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Analysis of Soil Carbon Sequestration in Teak (*Tectona Grandis*) Plantation within Nimbia Forest Reserve, Kaduna State, Nigeria.

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Abstract

Carbon sequestration has gain increased attention as the realization that increased trapping of carbon from the atmosphere into the soil can curb climate change and global warming. Simple analytical tools were employed to evaluate and characterize influence of tree ages on sequestered soil organic carbon content and carbon fraction of teak (Tectona grandis) plantation in Kaduna State, Nigeria. The aim was to provide a baseline data for further investigation and a future guide for management of forested ecosystems in view of the challenging impact of climate change. Soil samples were collected at 0 – 15 cm depth from two blocks planted in 1980 (P80) and 1990 (P90). The analysis reveal that the blocks belong to the same textural class (Sandy Clay Loam) with the same degree of compaction. Total OC and aggregated soil carbon fractions (OCa, OCb, OCc and OCd) were significantly influenced by teak age. The younger plantation (P90) had TOC value of 23.54 g/Kg and aggregated soil carbon fractions of 15.97g/Kg, 29.90g/Kg, 33.58g/Kg, 32.15g/Kg as against 7.20 g/Kg, 22.47 g/Kg, 19.93 g/Kg and 18.88 g/Kg obtained in P80. Plant age have significant influence on sequestered carbon content and aggregate soil carbon fraction. Therefore, forest management practices that can enhance carbon sequestration should be encouraged. Example reafforestation i.e. felling of older trees and replacing them with younger ones. More research involving both older and younger plantation in Nimbia Forest should be carried out to ascertain percentage increase or decrease in carbon sequestration with age differences.

Key Words: Carbon sink, Forest ecosystem, Nimbia Forest Reserve, Soil carbon sequestration, Tree age.

Introduction

Human activities including deforestation, fossil fuel burning and land use changes are altering the global carbon cycle, thereby contributing to possible climate changes that could impact food production, water resources, species habitat and distribution, and a suite of other important factors (Schlesinger and Andrews, 2000; Prentice *et al*., 2001). Land management may enhance or decrease atmospheric carbon uptake and storage by terrestrial ecosystems. There is increasing interest in understanding and quantifying this ecosystem carbon storage, and in managing land to favor a net accumulation of ecosystem carbon, a condition known as carbon sequestration or a carbon sink. Carbon sequestration is the capture of carbon dioxide (C0$_2$) and may refer specifically to the process of removing carbon from the atmosphere by vegetative cover and depositing it in a reservoir such as soil, when carried out deliberately, this may also be referred to as carbon dioxide removal, which is a form of geo-engineering (Kingsley, 2011). Importantly, the carbon dioxide is an influential gas leading to climate change. Estimating ground biomass content is necessary for considering total carbon content stored in forest ecosystem. Biomass density of each area in the forest widely varies according to weather, soil, topography, and forest utilization (Houghton, 1985).

Forest ability to sequester carbon is not only restricted to enhancing the plant-atmosphere relationship but also its ability to store carbon in the soil to reduce emission of CO_2 a greenhouse gas into the atmosphere (Lal *et al.*, 1998). Reduction of forest areas has a great impact on the amount of carbon dioxide stored in the atmosphere because forest is the great essential source of the world producing oxygen and storing carbon dioxide. The quantitative illustration of carbon pool in teak plantation is useful for understanding the key carbon sequestration channels which may serve as the basis for improving forest management (Pandey, 2000). Teak *Tectona grandis* as a tall tree species indigenous to India, Myanmar and Thailand and growing in seasonal dry tropical areas in Asia, a highly rated among hardwood plantation due to its durability, mellow colour, and long straight cylindrical bole. Although natural teak is distributed in relation to productive soils, derived from example lime stone, teak is planted over many tropical countries, such as Nigeria, the Cote d' Ivoire and Sierra Leone in Africa, and Costa Rica, Panama, Columbia, Trinidad and Tobago and Venezuela in Central America, as well as Asian countries (Pandey and Brown, 2000). By the year 2000, global teak plantation area reached 5.7 million hectares (FAO, 2001) and is still growing for investment by small land holders in agroforestry management as well as industrial wood supply (ITTO, 2004).

