Nigerian Journal of Agriculture, Food and Environment. 13(4):113-117

Published December, 2017

SOIL AGGREGATES AND CARBON DISTRIBUTION IN *Tectona grandis* (Linn. F.) PLANTATION, NIGERIA

Falade, O. F.

Department of Forest Production and Products, University of Ibadan. E-mail: faladedele@yahoo.com +2348076673405

ABSTRACT

Soil and tree biomass are reservoir for carbon but there is uncertainty regarding their influence on soil carbon stabilization. Carbon associated with clay size aggregate is considered a major determinant of soil carbon accumulation. However, other aggregates are becoming relevant in the estimation of soil carbon accumulation. These limit the detail carbon estimation of soil. Therefore, soil carbon accumulation of aggregate sizes was estimated 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 five points at depths of 0-15, 15-30 cm in each plot for period of six months. Soil core samples collected were oven dried at 105 ^{0}C. Soil sample (100g) from each core sample was sieved into >2.0, 2.0-1.0, 1.0-0.5, 0.5-0.050 and <0.050 mm aggregate sizes using dry sieve procedure and proportions weighed. A subsample of 10g of each fraction was combusted in Muffle furnace at 500 ^{0}C for 4 hours and carbon content estimated. Carbon content of the bulk soil was also determined. Data were analysed using descriptive statistics, regression analysis at $\alpha_{0.05}$ The 0.5-0.05 mm fraction had the highest proportion of soil at top and subsoil (39 and 28%, respectively). Aggregate size of <0.05 mm had the highest soil carbon concentration at topsoil and subsoil. Exponential and logistic equations performed better on the basis of R^2, F-value and Standard Error of Estimate. Therefore, carbon content of 0.5-0.05 and 1.0-0.5 mm aggregates accurately estimate carbon content of topsoil and subsoil using the exponential equation. Carbon content of fine silt size aggregate (0.5-0.05 mm) determined carbon accumulated. Exponential model of soil carbon is determined by the aggregate size distribution of each soil layer.

INTRODUCTION

Plantation trees accumulate atmospheric carbon dioxide through photosynthesis. Consequently, tree biomass serves as a large sink for carbon but there is considerable uncertainty regarding their influence on soil carbon stabilization. However, Wiesmeier *et al.* (2009) reported that soil carbon was higher in tree plantation of hardwood than softwood species. Although several mechanisms could be responsible, few studies provide objective evidence for the processes. Most of carbon compounds in the terrestrial pool are stored in soils (Janzen, 2004) and stable pool is stored in forest soils. Hence, loss of carbon in forest soil will contribute to greenhouse gases. Organic carbon stabilization involves the permanent protection and preservation of soil carbon in the soil aggregates (Honttoria *et al.*, 2016). Macro-aggregates and micro-aggregates are distinguished by their sizes and stabilization of organic carbon is considered to take place within the micro-aggregates. The stabilization of organic carbon within the soil aggregates facilitate sequestration of carbon compounds in soils

Yang *et al.* (2016) and Li *et al.* (2015) reported that carbon storage potential of soils could be determined by its proportion of clay size aggregates because it is more sensitive to changes in climate and land use than sand fractions. However, other aggregates are becoming relevant in the estimation of soil carbon distribution. Inadequate understanding is limiting the effort at tracking carbon sequestration and one of the reasons for unabated release of greenhouse gases from Ferric luvisol of Ibadan. Ferric luvisol is a black humus soil found mostly in un-disturbed Old-growth forest but despite its undisturbed state greenhouse gases is still released. Therefore, organic carbon accumulation in different aggregate size fractions requires further investigation. The objective of the study was to estimate relationship between carbon of bulk soil and aggregate size fractions in the two soil depths.

