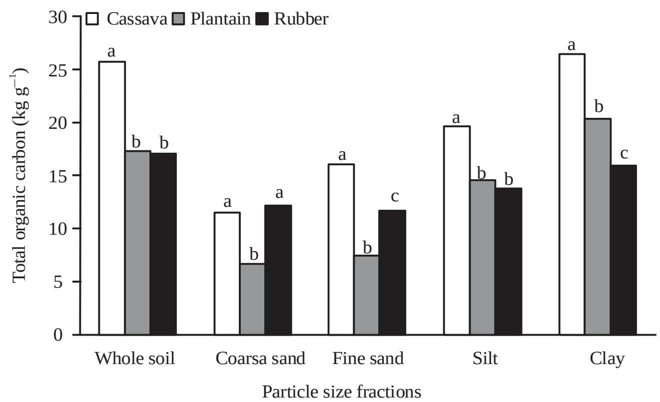

Fig. 1: Organic carbon in whole soil and particle size fractions at 0-15 cm under land use types. Columns followed by the same alphabets for each size fraction were not significantly different at $p<0.05$

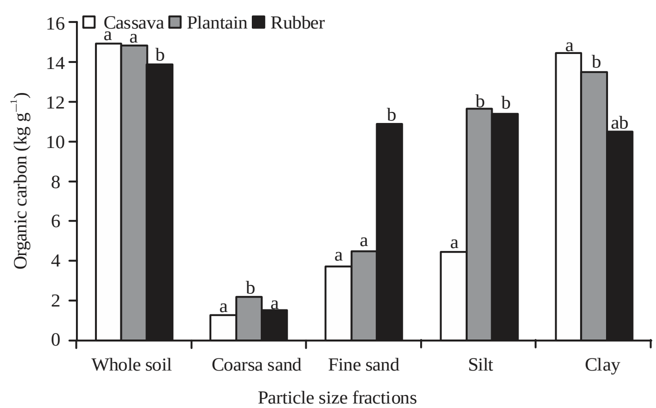

Fig. 2: Organic carbon in whole soil and particle size fractions at 15-30 cm under land use types. Columns followed by the same alphabets for each size fraction were not significantly different at $p<0.05$

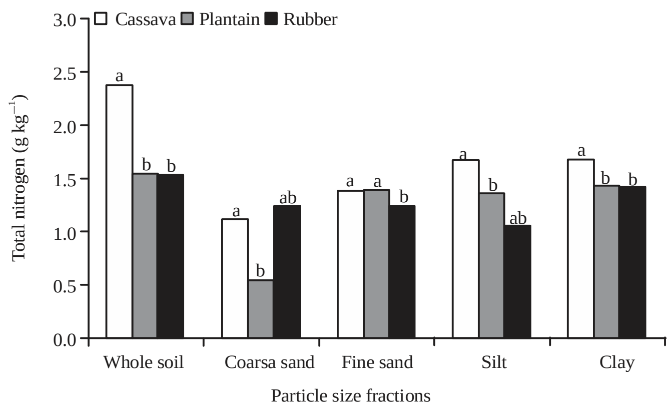

Fig. 3: Total nitrogen in whole soil and particle size fractions at 0-15 cm under land use types. Columns followed by the same alphabets for each size fraction were not significantly different at p<0.05

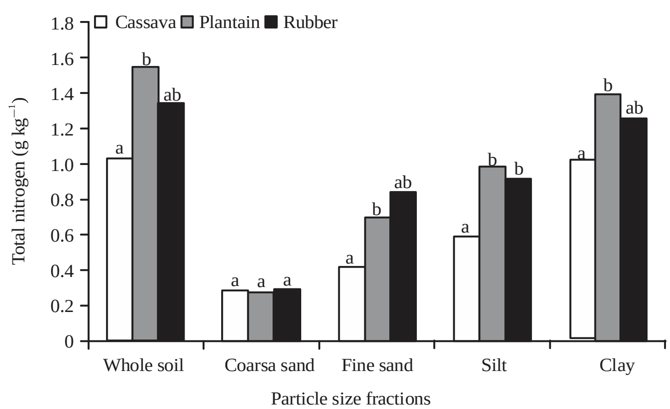

Fig. 4: Total nitrogen in whole soil and particle size fractions at 15-30 cm under land use types. Columns followed by the same alphabets for each size fraction were not significantly different at p<0.05

than 25% of SOC particularly, in plantain soils (Fig. 1). Soil organic carbon in coarse sands within the subsoil was 2 g kg^{-1} in cassava and rubber soils. Silt and clay fractions had the highest soil organic carbon content in all the land use types. The trend of SOC storage in primary particles was in the order of clay>silt>find sand>coarse sand.