Climate change an impact of greenhouse effect, has become a serious environmental problem for ecosystem and natural resources, at both National and International level (Parry, 2007).The realization that increased trapping of carbon from vegetation (forest) into soil can effectively remove CO_2 from the atmosphere to curb climate change and global warming, has made carbon sequestration an important topic in recent times (Lal, 2002; 2003; Denef and Six, 2005). However, the influences of the age of the tree and the aggregated fraction of carbon in soils have received little or no attention. Several studies (Hamblin and Greenland, 1977; Dormor, 1983) have showed that it is the fractions of soil carbon rather than the amount that are important in combating climate change and land degradation. Thus, this study was initiated to evaluate and characterize influence of tree ages on sequestered soil carbon content and carbon fraction of a forest ecosystem under teak (*Tectona grandis*) plantation in Kaduna State, Nigeria. The aim is to provide a baseline data for further investigation and a future guide for management of forested ecosystems in view of the challenging impact of climate change.

Material and Methods: ***Site description*** **:** The Nimbia operational unit is within the Jema'a Local Government Area of Kaduna State. It lies between latitude 9°29' N and 9°32' N of the equator and between longitudes 8° 32' E and 8°36' E of the Greenwich and with an altitude of 594 m (Fig. 1). It covers a geographical area of 2,282.4 hectares .with only 2,202 hectares (8.5 square miles) established. This established area is visibly divided into 4 parts by an access road called compartment ride for managerial purposes. The reserve is marked by a series of short steep steps separated by long stretches of level undulating ground with marked outcrops of basaltic boulders (Plate I).The soil types are red deed freely draining loams and dark brown loams, yellow brown loams, reddish yellow loams, red deep soils and pale brown loam, shallow overlying ironstones, shallow high level sandy loams derived from granite or gneiss basement complex (Howard, 1963). Odumodu (1983) stated that climate of Nimbia is determined by altitude and its location in relation to the seasonal migration of inter- tropical convergence zone. It has a yearly rainfall of 1650mm – 1750mm distributed between April and October, while November – March are relatively dry periods. The relative humidity ranges from 30% in the dry season to 95% in the rainy season (Samndi, 2006).

Sampling and Laboratory analysis: For the purpose of this study, soil samples were obtained from two blocks in one of the compartments. The plantation established in 1980 (P80) and the one established in 1990 (P90). Each of the block was divided into six replicate and randomly sampled in triplicate at depths of 0 – 15 cm where there is organic carbon accumulation. Both disturbed and undisturbed soil sample were collected at this depth. A total of 18 disturbed soil samples were collected from each block with the aid of a soil auger. While 36 undisturbed core samples were retrieved from each block and used for bulk density analysis in the laboratory. Soil samples were air-dried and divided into two parts. One was passed through a 2 mm sieve for analysis of particle size distribution, total nitrogen and organic carbon while the other part was passed through a 5 mm sieve and used for wet aggregate size distribution analysis. Bulk density was analyzed using core method by Brake and Hartage (1986), particle size distribution was determined by hydrometer method as described by Gee and Bauder (1986). The textural classes were ascertained with the aid of USDA textural triangle. Wet aggregate size distribution was determined by slaking method (Elliott, 1986). The aggregate size stability characterized by mean weight diameter (MWD) was defined according to Van Bavel (1949) as;

$$\mathrm{MWD} = \sum_{i=1}^{n} x_i\,\omega_i \qquad [1]$$

where: x_i = mean diameter of any particular size range of aggregate separated by sieve.

$\boldsymbol{\omega}_i$ = weight of aggregate in the size range as fraction of the total dry weight of sample.