MATERIALS AND METHODS

The study was conducted in University teak plantation, University of Ibadan, Nigeria. It is located between Latitude 7^o 26´58.20´´ and 7^o 26´58.08´´ N and Longitude 3^{o}53´48.56´´ and 3^{o}53´48.48´´E at an altitude of 208 m above sea level. The climate is characterized by dry and rainy seasons. The dry season starts from November and ends in March, while the dry cold harmattan wind and the rainy season starts from April to October with occassionl strong winds and thunderstorms. Annual rainfall is about 1300 mm while mean annual temperature ranges from 22 to 34^{o}C. Parent materials in part of the Southwestern Nigeria is Precambrian basement complex rocks which stretches to the northern part of Nigeria. They are predominantly metamorphic; paragneisses, micashists, quartzites and amphibolites. Most of the soils in Ibadan are Alfisols. 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. It is the oldest plantation in Nigeria.

Six (6) plots (30m x 30m) were established with in the plantation. Three hundred and sixty topsoil and subsoil samples were used for this study. 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 per month for six months (April to September). Soil cores were taken from 0 – 15 and 15 – 30 cm depths and transported to the laboratory in sealed plastic containers. Each subplot was sampled once every month for six months (April to September).

Laboratory analyses

The core samples were oven dried to a constant weight at 105^0C because the carbon concentration should be reported on an oven-dry basis (Soil and Plant Analysis Council, 1999; Schumacher, 2002). The oven dried soil sample from each core sample were sieved into aggregate size fractions by placing 100g sample of oven-dried fragmented soil on the top of a stack of four sieves (>2.0, 2.0-1.0, 1.0-0.5, 0.5-0.05 and <0.05 mm) and agitated for one minute with sieve shaker. Dry aggregates remaining on each sieve was collected and weighed.

A sub-sample of 10g of each aggregate fraction was heated in Muffle furnace at 500^0C for at least 4 hours and cooled in a desicator and then weighed for carbon content estimation. Carbon concentration of the bulk soil was also determined for the topsoil and subsoil. The estimated carbon represents the soil carbon.

Statistical analyses

Linear, exponential and logistic regressions were used to determine the relationship between carbon concentration associated with bulk soil and each aggregate fraction. The Linear (Equation 1), exponential (Equation 2) and logistic (Equation 3) models fitted the carbon values of bulk soil with carbon of each fraction. Therefore, carbon content of bulk and each fraction of topsoil and subsoil were subjected to regressions analysis using:

$$y = a + b\mathcal{X} \qquad equation\ 1$$

$$y = aexp^{bx} \qquad equation\ 2$$

$$y = \frac{1}{a + exp^{bx}} \qquad equation\ 3$$

where,

y is the quantity of carbon content of bulk soil (C g/kg),

χ is the quantity of carbon content of each aggregate size fraction (C g/kg).

a and b are the estimates of carbon concentration associated with an aggregate size

One-way ANOVA was used to test the differences between carbon content among different aggregate fractions. Duncan Multiple Range test determined statistically significant means ($p<0.05$). The model developed for each aggregate fraction was verified using Coefficient of determination (R^2), Root Mean Square Error (RMSE). Coefficient of determination measure the proportion of variation in the dependent variable that has been accounted or explained by its relationship with the independent variable. It was expressed as:

$$R = 1 - \left(\frac{RSS}{TSS}\right) \text{……………………………………………equation 4}$$

The R^2 value ranges between 0 and 1, and can be expressed in percentage by multiplying the value by 100.

Root Mean Square Error (RMSE) was expressed as:

