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Exploring Tree Growth Variables Influencing Carbon Sequestration in the Face of Climate Change

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Abstract**—**One of the major problems being faced by human society is that the global temperature is believed to be rising due to human activity that releases carbon IV Oxide (CO_2) to the atmosphere. Carbon IV Oxide is the most important greenhouse gas influencing global warming and possible climate change. With climate change becoming alarming, reducing CO_2 in our atmosphere has become a primary goal of international efforts. Forest lands are major sink and could absorb large quantities of carbon if the trees are judiciously managed. The study aims at estimating the carbon sequestration capacity of *Pinus caribaea* (pine) and *Tectona grandis* (Teak) under the prevailing environmental conditions and exploring tree growth variables that influences the carbon sequestration capacity in Omo Forest Reserve, Ogun State, Nigeria. Improving forest management by manipulating growth characteristics that influences carbon sequestration could be an adaptive strategy of forestry to climate change. Random sampling was used to select Temporary Sample Plots (TSPs) in the study area from where complete enumeration of growth variables was carried out within the plots. The data collected were subjected to descriptive and correlational analyses. The results showed that average carbon stored by Pine and Teak are 994.4±188.3 Kg and 1350.7±180.6 Kg respectively. The difference in carbon stored in the species is significant enough to consider choice of species relevant in climate change adaptation strategy. Tree growth variables influence the capacity of the tree to sequester carbon. Height, diameter, volume, wood density and age are positively correlated to carbon sequestration. These tree growth variables could be manipulated by the forest manager as an adaptive strategy for climate change while plantations of high wood density species could be relevant for management strategy to increase carbon storage.

Keywords**—**Adaptation, carbon sequestration, climate change, growth variables, wood density.

I. Introduction

GREENHOUSE gases play an important role on Earth's climate. When the concentration of greenhouse gasses in the atmosphere increased, temperature at the Earth's surface is expected to rise thereby resulting in global warming. The intense heat emitted in the earth surface through radiation has hazardous effect on plants, animals, human race, and its total environment. Reference [8] reported predicted increase in temperature with more precision at 1.8^{o}C to 4^{o}C at the end of the century. Increase in surface air temperature level was linked to increase in the concentration of Carbon IV oxide (CO_2) in the atmosphere [13].

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CO_2 is a greenhouse gas and a primary agent of global warming. Forests are critical to mitigating the effects of global climate change because they are large store house of carbon and have the ability to continually absorb CO_2 from the atmosphere [5]. The process of removing CO_2 from the atmosphere and 'storing' it in plants that use sunlight to turn CO_2 into biomass and oxygen is termed carbon sequestration [17].

Forests contain nearly 75 percent of the earth's biomass [3] and plays significant role in the global carbon cycle, having absorbed approximately one third of anthropogenic emissions of CO_2 to the atmosphere [12]. However, human activities in the forest have also been a source of carbon emission to the atmosphere, with deforestation (primarily in the tropics) contributing about one fifth of the annual anthropogenic emissions. Forest resources depletion and its current trends have serious implications, not only for resource base but also on the livelihood of humanity. Forest can be either sources or sinks of carbon, depending on the specific management regime and activities [7]. The rate of sequestration varies due to forest variation, mainly in terms of their structure and type. Reference [4] stated that sustainable management, planting and rehabilitation of forest can conserve and increase the amount of carbon sequester.

Issues of climate change and loss of biodiversity are increasingly prompting nations to focus on accounting for and managing greenhouse gas emissions [9]. Varieties of strategies are therefore needed to reduce CO2 emissions and remove carbon from the atmosphere in order to mitigate the potential effects of global warming and climate change. Many mitigation responses to climate change have been proposed, including land-use change, and forestry policies that increase carbon sink functions of terrestrial ecosystems [20]. Adaptation to climate change is necessary to address impact resulting from warming. Carbon sequestration projects could also enhance understanding of sustainable forest management practices [19]. Available estimates suggest that forests have a large mitigation potential. However, achieving the carbon mitigation potential will require accurate methods to assess the dynamics of carbon fluxes and storage under alternative management regimes [11] and the growth variables that influences it. Data is a prerequisite for any sustainable forest management project. There is a great need to reconsider "forest" in the face of climate change and take a fresh look no their conservation and factors that can better enhance their carbon sequestration capacity. This study is aimed at providing reliable information on growth variables influencing carbon sequestration capacity of Tectona grandis and Pinus caribea stands in Omo Forest Reserve, Ogun State in the face of climate change.

II. Materials and Methods

A. Study Area

The study was carried out Omo Forest Reserve (J4). It is situated between latitude 6°35[1] and 7°05[1]N and longitudes 4°19[1] and 4°40[I]E. The Reserve shares its northern boundary with Osun and Ago Owu Forest Reserves in Osun state and Oluwa Forest Reserve in Ondo state. The Omo and Oni Rivers mark the southern boundary. The Oni River continues futher north to form eastern boundary, while the western boundary is formed by surveyed paths and demarcated cut lines. The Reserve had a total area of approximately 130,550ha with 65km of enclaves. Communities present include Aberu, Abititun, Oloji, Osoko, Ajebandele, Abakurudu, Tisaba, Olomogo, Etemi, Abeku. The topography of the reserve is generally undulating with average elevation of 125m above sea level [1].