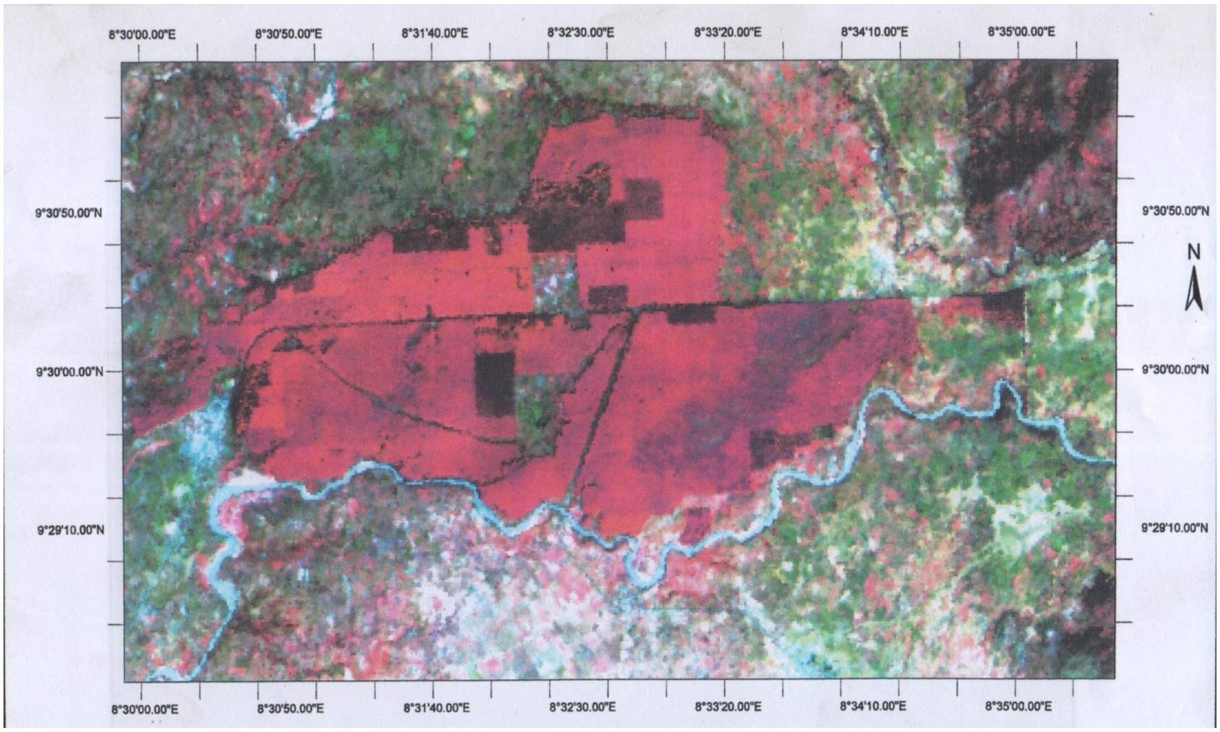

Fig. 1: Satellite image of Nimbia Forest Reserve

Plate I: Outcrop of basaltic boulders within the Reserve

Total Nitrogen (N) were determined using Kjeldahl method (Bremner, 1982). Soil organic carbon was analyzed by wet dichromate oxidation method of Walkey- Black as modified by Nelson and Sommer (1986) while soil organic carbon content was ascertained in each of the fractionated aggregates using the same oxidation method. Hence the following fractions were separated (Table 1).