$$RMSE = \sqrt{\frac{RSS}{n}} \text{…………………………………………………equation 5}$$

Where,

RSS = the regression sum of square

TSS = the total sum of square

n = the total number of observations

The suitable models were those with large values of R^2 and least values of RMSE

RESULTS

The aggregates size 0.5-0.05 mm had the highest proportion of soil at topsoil and subsoil (39 and 28% by weight, respectively) followed by 1-0.5 mm size fraction (27% of the soil by weight) at the topsoil and >2 mm fraction (28% of the soil by weight) at the subsoil. Topsoil and subsoil had approximately the same proportion of 2.0-1.0 mm and <50 µm aggregates (Figure 1). Therefore, loamy sand of Ferric luvisol was dominated by 0.5-0.05 mm aggregate size. The aggregates of <0.05 and >2.0 mm fractions contained 7.95 and 6.15 g C kg^{-1}, respectively, at topsoil (0-15 cm), while considerable part of soil carbon associated with other fractions varies between 2.85 and 3.89 gC kg^{-1} (Table 1). The soil aggregate size of 1.0-0.5 mm had the least carbon content (2.85 gC kg^{-1}). Therefore, <0.05 and >2.0 mm aggregates are responsible for the accumulation of carbon in the topsoil of ferric luvisol. This distribution shows that the highest amount of carbon in surface soil was associated with <0.05 mm and 2.0 mm aggregates but considerable part of the carbon was also associated with 2.0-1.0, 1.0-0.5, 0.5-0.05 mm fractions. The variability was high in carbon content of 1.0-0.5 mm and 2.0-1.0 mm aggregates at topsoil.

The distribution shows that the highest amount of soil carbon in the subsoil was associated with aggregate of <0.05 mm (6.41 gC kg^{-1}) and 2.0 mm (5.42 gC kg^{-1}) (Table 2). Hence, aggregates >2.0 and <0.05 mm contained largest amount of carbon and thus, responsible for the accumulation of soil carbon in the subsoil. This distribution shows that the highest amount of carbon accumulated in subsoil was associated with <0.05 and >2.0 mm aggregates but considerable part of the organic carbon was also associated with 2.0-1.0, 1.0-0.5, 0.5-0.05 mm aggregates. The variability was high in carbon content 1.0-0.5 mm (CV= 49.08%) and <0.05 mm (CV= 40.32%) aggregates at the subsoil.

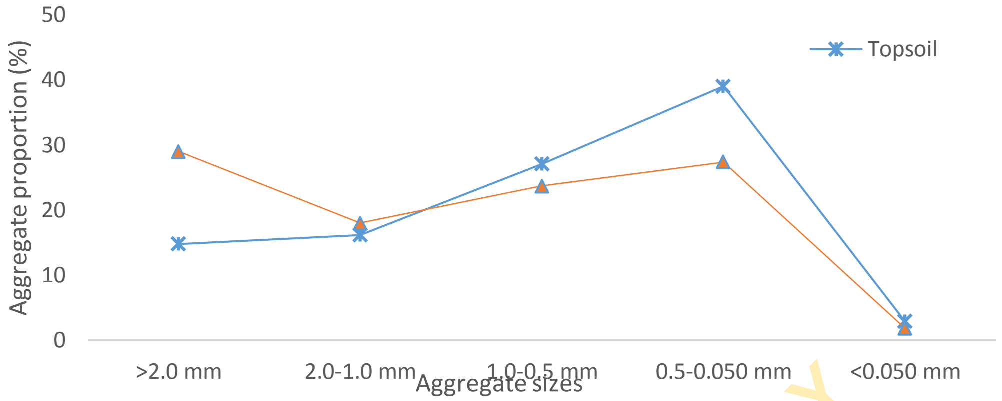

Figure 1. The proportion of soil aggregate fractions in topsoil and subsoil

Table 1: Statistics of carbon contents of soil aggregates at topsoil (0-15 cm)

Statistics	>2mm	2-1mm	1-0.5mm	0.5-0.05mm	<0.05mm
	(g C kg^{-1} soil)				
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

Table 1 and 2 showed that carbon contents of all aggregates decrease with increase in depth. However, the carbon content of 0.5-0.05 mm fractions decreased gradually from topsoil to subsoil (3.29 – 3.07 g C/kg soil) while there was rapid change in 2.0-1.0 and <0.05 mm fractions (3.89 – 3.04 and 7.95 – 6.41 g C kg^{-1} soil, respectively). The coefficient of variation (CV) of carbon content was higher among aggregates of topsoil than subsoil, especially 2-1 and 1-0.5mm aggregates (Table 1 and 2).