B. Data

Data used for this study was collected from fifteen (15) randomly selected temporary sample plots of size 400 m^2 within 2 selected exotic tree species (*Tectona grandis* and *Pinus carribaea*) of the different age series in the study area. Within each sample plot, the following tree growth variables were measured for all trees: total height (m), bole height (m), merchantable height (m), crown length (m), diameter (cm) outside bark at breast height (i.e. dbh measured at 1.3 m above the ground level), diameter (cm) outside bark at top, middle and base, crown diameter (cm).

C. Carbon Sequestration Estimation

Carbon sequestered was estimated based on the relationship between wood density and carbon dioxide. Two sample trees without defects were randomly selected in each sample plot based on non-destructive sampling method. Haglof increment borer was used to collect core sample from DBH of selected trees. The samples were oven dried at 70 degree centigrade for 48hrs and its dried weights were determined using a triple beam balance. The density of the core sample was estimated as the ratio of dry weight to fresh volume. The percentage carbon content of the core was also determined and hence the amount of carbon sequestered estimated.

$$C = V * D * \%\ CC \tag{1}$$

where C = Amount of C sequester; V = merchantable volume; D = wood density; CC = carbon content %.

D. Computation of Derived Variables

The following variables were derived from measured tree growth variables

1. Basal Area

$$BA = \frac{\pi (D^2)}{4} \tag{2}$$

where BA = Basal area, D = diameter at breast height (m)

2. Crown Projection Area and Crown Ratio

$$CPA = \frac{\pi (CD^2)}{4} \tag{3}$$

$$CR = \frac{CL}{H} \tag{4}$$

where CPA= Crown Projection Area, CR = crown ratio, CL = crown height and H = total height.

3. Tree Slenderness Coefficient

$$TSC = \frac{THT}{DBH} \tag{5}$$

4. Stem Volume

$$V = \frac{h}{6}(A_b + 4A_m + A_t) \tag{6}$$

where V = Stem volume (m^3), h = Merchantable height (m), A_b, A_m, A_t,= cross sectional areas at the base, middle and top of the tree respectively (m^2)

E. Statistical Analysis

Product moment correlation analysis was used to evaluate association between tree growth variables and carbon sequestered by the tree. Analysis of variance (ANOVA) was used to evaluate the effect of stand age on carbon sequestered.

III. Results and Discussion

The data set cover a wide range of growth variable for the study species. The average, standard deviation and coefficient of variation of the growth variable are presented in Table I.

TABLE I
CHARACTERIZATION OF THE TREE GROWTH VARIABLES FOR THE STUDIED SPECIES

Variable	Statistic	Pine	Teak
DBH (m)	Average	0.801	0.654
	S	0.288	0.212
	CV	35.955	32.416
MTH (m)	Average	17.567	14.933
	S	3.256	1.639
	CV	18.535	10.976
BA (m^2)	Average	0.567	0.370
	S	0.403	0.245
	CV	71.076	66.216
SV (m^3)	Average	6.418	3.784
	S	5.069	2.603
	CV	78.981	68.790
Density (Kg/m^3)	Average	487.39	512.41
	S	88.819	54.129
	CV	18.22	10.56
Carbon (Kg)	Average	994.4	1350.7
	S	188.3	180.6
	CV	68.44	79.79

S – Standard deviation, DBH- diameter at breast height, MTH- merchantable height, BA- basal area, SV- stems volume

Wood density was estimated in order to estimate the amount of carbon stored in the tree. Reference [16] stated that wood density is a key functional trait within forests in that it may influence woody biomass and ecosystem carbon stocks. The average wood density estimated for pine and teak were 487.39kg/m^3 and 512.41kg/m^3 and the average carbon stored were 994.4kg and 13507kg respectively.

A. Effect Of Species and Stand Age on Carbon Sequestered

Carbon sequester was higher for teak species when compared with Pine at age 24. Generally it was observed that the highest amount of carbon was sequestered by older trees (Fig. 1). Ages of the pine species used in the study did not significantly affect the amount of carbon sequestered (Table II) although older trees had higher amount of carbon stored. This may be attributed to the closeness in the age series used in the study.

