SUSTAINABLE DEVELOPMENT GOALS THROUGH APPROPRIATE FOREST MANAGEMENT STRATEGIES

Proceedings of the

41st Annual Conference

of the
Forestry Association of Nigeria
held in Abuja, FCT

7th - 11th October, 2019

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FAN
FORESTRY ASSOCIATION OF NIGERIA

Proceedings of the 41st Annual Conference of the Forestry Association of Nigeria

Held in Abuja, FTC.

7th – 11th October, 2019

ISBN: 978-978-310854-2

Printed by: Exotic Denzines Ltd.
Tel: 08035013307

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CARBON FRACTION DISTRIBUTION OF SOIL DEPTHS OF OMO BIOSPHERE RESERVE, NIGERIA

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Abstract

Soil is regarded as largest carbon reservoir in terrestrial ecosystem but availability of information on soil aggregates cum carbon fraction distribution along depths in relation to specified location is lacking. Soil carbon accumulation of aggregate sizes was estimated at five soil depths in natural forest reserve, Omo Biosphere Reserve, Nigeria. Guided by the heterogeneity of the reserve, it was stratified into close and open canopy structures. Fourteen and six (30m x 30m) sample plots were demarcated in close and open canopy, respectively. Profile pit was dug at the center of sample plots (30m x 30m) and soil samples were collected at 0 – 20, 20 – 40, 40 – 60, 60-80, 80 – 100cm depths and air dried. Air-dried soil samples (100g) were separated into five aggregate sizes (>2.0, 2-1, 1-0.5, 0.5-0.052mm, <0.052mm) using wet sieving method, and percentage carbon content of each aggregate fractions were determined using Loss on Ignition Method. Data collected were analyzed using descriptive statistics and ANOVA at $\alpha_{0.05}$. Carbon distribution varied among the soil aggregates and across the depths. The degree of carbon protection and carbon stability are higher in <0.052mm aggregate size than in other aggregates. Macro-aggregate and micro-aggregate are responsible for carbon accumulation in surface and sub-surface soils, respectively. Therefore, macro-aggregate and micro-aggregate are responsible for carbon sequestration in soil of Omo Biosphere Reserve.

Keyword: *Carbon distribution, Soil aggregates, Natural forest, Climate change mitigation.*

Introduction

Soil and vegetation are natural reservoirs of carbon in terrestrial ecosystem. Therefore, soil and vegetation can be managed to enhance amount of carbon stored in these natural reservoirs (Tuffour *et al.*, 2014). The quantity of carbon stored in the soil is highly significant, it contains about three times the amount of carbon in vegetation and twice the amount in the atmosphere (Batjes and Sombroek, 1997). Hence, soils are considered as the largest carbon reservoir. The ability to capture and retain carbon in soil is dependent on depth, texture, structure, farming system, soil management and tree species composition (Lal, 2004). Therefore, more research and information on carbon distribution along soil depths, effects of soil texture and structure on carbon storage and proper soil management techniques to enhance carbon uptake by plants and storage in soils are required.

Soil aggregates are the primary particles that adhere to each other more strongly than other surrounding soil particles. According to (Honttoria *et al.*, 2016), organic carbon stabilization involves the permanent protection and preservation of soil carbon in the soil aggregates.

Therefore, aggregation is seen as a key to maintaining soil structure stability which facilitate sequestration of carbon compounds in soils, and also an effective means of controlling erosion. Soil aggregation could be macro aggregates (>0.25mm) or micro aggregates (<0.25mm) depending on the soil factors and level of soil disturbances. Soil aggregates distribution is a key physical property of soil and has the potentials to physically protect soil from the loss of carbon, thus soil aggregation is important for carbon sequestration (Chivenge *et al.* 2011). Trujilo *et al.*, (1997), Martens *et al.*, (2003) reported that stabilized carbon is carbon within soil aggregates because it is less subjected to physical, microbial and enzymatic degradation. However, most previous studies reported carbon accumulation in shallow soil and little on distribution of profile carbon in natural forest. More so, soil depth is a factor of consideration in soil aggregate distribution and carbon content. Salome *et al.*, (2010) expressed that carbon at subsoil may be more important than topsoil carbon and factors controlling carbon dynamics in surface soil and subsoil may be different. However, Mikha and Rice (2004) revealed that most studies focused on carbon at surface soil and in subsoil are largely ignored. This knowledge gap limits the detail assessment of carbon distribution and underlying factors controlling them along depths. These limitations contribute to the unabated increase in greenhouse gases in the atmosphere. Therefore, determining the carbon content of aggregates is essential to have a detailed knowledge of the aggregate fraction that pre-determines the carbon content of bulk soils. This information is needed to enhance carbon accumulation in the forest soils. Hence, this research aims at quantifying the soil aggregates and carbon fraction distribution along 0cm -100cm depths in a natural forest.