Table 2: Statistics of carbon contents of soil aggregates at subsoil (15-30 cm)

	>2mm	2-1mm	1-0.5mm	0.5-0.05mm	<0.05mm
	(gC kg^{-1} soil)				
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 linear, exponential and logistic models were used to fit the carbon values of bulk soil and aggregate size fractions of topsoil. The exponential model had highest coefficient of determinations (R^2) of 31, 52, 45, 48, and 21% with standard error of estimates of 0.29, 0.24, 0.26, 0.25, and 0.31 in >2mm, 2.0-1.0, 1.0-0.50, 0.50-0.05 and <0.050 mm at the topsoil, respectively (Table 3). According to the exponential model, 52 and 48% of variation in bulk soil carbon were explained by a unit change in carbon of 1.0-0.5 mm and 0.5-0.05 mm at the topsoil, respectively. Carbon values of 1.0-0.5 and 0.5-0.05 mm fractions explained the highest variation in carbon value of the bulk soil. Based on the coefficient of determination (R^2), SEE and F ratio values, carbon content of 0.5-0.05 mm fraction produced the best estimates, followed by 1.0-0.5 mm fraction. Therefore, carbon content of 0.5-0.05 mm and 1.0-0.5 mm fractions could predict carbon content of topsoil using the exponential equation.

Table 4 shows the coefficient of determination (R^2), Standard error of estimate and F ratio values for the model among the subsoil aggregate size fractions. In the subsoil, the exponential model (Equation 2) fitted carbon values of bulk soil and aggregate size carbon of fractions. According to model results, 37% and 30% of carbon variations in bulk soil were explained by a unit change in soil carbon of 0.5-0.05 mm and 2.0-1.0 mm at subsoil, respectively (Table 4). Carbon values of 2.0-1.0 and 0.5-0.05 mm explained the highest variation in carbon values of the bulk soil. Based on the coefficient of determination (R^2) and F ratio values, carbon content of 0.5-0.05 mm fraction produced the best estimates, followed by 1.0-0.5 mm fraction. Therefore, carbon content of 0.5-0.05 mm and 1.0-0.5 mm fractions could be predicted by the exponential equation.

Table 3: Estimated values of the regression models for aggregate carbon in top soil

Models	Expression	R^2	SE	F-value
Linear	$y = 1.291 + 0.428(> 2mm)$	0.29	1.22	0.000
Exponential	$y = 1.915\, exp^{0.107(>2mm)}$	0.31	0.29	0.000
Logistic	$y = \dfrac{1}{0.493 +\ exp^{0.862(>2mm)}}$	0.30	0.41	0.000
Linear	$y = 1.816 + 0.541(2 - 1mm)$	0.51	1.01	0.000
Exponential	$y = 2.212exp^{0.131(2-1mm)}$	0.52	0.24	0.000
Logistic	$y = \dfrac{1}{0.406 +\ exp^{0.832(2-1mm)}}$	0.52	0.34	0.000
Linear	$y = 1.971 + 0.727(1 - 0.5mm)$	0.43	1.09	0.000
Exponential	$y = 2.290exp^{0.178(1-0.5mm)}$	0.45	0.26	0.000
Logistic	$y = \dfrac{1}{0.386 +\ exp^{0.780(1-0.5mm)}}$	0.44	0.36	0.000
Linear	$y = 0.626 + 1.021(0.5 - 0.05mm)$	0.48	1.04	0.000
Exponential	$y = 1.670exp^{0.245(0.5-0.05mm)}$	0.48	0.25	0.000
Logistic	$y = \dfrac{1}{0.604 +\ exp^{0.708(0.5-0.05mm)}}$	0.49	0.35	0.000
Linear	$y = 1.340 + 0.325(< 0.05mm)$	0.21	1.29	0.000
Exponential	$y = 1.959exp^{0.080(<0.05mm)}$	0.21	0.31	0.000
Logistic	$y = \dfrac{1}{0.479 +\ exp^{0.895(<0.005mm)}}$	0.21	0.43	0.000

Table 4: Estimated values of the regression models for aggregate carbon in sub-soil

