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# Quantification of Soil Aggregate Carbon in *Tectona grandis* (Linn. f) Plantation at University of Ibadan, Ibadan, Nigeria

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## Abstract

Forest soils are important reservoir for carbon and contribute to global climate mitigation. Fine clay size aggregate is considered a major determinant of soil carbon distribution. Other aggregate sizes are also important in carbon distribution and estimation. Therefore, soil carbon accumulation of aggregate sizes was quantified at two soil depths in *Tectona grandis* plantation. Six (30 x 30m$^2$) plots were randomly demarcated in the plantation and 360 topsoil and subsoil samples were used for this study. Soil core samples were collected at 4 corners and centre of each plot to depths of 0-15, 15-30 cm in each plot for period of five months. Soil core samples were oven dried at 105 $^0$C. Soil bulk density and moisture content were estimated from the core samples. Soil sample (100g) from each core sample was sieved into >2, 2-1, 1-0.5, 0.5-0.050 and <0.050 mm aggregate size fractions using dry sieve procedure and proportions estimated. Sub-sample (10g) of each fraction was combusted in Muffle furnace at 500 $^0$C for at least 4 hours and carbon content estimated. Carbon concentration of the bulk soil was also determined. Data were analysed using descriptive statistics and ANOVA at $\alpha_{0.05.}$ Bulk density ranged from 1.08 to 1.33 and 1.39 to 1.54 g/cm$^3$ for subsoil and topsoil, respectively. Soil moisture content ranged from 17.23 to 23.36 and 14.08 to 22.15 cm for topsoil and subsoil, respectively. The 0.5-0.05 mm fraction had the highest values at top and subsoils (39 and 28% of the soil by weight, respectively) followed by 1-0.5mm size fraction (27% of the soil by weight) at the topsoil and >2mm fraction (27% of the soil by weight) at the subsoil. Topsoil and subsoil had approximately the same proportion of 2-1mm and <50μm fractions. Fine silt (<0.05mm) fraction had the highest soil carbon concentration followed by sand size fraction (>2.0mm) and silt-size fraction (2-1mm) in topsoil and (0.5-0.05mm) in subsoil. The soil carbon associated with <0.05mm was greater than the >2mm fractions. The coefficient of variation of carbon content were higher among the aggregates of subsoil than topsoil. The mean values of carbon content of bulk soil in topsoil were high than subsoil. Carbon concentration of fine silt size aggregate (0.5-0.05 mm) accurately estimate carbon content of topsoil and subsoil. Moisture content of the bulk soil influence carbon concentration of aggregate size of 1mm and 0.05.

**Keywords:** Soil aggregate fraction, carbon distribution, Soil carbon, rainy season

## Introduction

Plantation trees accumulate atmospheric carbon dioxide. Consequently, tree biomass serves as a large sink for atmospheric carbon but there is considerable uncertainty regarding their transformation into organic matter and subsequence impact on soil carbon stabilization. This is because of several interactive factors involve in organic matter decomposition and stabilization. However, Wiesmeier *et al.* (2009) reported that soil carbon was higher in tree plantation of hardwood than softwood species and concluded that several mechanisms could be responsible, few studies provide objective evidence for the processes. Furthermore, most of carbon compounds in the terrestrial pool are stored in soils (Janzen, 2004) and the stable pool is stored in forest soils. Hence, loss of carbon in forest soil will contribute to greenhouse gases. Improved understanding of mechanisms involved in carbon sequestration and stabilization within the soil aggregates have been emphasized in recent times. Organic carbon stabilization involves the permanent protection and preservation of soil carbon of the soil aggregates (Honttoria *et al.*, 2016). Understanding of the critical factors that control stabilization of carbon in soil aggregate fractions is limited.

Soil texture has been considered an important factor in physical stabilization of soil carbon. Young (1976) reported that organic matter content of top soil in the forest may be considered low if it below 3.0% and 2.0% for soils with sandy-clay to clay and sandy-clay-loam to sandy loam, respectively. Organic carbon content of soil fluctuates between relatively narrow limits and influenced by textural characteristic of the soil of specific site. Agboola and Ayodele (1987) considered organic matter ranged between 0.0 and 3.0% as low, 3.4 and 4.8% as medium and above 4.8% organic matter as high for tropical forest soils. Yang *et al.* (2016) reported that soil organic carbon increases with decreasing aggregate sizes and concluded that carbon storage potential of soils could be determine by its proportion of fine size aggregates.