Nitrogen: Nitrogen distribution in the whole soil was 2.4 g kg^{-1} in cassava and 1.55 g kg^{-1} in plantain and rubber based land use soils (Fig. 3). The coarse sand was significantly (p<0.05) low in total N at the top 0-15 cm soil particularly in the plantain soils and showed non-significant different across the land use types at the 15-30 cm depth (Fig. 4). This significantly low total N found in the plantain soil may have been attributable to the root density, characteristics and high feeding demand for soil N by the growing plantain. Generally, total N was higher in the silt and clay size particles in all the land use types. Coarse size fractions had low total N similar to that of SOC that in the top and subsoil. Total N content in silt size fraction was in the order of

Cassava>plantain>rubber at the top 0-15 cm soil, whereas, that of the subsoil was in the order of plantain>rubber>cassava. This is indication much of the cassava litter falls did not enter beyond the 30 cm of the soil.

Carbon/nitrogen ratio: There were inconsistencies in C/N ration across size fractions and the land use types in the top subsoil. In cassava soils, the C/N ratios in size fractions were 10, 14, 12 and 17 for coarse sand, fine sand, silt and clay respectively (Fig. 5 and 6). The silt+clay C/N ratios among the land use types were 27.4, 24.8 and 24.3 in cassava, plantain and rubber soils, respectively at 0-15 cm depth (Fig. 5). Similarly, the silt+clay C/N ratios at 15-30 cm soil were 21.8, 21.6 and 24.1 for cassava, plantain and rubber soils respectively (Fig. 6). The C/N ratio observed may have been a reflection of the type of vegetation, in which the rubber and plantain may generate plant materials of high resistance to degradation and mineralization.

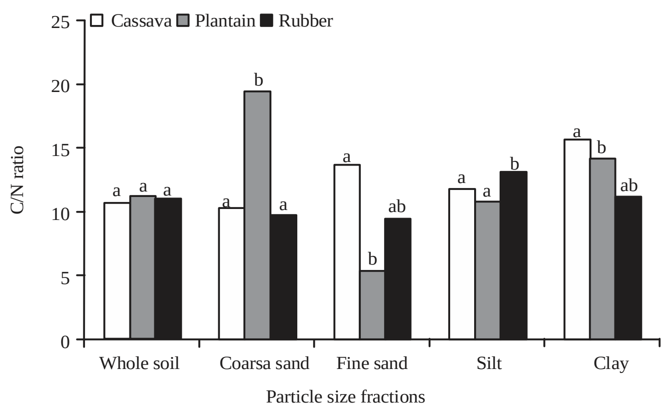

Fig. 5: Carbon/Nitrogen ratio in whole soil and particle size fractions at 0-15 cm under land use types. Columns followed by the same alphabets for each size fraction were not significantly different at p<0.05

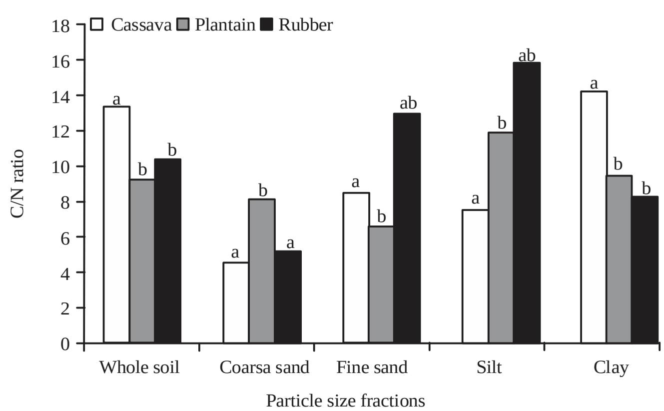

Fig. 6: Carbon/Nitrogen ratio in whole soil and particle size fractions at 15-30 cm under land use types. Columns followed by the same alphabets for each size fraction were not significantly different at p<0.05