Materials and Methodology

This study was carried out in Omo Biosphere Reserves, situated in Omo Forest Reserve. It is located between Latitudes 6° 35' - 7° 05'N and Longitudes 4° 19' - 4° 40'E, in Ijebu East and North Local Government Areas of Ogun State, southwestern Nigeria. The United Nations Educational, Scientific and Cultural Organization (UNESCO) pioneered the setting up of biosphere reserves when it hosted the 1968 UNESCO Conference on Rational Use and Conservation of the Resources of the Biosphere. This led to the establishment of biosphere reserves in several countries including Nigeria. Thus, Omo Biosphere Reserve which derives its name from river Omo that traverses it was established in the year 1977, it covered total area of 460 hectares. The mean annual rainfall in the area ranges from about 1600 to 2000 mm with two annual peaks in June and September, and temperature ranges from 32.150C to 21.400C and a minimum relative humidity of 76.34 % (Adebisi, 2004). Biologically, the Reserve is in the mixed moist, semi-evergreen rainforest zone, rich in species and has very high levels of endemism. It is an old growth forest reserve, rich in tree species diversity. Stratified random sampling technique was used to demarcate 20 temporary sample plots (TSPs) of 30x30m size. The reserve was stratified into close and open canopy structures using supervised classification. Fourteen (14) sample plots were established in close canopy cover while 6 sample plots were established in open canopy cover. A profile pit of 100cm depth was dug at the centre of each sample plots and samples were collected at depths (0 – 20, 20 – 40, 40 – 60, 60 - 80, 80 – 100cm). These were conveyed to soil laboratory in the Department of Agronomy, University of Ibadan. The soil samples were air dried in the laboratory, and further separated into five aggregate sizes (>2mm, 1mm, 0.5mm, 0.052mm, and <0.052mm) using wet sieving method. Soil total carbon was determined according to (Nelson and Sommers, 1996). The air dried soil samples from each depth were wet sieved into aggregate size fractions by placing 100g of soil sample 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) placed into a full bucket of water and agitated for one minute following up and down movement with sieve shaker. Wet aggregates remaining on each sieve were collected, oven dried and weighted. A sub-sample of 10g of each aggregate fraction were placed in ceramic crucible and heated in Murphy furnace at 440^0C for a minimum of 4 hours of constant light and cooled in a desiccator and then weighed for carbon content estimation. Then Total carbon (%) was calculated as expressed below.

$$\text{Total carbon}(\%) = \frac{i.w - f.w}{i.w} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where: i.w = initial weight of soil; f.w = final weight of the soil

Results

Carbon Distribution in Aggregate Fractions along Depths

Aggregate >2 and <0.05mm fraction contained high proportion of soil carbon at 0-20 and 20-100cm depths in close canopy structure, respectively. The least proportion of carbon occurred in aggregate 1-0.5 and 2.0-1.0mm fraction from 0-60 and 60-100cm depths, respectively in close canopy structure. The aggregates attained the highest carbon concentration at 0-20cm and decreased with increase in soil depth. This can be attributed to rich organic matter content at surface soil that decreases with increase in depths. Also, aggregate >2.0 and <0.05mm contributed the large amount of soil carbon at 0-40 and 40-100cm depths, respectively. Therefore, there was a change in high adsorptive capacity for carbon from aggregate >2.0mm to <0.052mm fraction in open canopy structure. Furthermore, aggregate 0.5mm fraction had the least carbon content at soil depths (Table 1a and 1b). Approximately, the carbon content of aggregate fractions decreased with increase in soil depth.