Manns *et al.* (2016) observed that water holding capacity of soil influence soil organic carbon in all soil textural classes. Further study revealed that accumulation of soil carbon on fine aggregates that remain moistened for most times of the year has high potential for carbon stabilization (Burmann *et al.*, 2007). This suggest that moisture level above water holding capacity of soil would reduce carbon mineralization and enhance carbon stabilization in the soil

Global warming is expected to cause weather extremes such as flooding and drought. These weather extremes could determine whether soil is carbon source or sink. Soil comprise macro and micro aggregate carbon. However, the potential effects of changes in precipitation on aggregate carbon have not adequately assessed. Therefore, improved understanding of soil carbon dynamics during the weather extremes is required to clarify the implications and ameliorate the consequences of precipitation changes to soil aggregate carbon. Soil chemical and physical conditions is mediated by soil moisture. It is widely known that soil moisture could influence soil organic carbon by influencing the quantity of plant litter input and decomposition of the plant litter.

Hypotheses for this study were to find significant difference in organic carbon among the soil aggregate sizes. Therefore, the objective of this study was to quantify the distribution of soil carbon among aggregate fractions in the two soil depths and describe the change in soil aggregate carbon during the rainy season.

## Materials and Methods

The study was conducted in University teak plantation, University of Ibadan, Nigeria. It is located between Latitude 7° 26'58.20" and 7° 26'58.08"N and Longitude 3° 53'48.56" and 3° 53'48.48" at altitude of 227m above sea level. The climate is characterized by dry and rainy seasons. The dry season starts from November and ends March with dry cold wind of harmattan and the rainy season starts from April to October with occasional strong winds and thunderstorms. Annual rainfall is about 1300mm while mean annual temperature ranges from 22 to 34°C. Parent materials in part of the Southwestern Nigeria is Precambrian basement complex rocks formation stretches to the northern part of Nigeria. They are predominantly metamorphic; paragneisses, micashists, quartzites and amphibolites. Most of the soils in Ibadan are Alfisols. Alfisols are low activity clay soils characterized by inherent low nutrient status and effective cation exchange capacity (< 14 meg/100g clay in the topsoils). However, soils in University of Ibadan teak plantation is Ferric luvisol but mostly derived from sandstones. The average texture in the top 15 cm was 58.8 % sand, 18.4 % silt and 22.8 % clay and thus, the soil textural class is loamy sand (Falade and Oyeleye, 2011). At the time of this study, the *Tectona grandis* plantation studied was 65 years old. It was established to occupy 1666 trees per hectare with a spacing of 3m by 3m between individual and total land area of approximately 8 hactares. It is the oldest plantation in Nigeria. It was established initially as a trial plots. Six (6) plots (30m x 30m) were established with in the plantation. Soil samples were collected from 8m x 8m subplots established at 4 corners and centre of the plot using stainless steel soil cores (diameter = 7.5 cm and height = 15.0 cm). Therefore, soil samples were collected at five different locations within each plot. Soil cores were taken from 0 – 15, 15 – 30 cm depths and transported to the laboratory in sealed plastic containers. Each subplot will be sampled once every month throughout the period of rainy season (April to September).

## Laboratory Analyses

The initial weight of the soil cores were taken in the Laboratory before oven drying. Final weight of the soil cores were taken after oven-dried to a constant weight at 105°C because the carbon concentration should be reported on an oven-dry basis (Soil and Plant Analysis Council, 1999; Schumacher, 2002). Soil bulk density and soil moisture content were computed from the intact soil cores after oven dried. The bulk density of the core samples were calculated with the mass of the oven dry soil divided by the core volume. Soil moisture content was difference between initial and oven-dried weight of the intact soil core.

The oven dried soil were sieved into five aggregate size fractions (>2, 2-1, 1-0.5, 0.5-0.05 and < 0.050 mm) using a dry sieve procedure by placing 100g sample of oven-dry fragmented soil on the top of a stack of four sieves and agitated for one minute with sieve shaker. Dry aggregated remaining on each sieve was collected and weighed.

Sub-sample (10g) of each aggregate fraction was heated in Muffle furnace at 500°C for at least 4 hours and carbon content was estimated. Carbon content of the whole (bulk) soil was also determined for topsoil and subsoil. The estimated carbon represent the soil organic carbon as all samples were free of carbonates.