Table 1: Soil carbon organic content in fractionated aggregates

Sieve size	Measure OC	Conceptual SOC
5 - 2 mm	Large particulate organic carbon	Unprotected
2 - 0.25 mm	Fine particulate organic carbon	Unprotected
0.25 - 0.05mm	Intra aggregate particulate organic carbon	Physically protected
<0.05 mm	Silt and clay associated organic carbon	Chemically protected

Data analysis

Laboratory data generated were analyzed for measures of central tendency (mean, minimum and maximum) and dispersion (skewness, kurtosis, standard deviation) using SPSS version 15. Independent sample T-test was used to determine the effect of tree age on sequestered soil organic carbon

Results and Discussion: ***Descriptive statistics analysis*****:** Descriptive data analysis were performed in order to obtain preliminary knowledge of the data set and presented in Tables 2 and 3. The descriptive statistics for the study area revealed differences from low to high in the amount of the variability of the soil properties. Large differences were found between minimum and maximum values of the soil properties. The values ranges from 23% in OCd to 195% in OCa under the P80 and from 11% in Silt to 152% in <0.05mm. Similar trend of results were also observed by Gokalp *et al.* (2010) and Obidike-Ugwu *et al.* (2022) The coefficient of skewness and kurtosis described the shape of sample distribution. The value of skewness is a measure of departure of a distribution from normal while kurtosis describes relative size of the distribution's tail. Based on the coefficient of skewness and kurtosis (Tables 2 and 3), none of the investigated soil properties were significantly skewed (2.00) or significantly kurtotic (4.00). This may not be unconnected to the number of sample collected and topographical nature of the study area.

Table 2: Descriptive statistics for the studied soil properties under 1980 plantation

Properties	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Sand (g/Kg)	18	460	600	516.67	54.283	.712	-.955
Silt (g/Kg)	18	120	280	176.67	54.283	1.702	3.792
Clay (g/Kg)	18	160	380	306.67	79.666	-1.536	2.465
BD (g/cm^3)	36	1.41	1.77	1.62	0.131	-.578	.016
5-2mm	18	1.0645	1.8758	1.5177	0.3018	-.212	-.477
2-0.25mm	18	0.3606	0.5451	0.4572	0.0724	-.097	-1.782
0.25-0.05mm	18	0.0088	0.0182	0.0129	0.0036	.260	-.918
<0.05mm	18	0.0006	0.0015	0.0010	0.0003	.329	-.271
MWD	18	1.6293	2.2863	1.9888	0.2335	-.268	.016
TOC (g/Kg)	18	13.50	17.20	15.52	1.353	-.323	-.714
N (g/Kg)	18	1.26	1.82	1.54	.198	.000	-.300
OCa (g/Kg)	18	3.80	11.20	7.20	3.119	.542	-1.875
OCb (g/Kg)	18	16.80	30.30	22.47	5.151	.287	-.426
OCc (g/Kg)	18	15.20	27.00	19.93	3.940	1.177	2.482
OCd (g/Kg)	18	16.80	20.70	18.88	1.522	-.270	-1.737
						NS	NS

BD= bulk density, 5mm – 2mm, 2mm – 0.25mm, 0.25mm -0.05mm, <0.05mm = wet aggregate fractions, TOC= Total Organic carbon, N= Total Nitrogen, OCa – Ocd = Organic carbon fractions, (5mm – 2mm, 2mm – 0.25mm, 0.25mm -0.05mm, <0.05mm respectively), MWD = Water stable mean weight diameter.

Significant if the absolute value of skewness or kurtosis is ≥2X its standard error. The standard error of skewness is $(6/n)^{0.5}$ while the standard error for kurtosis = $(24/n)^{0.5}$.

Table 3: Descriptive statistics for the studied soil properties under 1990 plantation