Table 1a. Mean Distribution of Total Carbon at Five Depths in the Close Canopy Structure of Omo Biosphere Reserve

Close canopy cover	Total Carbon (%)				
Depths (cm)	>2mm	2-1mm	1-0.5mm	0.5-0.052mm	<0.052mm
0-20	4.09±1.93	3.08±1.29	3.00±1.06	3.31±1.44	4.03±1.45
20-40	2.28±1.03	1.67±0.88	1.37±0.76	2.05±1.17	3.29±0.96
40-60	3.20±1.90	2.39±2.26	1.81±1.24	2.30±1.49	3.97±1.75
60-80	2.09±0.98	1.73±1.19	2.11±1.09	2.73±1.44	3.87±1.68
80-100	2.45±1.40	1.65±1.00	1.87±1.07	2.32±1.22	3.81±1.58

Table 1b. Distribution of Total Carbon at Five Different Depths in the Open Canopy Structure of Omo Biosphere Reserve

Open canopy cover	Total Carbon(%)				
Depth (cm)	>2mm	2-1mm	1-0.5mm	0.05-0.052mm	<0.052mm

0-20	4.93±3.23	3.03±2.91	2.60±1.54	2.76±2.10	3.88±1.67
20-40	2.76±2.31	1.51±1.03	1.51±1.19	1.55±1.50	2.70±2.00
40-60	1.36±1.14	0.88±0.52	0.88±0.64	0.91±0.85	2.53±2.07
60-80	1.23±0.59	1.05±0.48	0.68±0.52	1.05±0.88	2.31±1.83
80-100	1.48±0.66	0.91±0.38	0.63±0.54	0.96±0.79	2.48±1.98

Sample Plots, Soil Depths, Aggregate Sizes and Carbon Distribution

The ANOVA result shows that soil carbon associated with aggregate fractions was significantly different with depths. Also, soil carbon content among aggregate sizes was significantly different (P≤0.05) in close canopy structure. Open canopy structure, soil carbon content was significantly different with depths. Soil carbon content among aggregate sizes was significantly different (P≤0.05). Soil carbon content of aggregate sizes was significantly different among the plots of Open canopy structure. This Indicates homogeneity of aggregate structure in close canopy plots.

The result of LSD test indicates that soil carbon content of aggregate sizes at 20-40 (2.13±1.15), 40-60 (2.73±1.87), 60-80 (2.51±1.47), 80-100cm depth (2.42±1.45) was not significantly different with one another but significantly different with 0-20cm depth (4.90±11.62), this shows that different factors influence carbon accumulation in surface and sub-surface soils. The result of LSD test indicates that soil carbon content among aggregate 2.0-1.0mm (2.10±1.48), 1-0.5mm (2.03±1.16), 0,5-0.052 mm (2.54±1.39) were not significantly different from one another but significantly different with >2mm (4.22±11.72) and <0.052mm (3.79±1.49) in Close canopy structure. Furthermore, carbon content of aggregate fractions of plots 1 (0.66±0.71) and 7 (0.52±0.35) was significantly different from plot 9 (2.43±2.67), 10 (2.69±1.81), 16 (2.35±1.13) and 20 (2.53±1.48). Also, distribution of carbon content of aggregate fraction of 0-20cm (3.44±2.38) and 20-40cm (2.01±1.67) depths was significantly different from 40-60cm (1.31±1.27), 60-80cm (1.26±1.08), 80-100cm depths (1.29±1.17) but no significant different between 0-20 (3.44±2.38) and 20-40cm depths (2.01±1.67) in Open canopy structure. Furthermore, the carbon content of aggregate 2-1.0mm (1.48±1.56), 1-0.5mm (1.29±1.35), and 0.5-0.052mm fractions (1.41±1.26) was not significantly different from one another but significantly different from >2.0 (2.35±2.26) and <0.052mm fractions (2.78±1.87).