One-way ANOVA was used to test the differences between carbon content among different aggregate fractions. Duncan range test determined statistically significant means ($p<0.05$).

## Results

The bulk density of subsoil was consistently higher than that of topsoil. It ranged from 1.39 to 1.54 and 1.08 to 1.33 $g/cm^3$ for subsoil and topsoil, respectively. The soil bulk density was stable between April and May at both layers but increased slowly from May to July and then slightly decreased by August (Figure 1). The differences in bulk density of the two layers reduced continuously from April to August, 21.98 to 6.38%. The highest bulk density was obtained in July at both layers due to effect of moisture from rainfall. The difference in bulk density of the two layers was significant in April, May, June and July ($p<0.05$) but not in August. The reduction observed after July, just after the peak was due to decrease in amount of moisture through a break in rainfall.

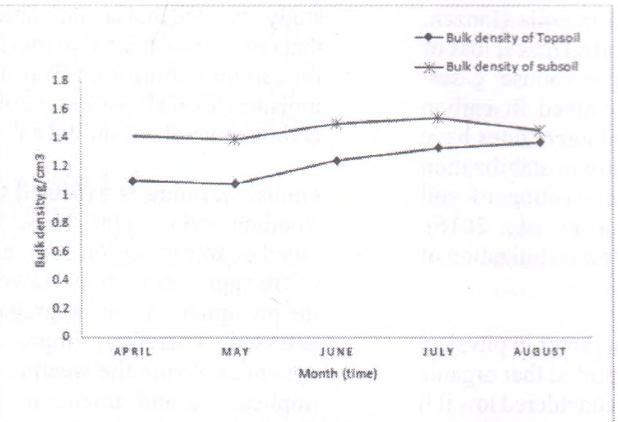

Figure 1. Bulk density of topsoil and subsoil of *Tectona grandis* Plantation

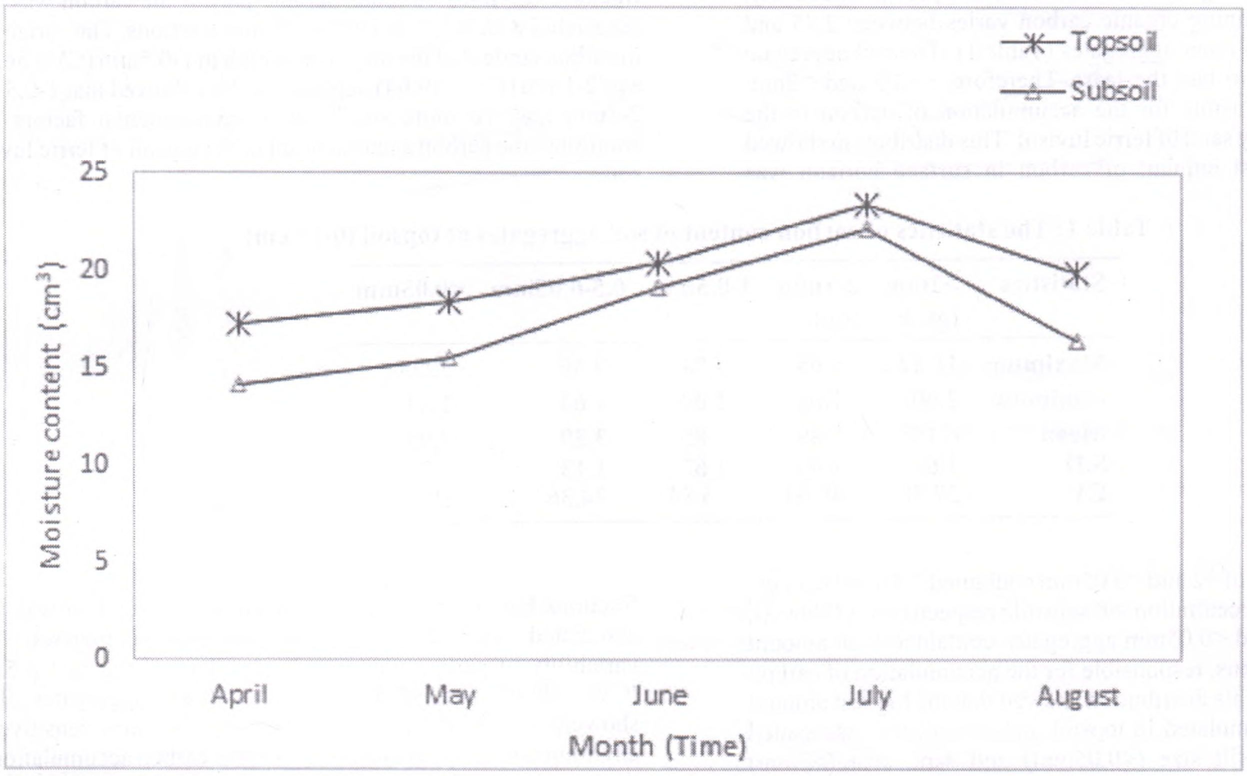

Figure 2. Moisture content of the Topsoil and subsoil in Tectona gransis Plantation