Table 2: Water stable aggregates of the soils

	Aggregate sizes (mm)					
Land use	4.75-2	2-1	1-0.5	0.5-0.25	<0.25	MWD (mm)
0-15 cm						
Cassava	13.65[a]	19.05[a]	19.40[a]	20.50[a]	27.40[a]	1.03[a]
Plantain	11.25[b]	17.10[b]	21.55[a]	28.06[b]	23.04[b]	0.97[a]
Rubber	7.70[c]	14.25[ab]	27.30[b]	29.70[b]	21.05[b]	0.85[b]
15-30 cm						
Cassava	11.85[a]	19.6[a]	19.15[a]	27.30[a]	22.10[a]	1.00[a]
Plantain	10.50[a]	14.10[b]	19.75[a]	33.60[b]	20 .05[a]	0.91[b]
Rubber	7.30[b]	10.10[ab]	20.15[a]	35.70[ab]	26.75[b]	0.85[b]

MWD: Mean weight diameter, Means followed by the same letters within the same aggregate size range were not significantly different at p>0.05

Aggregate stability: Water stability of macro aggregates was higher in cassava soils than in plantain and rubber soils at both 0-30 and 15-30 cm depths (Table 2). This may be attributable to amounts of SOC content of the soils which was much higher in cassava soils. The positive relationships between SOC and aggregate stability may have been responsible for this result. The mean weight diameter of water stable aggregates in cassava and plantains were significantly different from rubber (p>0.05) in the order of cassava>plantain>rubber soils. However, rubber plantation had higher water stable aggregates in the 0.5-0.25 mm size range.

DISCUSSION

The soil physical properties changed due land use types and also remarkable variation SOC and total N stored in each particle size class. The low bulk found in topsoil in the cassava soils was not surprising. This is because organic litter fall from the cassava may have contributed to lower the soil bulk density. Kou *et al*. (2012) and Udom and Ogunwole (2015) have agreed that, the volume of organic matter in the soil usually improved soil structure and consequently, the bulk density. Total porosity and permeability of the soils were higher in cassava and plantain soils, an indication of great input of organic residues which enhanced these soil physical properties. In all the land use, total porosity and saturated hydraulic conductivity decreased with depth possibly due to decrease in soil organic matter with depth earlier been reported by Aweto (2001). The silt and clay fractions preserve large amounts of SOC across land use types, especially in cassava soils. Earlier reports (Feller and Beare, 1997; Yang *et al*., 2004) agreed that rubber plantation decreased soil organic carbon. However, the high amount of SOC found in fine sand and silt fraction at 15-30 cm in rubber soils was in agreement with Wang and Li (2003) and Yang *et al*. (2005) who reported that rubber plantation could potentially enhance SOC sequestration due the age of the plantation. Usually, mature plantations and native forest have more soil organic carbon pools than immature plantations (Yang *et al*., 2004; Zhang *et al*., 2006). The increased amounts of total N in the fine particle fractions of the soils is an indication that clay size fractions are very important in preservation of soil fertility and ability to prevent loss of nitrogen in the soil. Obviously, total N was higher in the clay+silt fractions in cassava soils, suggesting that cassava produced more easily mineralized litter with low C:N ratio. Protection of clay+silt size fractions from losses due to aggregate breakdown (Udom and Ogunwole, 2015) is very important in the maintenance of soil fertility and the quality of the environment. The importance of clay and silt size particle also manifested in their C:N ratio, which was consistently higher in cassava and plantain soils. The inconsistencies in C:N ratio of particle size fractions observed in rubber soil was possible that only a part of the organic litter from the rubber plants actually entered into close association with the soil particle size fractions. Udom and Nuga (2014) had reported similar result in their studies on partially submerged tropical soils.

CONCLUSION

This study showed that land use resulted in variations in soil organic carbon storage in primary soil particle as well as other hydrological characteristics of the soil. Fine particle size fractions stored greater soil organic carbon and total N than coarse soil particles. The C: N ratio was also higher in clay size fractions of the soils. Cassava generated higher quality organic litters in terms of its C:N ratio and amount of total N. The high organic matter on the top soil layer contributed to improved amounts of organic carbon and total nitrogen in whole soils and their distributions in coarse sand, fine sand, silt and clay size fractions. Overall the study indicated that primary soil particles, especially the silt and clay fractions were very important in sequestration of soil organic carbon pools and total N. The percentage SOC, total N and C/N ratio in each particle size fraction also depend on land use types.

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