Table 2a: Analysis of Variance for Carbon Distribution of Aggregate Sizes in Close Canopy

SV	DF	SS	MS	F-cal	P-tab
Plot	13	500.91	38.532	1.3934*	0.160741
Depth	4	350.35	87.587	3.1674**	0.014247
Size	4	283.68	70.919	2.5647**	0.038361
Depth*Size	16	545.42	34.088	1.2327*	0.241154
Error	312	8627.57	27.652		
Total	349	10307.93			

Where (**) significantly different and (*) not significantly different (P≤0.05)

Table 2b: Analysis of Variance for Carbon Distribution of Aggregate Sizes in Open Canopy

SV	DF	SS	MS	F-cal	P-tab
Plot	5	123.6557	24.7311	16.7384**	0.000000
Depth	4	104.8147	26.2037	17.7350**	0.000000
Size	4	52.7187	13.1797	8.9202**	0.000002
Depth*Size	16	14.4233	0.9015	0.6101*	0.870639
Error	120	177.3009	1.4775		
Total	149	472.9133			

Where (**) significantly different and (*) not significantly different (P≤0.05)

Discussion

Carbon Distribution in Aggregate Fractions along Depths

Soil carbon was higher among aggregate sizes at surface (0-20cm) than sub-surface soils (40-100cm depth). Also, soil carbon among aggregate was higher in close than open canopy structure. This could be attributed to high surface litter accumulation on surface soil of close and open canopy structure. This suggests that organic matter accumulation on aggregate fractions decreased with increasing depths (Yang *et al*. 2008). This explains the reason for low carbon concentration among aggregates at subsoils.

Carbon Distribution between Soil Aggregates and Depths

There was no significant different in carbon distribution among subsoils but significantly different with carbon distribution in surface soil. This suggest that different factors influence carbon distribution of surface soils and sub-surface soils, hence supports the findings of Salome *et al*., (2010) earlier stated. Furthermore, the differences in carbon accumulation of sub soil and surface soil could be linked to the report of Rasse *et al*. (2005), that root litter and root exudate are the major sources of soil carbon at deep soil depth and may be more stable and recalcitrant than carbon of surface soil because of higher concentrations of aliphatic and lignin materials. Also, Paul *et al*., (1997) revealed that deep soil carbon is stable with long resident and turnover time than surface soil carbon.

Macro-aggregate >2.0 mm fraction contained more carbon at surface soil (0-20cm) but micro-aggregate <0.052mm fraction contained more carbon at subsoil (20-40cm depth). This supports the finding of Yang *et al*., (2013). The accumulation of higher carbon in macro aggregates at surface soil could be attributed to high proportion particulate organic which preferentially accumulates on macro-aggregates (Smucker and Park, 2005b). Hence, micro aggregates (<0.052mm) contained large proportion of carbon than the macro aggregate at subsoil depth (20-100cm). This indicates that soil carbon trapped in micro-aggregate are more physically protected from mineralization and therefore, more stable than particulate organic matter on macro-aggregates. This supports the finding of Six and Jastrow (2002) which reveals that there is variation in degree of soil carbon protection among different aggregate sizes, and the degree of carbon protection is more in micro-aggregates than macro-aggregates probably because smaller aggregates have larger surface area and then can absorb more carbon. Also, soil micro-aggregates are characterized with more stable and recalcitrant carbon than particulate organic matter associated with macro-aggregates. Therefore, aggregate >2.0mm and <0.052mm fractions were responsible for high proportion of carbon accumulation in surface soil and subsoils, respectively. Hence, they have the highest potential for carbon sequestration and carbon stability in Omo Biosphere Reserve. As a result of this, any activities that disturbs or breaks the macro aggregates at soil surface in any land use system should be discouraged.

There is variation in soil carbon distribution among sample plots in close and open canopy structures. Variation in close canopy structures are not significantly different whereas there is significant different in open canopy structures. This reveals the homogeneity and a more micro climatic environment in close canopy than in open canopy structures. And could be the reason we recorded higher carbon in close canopy structure than in open canopy structure.

Conclusion and Recommendation

Carbon distribution varied among the aggregates and soil depths. Carbon content of aggregate fractions was higher at surface soil (0-20cm) than the subsoil. Macro aggregates (>2mm) were observed to have more carbon at surface soils (0-20cm) and micro aggregates (<0.052mm) at sub soils (20-100cm). Thus, different factors influence carbon accumulation in surface soils and sub-surface soils. There is variation in degree of soil carbon protection among different aggregate sizes. Aggregate fractions >2.0mm and <0.052mm are responsible for high percentage of carbon accumulation in surface soil and sub-surface soils respectively. Hence, they have the highest potentials for carbon sequestration, and <0.052mm has more stable carbon in forest soils. As a result of this, any activities that disturbs or breaks the macro aggregates at soil surface in any land use system should be discouraged.

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