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Carbon Stock Estimation in Teak (*Tectona grandis* Linn. F.) Stands of Selected Forest Reserves in Ekiti State, Nigeria

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Abstract

The assessment of carbon stock in forests has gained global attention in view of its roles in sequestering atmospheric carbon. The carbon stock of teak (*Tectona grandis* Linn. F.) stands was estimated in a total of twenty 20 X 20 m plots randomly laid in Aramoko and Ikere Forest Reserves (FRs) in Ekiti State, Nigeria. The diameter at breast height (dbh) was measured for each tree. An allometric equation was adopted to estimate biomass and subsequently carbon for the study locations. The biomass per hectare and carbon per hectare were 625.25 kg and 312.63 kg; and 580.25 kg and 290.13 kg for Aramoko and Ikere FRs respectively. Student's t-test revealed significance (p 0.05) for number of trees per hectare and basal area per hectare for the FRs but not for diameter at breast height. The estimated highest number of trees per hectare was 1,025 and 600 in Aramoko and Ikere FRs respectively but the least number was 375 trees per hectare in both reserves. The highest basal area and least basal area values were 23.97 and 10.11 m^2; and 11.64 and 6.66 m^2 in Aramoko and Ikere Forest Reserves respectively. Local and global benefits will ensue if carbon stock in the locations is increased by growing more trees.

Keywords: Allometric equations; aboveground biomass; diameter at breast height; carbon stock

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Introduction

The emission of carbon dioxide into the atmosphere has contributed greatly to climate change whereas tropical forests can play an important role in its mitigation (Beer *et al.*, 2010). The two main sources of this emission are fossil fuel burning and deforestation. Fossil fuel burning is the major source of carbon dioxide emission in the developed countries while deforestation and forest degradation are the major sources in the developing countries. Ramankutty *et al.* (2007) observed that about one-quarter of the global atmospheric carbon dioxide concentration comes from the removal of tropical forests. Despite this alarming influence of deforestation in the tropics, the tropical forests still have the potential to sequester large amounts of carbon from the atmosphere if properly managed and since they harbor about two times of carbon more than the forests of other regions, the importance in maintaining the global balance of greenhouse gases cannot be downplayed (Ekanayake *et al.*, 2012).

Forests can serve as a carbon sink or source depending on the state of such forests at any particular time. A growing forest or a well-managed forest can act as a sink for carbon dioxide through the process of photosynthesis but where the forest is removed for one reason or the other, it will serve as a source particularly through biomass decomposition and burning. Therefore, growing new forests through reforestation and afforestation programmes in the tropics has the capacity to foster storage of carbon in the biomass of such forests (Nair *et al.*, 2009).

The world's forest area decreased from 31.6 percent of global land area to 30.6 percent between 1990 and 2015 but that the pace of loss has reduced in recent years (FAO, 2018). However, this may not be the case for many developing countries where forests serve as the source of livelihoods for many rural people and deforestation is still at an alarming rate. Therefore, the knowledge of carbon stock in any forest is crucial for its proper management as this will elucidate the state of such a forest and whether or not to grow more trees in order to make a forest in such an area. Also, this will significantly contribute to devising new policies for such a forest (Cole and Ewel, 2006).

There are two main methods for estimating the carbon stock of trees. The destructive method directly measures the biomass by felling the tree and measuring the actual mass of all the components of the tree such as the bole, branches, leaves, roots (roots can be excluded if it is above-ground biomass) (Jandl *et al.*, 2007). The indirect method uses measured variables such as wood volume and gravity to estimate tree biomass and has the advantage of being less time-consuming (Venkateswaran and Parthasarathy, 2005). Since the principal goal in forest management is the production of timber volume, therefore the tree volume and biomass are crucial measures in forest inventories (Almeida *et al.*, 2014). Majority of biomass studies adopt the allometric models for estimation of the above-ground biomass because the direct method is laborious, destructive and costly (Viera *et al.*, 2008).