The aggregates size 0.5-0.05mm had the highest proportion at top and subsoils (39 and 28% of the soil by weight, respectively) followed by 1-0.5mm size fraction (27% of the soil by weight) at the topsoil and >2mm fraction (28% of the soil by weight) at the subsoil. Topsoil and subsoil had approximately the same proportion of 2-1mm and <50µm fractions (Figure 3).

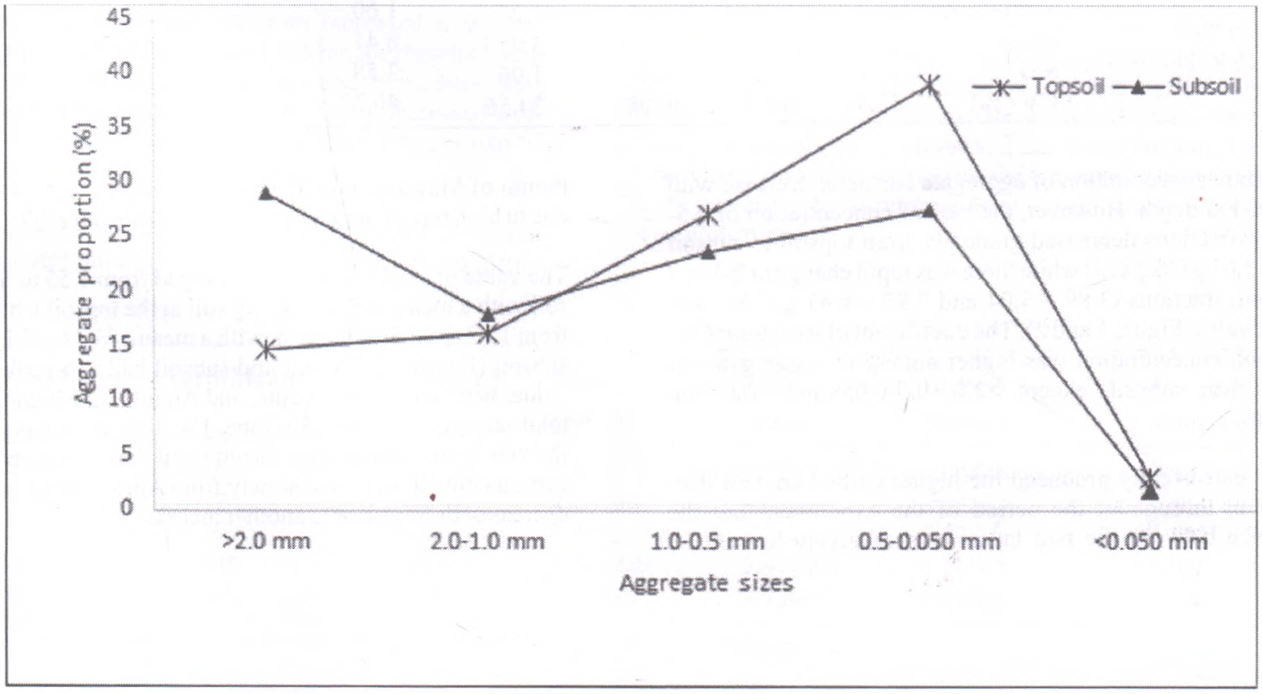

Figure 3. The Proportion of Soil Aggregate Fractions in Topsoil and Subsoil

The aggregates of <0.05 and >2.0mm fractions contained 7.95 and 6.15 gC kg$^{-1}$ organic carbon content of topsoil, respectively, while the remaining organic carbon varies between 2.85 and 3.89 gC kg$^{-1}$ on other aggregates (Table 1). The soil aggregate size of 1-0.5mm had the least. Therefore, <0.05 and >2mm fractions responsible for the accumulation of carbon in the topsoil of loamy sand of ferric luvisol. This distribution showed that the highest amount of carbon in surface horizon was associated with the fine silt size fraction (<0.05mm) and sand size fractions (2.0mm) but considerable part of the carbon was also associated with 2-1, 1-0.5, 0.5-0.05 mm fractions. The variability in carbon content of the topsoil was high in 1-0.5mm (CV= 56.84) and 2-1mm (CV = 49.04) aggregates. This showed that 1-0.5 and 2-1mm may be more sensitive to environmental factors that controlled the carbon accumulation in the topsoil of ferric luvisol soil.