Properties	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**	**Skewness**	**Kurtosis**
Sand (g/Kg)	18	460	540	503.33	29.439	-.418	-.859
Silt (g/Kg)	18	180	200	186.67	10.328	.968	-1.875
Clay (g/Kg)	18	280	340	310.00	24.495	.490	-1.467
BD (g/cm^3)	36	1.06	1.94	1.56	.329	-.522	-.821
5-2mm	18	.4989	1.3689	.9975	.3486	-.345	-1.655
2-0.25mm	18	.5279	.6796	.6022	.0608	.132	-1.607
0.25-0.05mm	18	.0129	.0265	.0173	.0051	1.436	1.626
<0.05mm	18	.0006	.0016	.0010	.0004	.723	.058
MWD	18	1.1242	1.9103	1.6179	.3064	-.796	-.395
TOC (g/Kg)	18	20.00	27.00	23.54	3.002	.001	-2.681
N (g/Kg)	18	1.54	1.96	1.77	.169	-.075	-1.550
OCa (g/Kg)	18	9.40	19.60	15.97	3.898	-1.039	.449
OCb (g/Kg)	18	23.10	39.10	29.90	6.455	.432	-1.752
OCc (g/Kg)	18	29.00	43.10	33.58	5.141	1.548	2.635
OCd (g/Kg)	18	21.50	39.90	32.15	6.309	-.794	1.192
						NS	NS

BD= bulk density, 5mm – 2mm, 2mm – 0.25mm, 0.25mm -0.05mm, <0.05mm = wet aggregate fractions, TOC= Total Organic carbon, N= Total Nitrogen, OCa – Ocd = Organic carbon fractions, (5mm – 2mm, 2mm – 0.25mm, 0.25mm -0.05mm, <0.05mm respectively), MWD = Water stable mean weight diameter.

Significant if the absolute value of skewness or kurtosis is $\geq$2X its standard error. The standard error of skewness is $(6/n)^{0.5}$ while the standard error for kurtosis = $(24/n)^{0.5}$.

Effect of teak age on some soil physical properties in the study area: The proportion of sand in the P80 was higher than the proportion of sand in P90 but no significant difference (Table 4). High value was recorded for silt under P90 but the value was at par with the value of silt in P80. For clay, P90 recorded higher value but the value was statistically similar with the value of clay in P80. These results imply that teak age have no significant influence on the texture of the soil. The soil texture is classified as Sandy Clay Loam (SCL) according to USDA soil textural class.

The bulk density (Table 4) which is a measure of the degree of compactness of soil, were statistically similar, indicating certain spatial homogeneity. Tominaga *et al.*, (2002) showed that these physical soil attributes can greatly influence important soil processes like water movement (Reichardt and Timm, 2004) and soil compaction (Logsdon and Karlen, 2004) hence affecting microbial activities.

Influence of teak age on wet aggregate characteristics: In the water stable aggregate fractions, the proportion of wet aggregate in the 5mm- 2mm fraction were affected by Teak age (Table 4), P80 recorded a higher value than P90. Meanwhile, under the 2mm – 0.25mm fraction, the reverse was the case, P90 recorded a higher value. The P80 recorded 52% increase in macroaggregate (5mm - 2mm) while P90 accounted for 32% in 2mm – 0.25mm fraction, an indication of resistance to water erosion (Table 4). The recorded high value in P80 could be attributed to overtime formation of macroaggregae obtainable by none disturbance of the forested soil. The result obtained under 2mm – 0.25mm fraction could be probably due to the increase in soil organic carbon. Organic soil carbon contributes to the formation of water stable macro aggregates because of its ability to bind soil aggregate together (Schlesinger, 2000).

Water stable aggregates of 0.25mm – 0.05mm and <0.05mm fraction showed no significant different with Teak age (Table 4). The fraction of aggregate <0.05mm enable the formation of micro aggregate which then becomes basis for formation of macroaggregate (Tisdall and Oades, 1982). Non-significant values obtained could be due to degradation when rapidly immersed in water and destabilization of the soil by dispersing larger soil aggregate (Ogunwole, 2008).

There was a significant different ($P \leq 0.05$) in the MWD values obtained by wet sieving with different teak age. High MWD value was reported in P80 (Table 4). This implies that P80 would have a high aggregate stability characterized by MWD as a result of high macro aggregate encouraged over time (Ike, 1986; Lal, 2003).