Teak (*Tectona grandis* Linn. F.) is one of the major fast-growing tree species that have been adopted for plantation development in Nigeria for a long time (FAO, 1984; Akindele, 1989; Adekunle *et al.*, 2011). Teak ranked third among tropical hardwood species in terms of plantation areas established worldwide, covering 2.25 million ha and planted extensively in the tropics for the high quality timber (Krishnapillay, 2000). Thus, Aniek and Mochamad (2014) observed that the information about patterns of changes in carbon storage of teak forests is vital and urgent so that it can be used as a determinant of forest management and environmental policies in order to predict and identify deposit patterns or carbon storage and changes as early as possible. There is scarcity of information with respect to carbon stock of most forest reserves in Nigeria (Olayode *et al.*, 2015). Therefore, an estimation of carbon stock in teak plantations was carried out to assess the carbon status and carbon storage potentials of two forest reserves in Ekiti State, Nigeria.

Materials and Method

Study areas

Two forest reserves (FRs) in Ekiti State, Southwestern Nigeria which preliminary investigations revealed contained teak (*Tectona grandis*) stands were purposively selected for this study. The two FRs are Aramoko FR with a land area of 19.66km and Ikere FR having a land area of 14.19km (Ibimilua, 2012). Ekiti State is located between Latitudes 7°23' and 7°46'N and Longitudes 4°47' and 5°45'E. The climate of Ekiti State is of West Africa monsoon type with rainy and dry seasons. The rainy season normally starts from March through October with occasional strong wind and thunderstorms usually at the onset and the end. The dry season usually ranges from November to February although with occasional variations. The annual rainfall ranges from 750mm in the northern zone to 1,500mm in the southern zone. The diurnal temperature ranges from 21°C to 31°C with little variations throughout the year. Annual average relative humidity is about 90% at 7.00a.m. and 65% at 4.00p.m.

Carbon stock estimation in the study locations

The forest inventory-based approach was adopted to estimate the biomass in the study areas. Ten 20 20 m sample plots were randomly laid in each reserve. The diameter at breast height (dbh) was measured in all the trees within a sample plot. An allometric equation developed by Faboye (2012) for a study conducted in three forest reserves, southwestern Nigeria was adopted for this study.

$$\ln B = 2.56 + 0.04 Dbh \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$R^2 = 0.87$, SE = 0.40

where, lnB is the natural logarithm of biomass,
Dbh is the diameter at breast height in cm,
R^2 is the coefficient of determination and SE is the standard error.

The equation was developed from data collected from southwestern Nigeria where this present study was also conducted. The equation was used to generate the natural logarithm of biomass for each tree in a sampled plot by supplying the measured dbh while the actual value for biomass was obtained by finding the exponential value of the natural logarithm of biomass. This was done to generate the biomass of all trees within a plot. The mean plot biomass was then obtained. The mean plot biomass for *T. grandis* in each location was calculated and multiplied by 25 (the number of 20 20 m plots in a hectare) to obtain the biomass ha^{-1}. Half of this value gave carbon ha^{-1} for each location.

Basal area determination

The basal area for every tree in each plot was determined using the following formula:

$$\text{Basal area} = \pi \, {D^2}/{4} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (2)$$

where D is diameter at breast height in m is taken as 3.142.

The basal area ha^{-1} for each plot was calculated by adding all the basal area values for all the trees in a plot and multiplied by 25 (the number of 20 20 m plots in 1 ha).

Results

Table 1 shows the number of trees in diameter at breast height (dbh) classes (range of values) and the cumulative number of trees in Aramoko and Ikere Forest Reserves. In Aramoko Forest Reserve, there were three dbh classes: 10-20, 20-30 and 30-40 cm with 224, 22 and 3 trees respectively. Only two dbh classes: 10-20 and 20-30 cm were obtained with 184 and 7 trees respectively in Ikere Forest Reserve. The cumulative number of trees was 259 and 191 in Aramoko and Ikere Forest Reserves respectively.

Table 1: Cumulative number of trees across diameter classes in the study locations

Diameter classes (cm)	Aramoko	Ikere
10-20	224	184
20-30	256	191
30-40	259	-

Student's t-test results for diameter at breast height, basal area per hectare and number of trees per hectare in Aramoko and Ikere Forest Reserves are shown in Table 2. The results revealed significance (p 0.05) for basal area per hectare and number of trees per hectare whereas significance was not obtained for diameter at breast height between the two locations.