**Table 1: The statistics of carbon content of soil aggregates at topsoil (0-15 cm)**

| **Statistics** | **>2mm**<br>(gC k | **2-1mm**<br>soil) | **1-0.5mm** | **0.5-0.05mm** | **<0.05mm** |
|---|---|---|---|---|---|
| **Maximum** | 11.42 | 8.95 | 7.74 | 7.36 | 20.00 |
| **Minimum** | 2.60 | 1.03 | 1.09 | 1.64 | 1.43 |
| **Mean** | 6.15 | 3.89 | 2.85 | 3.29 | 7.95 |
| **S.D** | 1.69 | 1.90 | 1.62 | 1.13 | 2.36 |
| **CV** | 27.58 | 49.04 | 56.84 | 34.36 | 29.79 |

The aggregates of >2 and <0.05mm contained 5.42 and 6.41 gC kg$^{-1}$ carbon concentration of subsoil, respectively (Table 2). Hence, >2.0 and <0.05mm aggregates contained high amount of carbon and thus, responsible for the accumulation of carbon in the subsoil. This distribution showed that the highest amount of carbon accumulated in topsoil and subsoil was associated with the fine silt size (<0.05mm) and sand size (>2mm) fractions but considerable part of the organic carbon was also associated with 2-1, 1-0.5, 0.5-0.05mm aggregates. The variability of carbon content of subsoil was high in 1-0.5mm (CV= 49.08) and <0.05mm (CV= 40.32) aggregates. This showed that 1-0.5 and <0.05mm may be more sensitive to environmental factors that controlled the carbon accumulation in the subsoil of ferric luvisol soil.

**Table 2: The Statistics of Carbon Contents of Soil Aggregates at Subsoil (15-30 cm)**

| **Statistics** | **>2mm**<br>(gC kg | **2-1mm**<br>soil) | **1-0.5mm** | **0.5-0.05mm** | **<0.05mm** |
|---|---|---|---|---|---|
| **Maximum** | 8.83 | 8.00 | 7.06 | 5.99 | 13.64 |
| **Minimum** | 1.68 | 0.96 | 0.91 | 1.20 | 1.00 |
| **Mean** | 5.42 | 3.04 | 2.13 | 3.07 | 6.41 |
| **S.D** | 1.78 | 1.22 | 1.04 | 1.06 | 2.58 |
| **CV (%)** | 32.89 | 40.24 | 49.08 | 34.56 | 40.32 |

The carbon concentration of aggregate fractions decrease with increased in depth. However, the carbon concentration of 0.5-0.05mm fractions decreased gradually from topsoil to subsoil (3.29 – 3.07 g C/kg soil) while there was rapid change in 2-1 and <0.05mm fractions (3.89 – 3.04 and 7.95 – 6.41 g C/kg soil, respectively) (Figure 1 and 2). The coefficient of variation (CV) of carbon concentration was higher among the aggregates of topsoil than subsoil, except >2.0, 0.5-0.05 and <0.05mm fractions.

Topsoil consistently produced the higher carbon content than subsoil in throughout the period of the experiment but the difference between the two layers was relatively low in the month of May and July. High carbon content at topsoil could be due to high rate of organic matter input from litter fall.

The value of total C in bulk soil ranged from 1.55 to 8.36 g C/ kg soil with a mean of 3.68 g C/ kg soil at the topsoil while it ranged from 1.82 to 9.45g C/kg soil, with a mean of 3.42 g C/kg soil at the subsoil (Figure 4). Topsoil and subsoil had two peaks of carbon value, which occurred in June and August. The highest values of total carbon was obtained in June. The difference in bulk carbon of the two layers was not significant in all the months ($p<0.05$). The carbon content increased slowly from April to June and suddenly decreased in July prior to another increase in August.