Model	Expression	R^2	SE	P-value
Linear 2mm	$y = 1.517 + 0.358(> 2mm)$	0.23	1.235	0.000
Exponential	$y = 1.892exp^{0.099(>2mm)}$	0.30	0.287	0.000
Logistic	$y = \dfrac{1}{0.485 +\ exp^{0.860(>2mm)}}$	0.24	0.511	0.000
Linear 1mm	$y = 1.563 + 0.617(2 - 1mm)$	0.30	1.181	0.000
Exponential	$y = 2.043exp^{0.150(2-1mm)}$	0.30	0.288	0.000
Logistic	$y = \dfrac{1}{0.454 +\ exp^{0.782(2-1mm)}}$	0.27	0.500	0.000
Linear 0.5mm	$y = 1.970 + 0.692(0.5mm)$	0.25	1.217	0.000
Exponential	$y = 2.240exp^{0.172(1-0.5mm)}$	0.26	0.295	0.000
Logistic	$y = \dfrac{1}{0.387 +\ exp^{0.759(1-0.5mm)}}$	0.23	0.513	0.000
Linear 0.05mm	$y = 1.009 + 0.790(0.5 - 0.05mm)$	0.35	1.136	0.000
Exponential	$y = 1.755exp^{0.198(0.5-0.05mm)}$	0.37	0.272	0.000
Logistic	$y = \dfrac{1}{0.574 +\ exp^{0.727(0.5-0.05mm)}}$	0.33	0.480	0.000
Linear <0.05mm	$y = 2.103 + 0.204(< 0.05mm)$	0.14	1.308	0.000
Exponential	$y = 2.210exp^{0.058(<0.05mm)}$	0.19	0.310	0.000
Logistic	$y = \dfrac{1}{0.368 +\ exp^{0.922(<0.05mm)}}$	0.13	0.547	0.000

DISCUSSION

The proportion of aggregate size of 0.5-0.05 mm was high at topsoil and subsoil and followed by 1.0-0.5 mm fraction at the topsoil and >2.0 mm fraction at the subsoil. Therefore, there was a change in proportion of 1.0-0.5 and >2.0 mm fractions from topsoil to the subsoil. Moreover, large amount of soil carbon was associated with >2.0 mm (coarse sand-size) and <0.05 mm (fine silt-size) fractions of topsoil and subsoil, though greater accumulation of soil carbon occurred in aggregate fractions of topsoil than subsoil. This implies that coarse sand-size of >2.0 mm and fine silt-size of <0.05 mm fractions of ferric luvisol (sandy loam) are responsible for large portion of carbon accumulation. Therefore, these fractions have potential for carbon stabilization in loamy sand of ferric luvisol of Ibadan. The soil carbon associated with fine silt-size of <0.05 mm was greater than the coarse sand-size of >2.0 mm. It was observed that carbon does not associate only with the soil fractions that have extremely large surface areas but also with the coarse fractions with much smaller surface areas. This suggests that surface area may not be the only factor responsible for accumulation of carbon on ferric luvisol of Ibadan. Similar observation was made by Kroersma and Lavkulich (1980). The fine silt-size of <0.05 mm and coarse sand-size of >2.0 mm fractions displayed high variability of organic carbon in both layers because these fractions may be more sensitive to environmental factors. 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.

A unit increase in carbon concentration of 1.0-0.5 and 0.5-0.05 mm caused a relatively 45% and 48%, respectively, increase in carbon content of the bulk soil of the topsoil. Thus, carbon values of 1-0.5mm and 0.5-0.05 mm explained the highest variation in carbon value of the bulk soil of the topsoil. Also, a unit increase in carbon content of 2.0-1.0 and 0.5-0.05 mm caused a relatively 30% and 37%, respectively, increase in carbon content of the bulk soil of the subsoil. Thus, carbon values of 2.0-1.0 and 0.5-0.05 mm explained the highest variation in carbon value of the bulk soil of the subsoil. The exponential equation best fit the soil carbon estimate of topsoil and subsoil of loamy sand textue. The results show that exponential model of soil carbon is determined by the aggregate size with highest proportion of carbon at each soil layer (Zhao et al., 2006). However, linear regression model do not adequately predict soil carbon of topsoil and subsoil of loamy sand texture.