Influence of teak age on total organic carbon and aggregate soil carbon fraction

Total amount soil carbon and aggregate soil carbon fraction values revealed significant different with Teak age (Table 4). There was a significant different ($P \leq 0.001$) in the TOC as influenced by age. The P90 plantation recorded a value of 23.54g/kg and 52% higher than the P80 value. There was also significant different in all the aggregated carbon fractions with P90 recording higher values in all (Table 4). Highest value of 33.58g/kg was recorded under OCc followed by OCd (32.15g/kg), then OCb (29.90g/kg) and OCa (15.97g/kg). The values also revealed an increment of 68%, 70%, 33% and 122% over the valued obtained in the

Table 4: Level of interaction or relationship between two Teak plantation and the studied soil properties

Properties	**1980**	**1990**	**Significant level**
Sand (g/Kg)	516.67	503.33	NS
Silt (g/Kg)	176.67	186.67	NS
Clay (g/Kg)	306.67	310.00	NS
BD (g/cm^3)	1.62	1.56	NS
5-2mm	1.5177	.9975	*
2-0.25mm	0.4572	.6022	**
0.25-0.05mm	0.0129	.0173	NS
<0.05mm	0.0010	.0010	NS
MWD	1.9888	1.6179	*
TOC (g/Kg)	15.52	23.54	***
N (g/Kg)	1.54	1.77	*
OCa (g/Kg)	7.20	15.97	**
OCb (g/Kg)	22.47	29.90	*
OCc (g/Kg)	19.93	33.58	***
OCd (g/Kg)	18.88	32.15	***

BD= bulk density, 5mm – 2mm, 2mm – 0.25mm, 0.25mm -0.05mm, <0.05mm = wet aggregate fractions, TOC= Total Organic carbon, N= Total Nitrogen, OCa – Ocd = Organic carbon fractions, (5mm – 2mm, 2mm – 0.25mm, 0.25mm -0.05mm, <0.05mm respectively), MWD = Water stable mean weight diameter.

NS: Non-significant, * Significant at 0.05 probability level, ** Significant at 0.01 probability level and *** Significant at 0.001 probability level

P80 respectively. However, high values observed under P80 are obtained in aggregate fractions that are not easily eroded by rain water. The lower organic carbon content obtained under the older plantation (P80) might be attributed to several factors such as lower litter accumulation to canopy closure, translocation of dry matter to the bole and lower rate of mineralization, a view expressed by several authors (Ezenwa, 1985;1988; Okoro *et al.,* 1999; Nwoboshi, 2000; Houghton , 2005). Jose and Koshy (1972) also reported a sharp decrease in organic matter content between 15 and 30 years old Teak stand thus supporting the negative relationship between stand age and organic carbon.

Conclusion and Recommendation

Descriptive analysis and independent samples T-test were applied to evaluate sequestered soil carbon content and assess the relationship between Teak age and aggregated soil carbon-fraction in two blocks (P80 and P90) of Nimbia Forest Reserve in Kaduna State. Descriptive Statistics for the study area revealed large differences in the minimum and maximum values of the soil properties. None of the measured properties were significantly skewed or Kurtosis. The proportion of sand, silt and clay also revealed that the two blocks or plot belonged to the same textural class (Sandy Clay Loam) and their degree of compaction are also the same. The wet macroaggregates and MWD showed significant different while the microaggregates were statistically similar. Total OC and aggregated soil carbon fraction also showed significant differences with P90 having higher values in all the carbon fractions. In conclusion, teak age have significant influence on sequestered carbon content and aggregate soil carbon fraction. Aggregate soil stability is a measure of soil resistance to dispersion by erosion. Organic carbons obtained are stored in the fraction of the aggregate that are not easily dispersed by rainfall. Based on the above findings, the following recommendations are put to bear: Forest management practices that can enhance carbon sequestration should be encouraged. Example reafforestation i.e. felling of older trees and replacing them with them with younger ones.; More research involving both older and younger plantation in Nimbia Forest should be carried out to ascertain percentage increase or decrease in carbon sequestration with age differences.

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