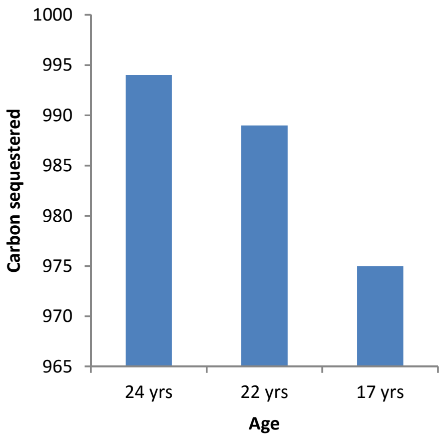

Fig. 1 Carbon sequestered against age for pine species

Carbon sequestered by teak species was affected by age. Result from study shows that old growth trees are considerable reservoir for carbon which is in agreement with [10], who reported that old growth forest plays an important role in biodiversity conservation and carbon storage. Forest with old growth trees is important carbon reservoirs and they represent a huge pool of carbon. Reference [14] also found out that old growth trees are much richer in carbon than what carbon cycle model assumes. The old standing trees steadily accumulate vast quantities of carbon over centuries. These forest will emit much more carbon if their site is been disturbed.

TABLE II
EFFECT OF SPECIES AND STAND AGE ON CARBON SEQUESTERED

Pine		Teak	
Age	Carbon sequestered	Age	Carbon sequestered
24	994.41 ± 188.29a	24	1350.7 ± 180.58a
22	989.20 ± 233.38a	12	806.42 ± 105.14b
17	975.98 ± 157.73a	9	734.27 ± 77.96b

Means with the same alphabets are not significant from each other.

B. Tree Growth Variables Relationship with Carbon Sequestration

Correlation analysis was carried out to investigate the association between tree growth characteristics and carbon sequestered. Reference [6] showed that carbon sequestration depended not only on rates of productivity but also on the size of the tree. It was observed from the correlation matrix that carbon sequestration increases with increase in tree growth variables but decreased with increasing tree slenderness coefficient. The negative correlation of carbon sequestration with tree slenderness coefficient indicates that trees that are tall and slender sequester less carbon. Diameter at breast height (DBH), tree height and age were linearly related to the amount of carbon sequestered (Tables III and IV). This conforms to the findings of [17], [18] who mentioned that carbon sequestration potential in the different forest types tends to be correlated to DBH and tree height .Wood density was also positively related to carbon sequestered by the stand which is similar to the research of [2], forest biomass increased with community wood density. Basal area was another variable that was highly correlated to carbon sequester. Reference [15] observed a linear positive correlation between forest biomass, stand wood density and total basal area in his findings. Similar trend was observed in this study. This makes intuitive sense: basal area is intimately linked to standing biomass so that an increase in basal area with wood density leads to an increase in biomass. The positive relationship between diameters, wood density, and age etc. with carbon sequestration implies that the higher these variables the higher the amount of carbon sequestered.

TABLE III
CORRELATION MATRIX FOR INDIVIDUAL MEASURED TREE GROWTH VARIABLES

	THT	*MTH*	*CD*	*DBH*	*DB*	*DM*	*DT*	*CS*
THT	1.000							
MTH	.730*	1.000						
CD	.226*	.224*	1.000					
DBH	.444*	.377*	.512*	1.000				
DB	.440*	.321*	.533*	.969*	1.000			
DM	.471*	.365*	.537*	.975*	.959*	1.000		
DT	.521*	.405*	.466*	.880*	.871*	.895*	1.000	
CS	.448*	.462*	.454*	.857*	.825*	.877*	.791*	1.000

CD- crown diameter, DB, DM, DT- Diameter at base, middle and top, CS- carbon sequestered

TABLE IV
CORRELATION MATRIX FOR INDIVIDUAL ESTIMATED TREE VARIABLES

	CS	*AGE*	*BA*	*TSC*	*SV*	*CPA*	*CR*	*D*
CS	1.000							
AGE	.405*	1.000						
BA	.828*	.337*	1.000					
TSC	-.788*	-.355*	-.866*	1.000				
SV	.866*	.296*	.960*	-.818*	1.000			
CPA	.451*	.261*	.478*	-.516*	.521*	1.000		
CR	-.024	.020	.011	-.100	-.089	.261*	1.000	
D	.247*	-.196	-.115	.037	-.114	.023	.160	1.000

BA- basal area, TSC- tree slenderness coefficient, CPA- crown projection area, CR- crown ration, D- wood density

The positive relationship between diameters, wood density, and age etc. with carbon sequestration implies that the higher these variables the higher the amount of carbon sequestered. It has been shown from the result that provided the trees are allowed to grow and are not fell; they will continue to provide the safety net for the adverse effects of climate change. Hence it is the sole responsibility of the manager to ensure that these trees get to their maximum sizes through the help of silvicultural treatment so as to maximize their carbon sequestration capacity.

IV. CONCLUSION

Carbon sequestration capacity varies from species and age of forest and the potential of a tree to sequester carbon relies on its sizes. Older trees store more carbon than younger trees but these young trees are relevant in terms of their future potential to grow up and also store high amount of carbon. With high carbon sequestration potential of high wood density trees, plantations of high wood density species can be proposed.

The limitation of this study was that the age series used in the study was too close. As more data becomes available to cover a wider range of age, these growth variables that influences the amount of carbon sequestered will be easily appreciated and forest managers can therefore manipulate the management of afforestation and reforestation program in order to achieve higher sink potentials.

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