Carbon content of 0.5-0.05 mm, which accounted for highest proportion at topsoil and subsoil, explained the highest variation in carbon value of the bulk soil of the topsoil and subsoil, followed by 1.0-0.5 mm fraction at the topsoil and >2.0 mm fraction at the subsoil. Therefore, the proportionate change in aggregate size of 1.0-0.5 and >2.0 mm at topsoil and subsoil could probably cause change in possible exponential models of carbon at topsoil and subsoil.

CONCLUSION

The organic carbon content gradually decreased from topsoil to subsoil in all the fractions. Largest soil carbon was associated with aggregate size of <0.05 followed by >2.0 mm at topsoil and subsoil. Therefore, surface area may not be the only factor responsible for accumulation of carbon on ferric luvisol of Ibadan. Regression analysis indicates that exponential equation is the best for carbon content estimation of both topsoil and subsoil aggregates. Exponential model of soil carbon is determined by the aggregate size distribution of each soil layer. However, linear regression model do not adequately predict soil carbon of topsoil and subsoil of loamy sand texture

REFERENCES

Broersma, K. and Lavkulich, L. M. 1980. Organic matter distribution with particle-size in surface horizons of some Sombric soils in Vancouver Island. *Canadian Journal of Soil Science* 60: 583-586

Falade, O. F. and Oyeleye, B. 2011. Nutrient-use efficiency of *Tectona grandis* (linn. f.) seedlings on basement complex and ferric luvisol soils of Ibadan, Nigeria. *Journal of Applied Agricultural Research* 3: 193-201

Honttoria, C., Gomez-Paccard, C., Mariscal-Sancho, I., Benito, M., Perez, J. and Espejo, R. 2016. Aggregate size distribution and associated organic carbon and N under different tillage systems and Ca-ammendment in a degraded Ultisol. *Soil and Tillage Research* 160: 42-52

Janzen, H. H. 2004. Carbon cycling in earth systems: a soil science perspective. *Agric-Ecosyst. Environ.* 104:399-417

Broerma, K. and Lavkulich, L. M. 1980. Organic matter distribution with particle-size in surface horizons of some Sombric soils in Vancouver Island. *Canadan Journal of Soil Science* 60: 583-586

Li, Y., Zhao, X., Wang, S., Zhang, F., Lian, J., Huang, W. and Mao, W. 2015. Carbon accumulation in the bulk soil and different soil fractions during the rehabilitation of desertified grassland in Horgin Sandy Land, Northern China. *Polish J. Ecology* 63(1): 88-101

Schumacher, B. A. 2002. Methods for the determination of total organic carbon in soils and sediments. Ecological Risk Assessment Support Center. United State Environmental Protection Agency (USPA). 22p

Soil and Plant Analysis Council (SPAC) 1999. Anaysis handbook of reference methods. First edition. CRC Press LLC, Florida, U.S.A. 178p

Wiesmeier, M ., Dick, D. P., Rumpel, C., Dalmolin, R. S. D., Hilscher, A. and Knicker, H. 2009. Depletion of soil organic carbon and nitrogen under Pinus taeda plantations in Southern Brazilian grasslands (Campos). *European Journal of Soil Science* 60: 347-359

Yang, X. M., Drury, C. F., Reynolds, W. D. and Yang, J. Y. 2016. How do changes in bulk soil organic carbon content affect carbon concentrations in individual soil particle fractions? *Scientific Reports* 6: 27173 Doi:10.1038/srep27173

Zhao, L. P., Sun, Y. P., Yang, X. M. and Drury, C. P. 2006. Soil organic carbon in clay and silt size particles in Chinese mollisols: relationship to the predicted capacity. *Geoderma* 132(3&4): 314-323