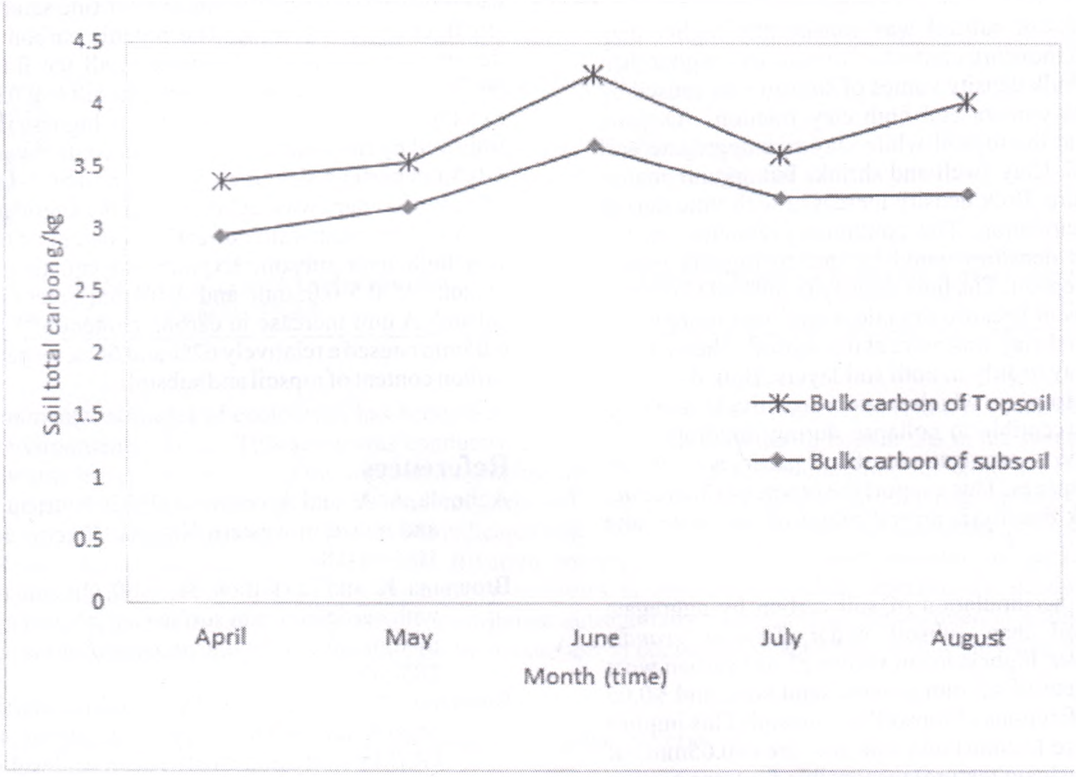

Figure 4. Bulk soil carbon concentration of topsoil and subsoil in *Tectona grandis* Plantation

There was significant difference in soil carbon associated with aggregate size of 0.05mm among the months. Soil carbon associated with aggregate size of 0.05mm increased from the month of April to August. Although there were differences in carbon of others aggregates among the months but the differences were not significant (Table 5). Soil carbon associated with aggregate size of 2mm increased with time (month) and the difference was more between the month of July and August, followed by between May and June. Also, soil carbon associated with aggregate size of 1.0 mm increased with time until the month of June and then decline in the month of July and rise again in the month of August.

Soil carbon associated with aggregate size of 0.5mm increased with time (month) until the month of June and then suddenly decline at month of July before rise again at month of August. These show that 1.0 and 0.5 mm carbon content were more sensitive to moisture condition of the soil.

Amount of carbon accumulated in each particle fraction increased with time. In > 2mm fraction, the variation between April and May was higher but carbon accumulation was lowest in April and highest in August. In < 50um fraction, the variation between April and May was wider than other fractions. Carbon content of all the fractions was consistently lowest in April and highest in August. Therefore, amount of soil moisture content affect the rate of carbon accumulation of all the soil fractions. The implication of the wide variation of aggregate carbon concentration with time may be caused by varying amount of soil moisture contents at sampling time.

| Fractions | April(Mean) | May(Mean) | June (Mean) | July Mean) | August (Mean) | P-value |
|---|---|---|---|---|---|---|
| **2mm** | 5.3600a | 5.5726 ab | 5.9444 ab | 6.2720 ab | 6.6444b | 0.157 |
| **1mm** | 2.9773a | 3.4726 a | 4.0936a | 3.9880a | 4.0880a | 0.316 |
| **0.5mm** | 2.1293a | 2.3811ab | 2.8172ab | 2.8116ab | 3.3732b | 0.127 |
| **0.05mm** | 2.8500a | 2.7184a | 3.2480ab | 3.4112ab | 3.7080b | 0.026 |
| **<0.05mm** | 6.4567a | 7.9532b | 8.2116b | 8.2864b | 8.2168b | 0.134 |

Means with similar alphabet along the role are not significantly different

## Discussion

Bulk density values of subsoil was consistently higher than topsoil but the soil moisture content of topsoil was higher than subsoil. The high bulk density values of subsoil was caused by low organic matter content and high clay fraction. Organic carbon was more at the topsoil while clay size aggregate was more at the subsoil. Clay swell and shrinks but organic matter retain more moisture. Bulk density increased with time during the period of precipitation. The continuous reduction in the difference of bulk densities could be due to organic matter decomposition at topsoil. The bulk density of subsoil was more stable than the topsoil because organic matter was more at the topsoil while mineral clay was more at the subsoil. The increase was linear from May to July in both soil layers. Bulk density is determined by macro-pores which are very sensitive to rain drop impact and are susceptible to collapse during raindrop. Rain dropping caused the re-arrangement of soil particles by filling the available pore spaces. This support the report of Chen *et al.*, 1994 that soil bulk density is an indication of soil water and aeration.

There was greater accumulation of soil carbon by aggregate fractions at topsoil than subsoil under *Tectona grandis* plantation. Moreover, highest mean values of soil carbon were obtained in aggregate of >2 mm (coarse sand size) and <0.05 mm (fine silt size) fractions of topsoil and subsoil. This implies that coarse sand size (>2mm) and fine silt size (<0.05mm) of ferric luvisol (sandy loam texture) responsible for large portion of carbon accumulation. Therefore, these fractions have potential for carbon sequestration in loamy sand of ferric luvisol of Ibadan. Also, the aggregate size distribution showed that the highest amount of carbon in the surface horizon was associated with the fine silt size (<0.05mm) and coarse sand size (>2mm) fractions, though considerable small proportion of organic carbon was also associated with other fractions. The soil carbon associated with fine silt size was greater than the coarse sand size fractions. It was observed that organic carbon do not associate only with the soil aggregate fractions that have extremely large surface areas but also with the aggregate fractions with smaller surface areas. This suggest that surface area may not be the only factor responsible for accumulation of carbon on ferric luvisol of Ibadan (Broersma and Lavkulich, 1980). The fine silt size (<0.05mm) and coarse sand size (>2mm) fractions displayed high variability of organic carbon in both layers because these fractions may be more sensitive to environmental factors that influence the accumulation of organic carbon. Also, the coefficient of variation (CV) of carbon concentration was higher among the aggregates of topsoil than subsoil. This is because topsoil fractions are more exposed and sensitive to environmental factors that controlling accumulation of carbon in loamy sand of ferric luvisol soil.

There was decline in carbon associated with fine silt size (<0.05mm) and coarse sand size (>2mm) fractions from topsoil to subsoil. Also, carbon associated with fractions shift from fine sand at the topsoil to course sand at subsoil. These show that 0.5 and 0.05mm carbon content were more sensitive to moisture condition of the soil.

## Conclusion

The loamy sand of Ferric luvisol is dominated by aggregate of the silt fraction (1-500mm) and consequently, the bulk density was relatively high, especially in subsoil. Topsoil and subsoil had relatively the same proportion of fine sand (2-1mm) and fine silt fractions (<0.05mm). The organic carbon content gradually decrease from topsoil to subsoil in all the fractions. There was decline in carbon associated with fine silt (<0.05mm) from topsoil to subsoil. Total carbon content was highest in the fine silt size followed by the coarse sand. Carbon content varied widely within 1-0.5mm particle size fraction, followed by 2-1mm. The variation of carbon content was higher among the aggregates of topsoil than subsoil. The mean value of carbon content of bulk soil in topsoil was high than subsoil. Exponential equation estimates carbon content of 0.5-0.05mm and 1-0.5mm fractions of topsoil and subsoil. A unit increase in carbon content of 1.0-0.5mm and 0.5-0.05mm caused a relatively 62% and 64%, respectively, increase in carbon content of topsoil and subsoil.

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