Table 2: Students' T-Test Result for Diameter at Breast Height, Basal Area per Hectare and Number of Trees per Hectare in the Study Locations

Assessment Variable	Mean and Mean Standard Error		p-level
	Aramoko	Ikere	
Diameter at breast height (cm)	16.02 ± 0.95	14.47 ± 0.31	0.14
Basal area per ha (m^2)	14.69 ± 1.39	8.40 ± 0.46	0.00*
Number of trees per ha	652.50 ± 60.95	482.50 ± 22.68	0.02*

Furthermore, the mean dbh, basal area and number of trees ha^{-1} for the sampled plots in Aramoko Forest Reserve are shown in Table 3. Plot 3 had the highest mean dbh of 20.64 cm followed by 20.35 cm in plot 1 while the least value was 13.39 cm in plot 6. The highest basal area ha^{-1} was 23.97 m^2 in plot 3 followed by 18.58 m^2 in plot 8 while the least basal area of 10.11 m^2 was obtained in plot 5. The number of trees ha^{-1} was highest in plot 7 at 1025 followed by 875 in plot 6 while the least value was 375 in plot 1.

Table 3: Mean diameter at breast height, basal area and number of trees in sampled plots of Aramoko Forest Reserve

Plots	Average Dbh (cm)	Basal area Ha^{-1} (m^2)	Number Ha^{-1}
1	20.35	13.20	375
2	19.39	16.48	525
3	20.64	23.97	575
4	14.01	10.66	600
5	13.98	10.11	500
6	13.39	15.30	875
7	14.15	16.69	1025
8	16.71	18.58	750
9	13.93	11.17	575
10	13.63	10.78	725

Table 4 shows the mean dbh, basal area and number of trees ha^{-1} in sampled plots of Ikere Forest Reserve. The highest mean dbh was 16.30 cm in plot 6 followed by 15.66 cm in plot 9 while the least mean dbh was 13.15 cm in plot 5. The highest basal area ha^{-1} was 11.64 m^2 in plot 2 with the closest value to it being 9.49 m^2 in plot 9 while the least was 6.66 m^2 in plot 7. The highest number of trees was 600 ha^{-1} in plot 2 followed by 575 in plot 10 and the least was 375 in plot 7.

Table 4: Mean diameter at breast height, basal area and number of trees in sampled plots of Ikere Forest Reserve

Plots	Average Dbh (cm)	Basal area Ha^{-1} (m^2)	Number Ha^{-1}
1	13.56	7.45	425
2	14.66	11.64	600
3	14.22	7.78	475
4	14.81	8.69	525
5	13.15	6.95	500
6	16.30	8.59	400
7	14.54	6.66	375
8	13.43	7.65	475
9	15.66	9.49	475
10	14.34	9.05	575

Table 5 shows the estimated biomass and carbon contents in the study locations. The mean plot biomass was 25.01 and 23.21 kg for Aramoko and Ikere Forest Reserves respectively. The mean plot biomass values were used to calculate the biomass ha^{-1} for the respective reserve and the values obtained were 625.25 and 580.25 kg ha^{-1} Aramoko and Ikere Forest Reserves respectively. The half of these values are 312.63 and 290.13 kg which represent the carbon content ha^{-1} in the biomass at Aramoko and Ikere Forest Reserves respectively.

Table 5: Carbon stock values in Aramoko and Ikere Forest Reserves

		Aramoko	Ikere
Mean plot biomass	(kg)	25.01	23.21
	(t)	0.03	0.02
Biomass ha^{-1}	(kg)	625.25	580.25
	(t)	0.63	0.58
Carbon ha^{-1}	(kg)	312.63	290.13
	(t)	0.31	0.29

Discussion

Adequate management of forest plantations requires information on the growth and biomass yield with which to consequently, fit the functions for estimating the biomass (Onyekwelu, 2007). The carbon ha^{-1} values for Aramoko and Ikere Forest Reserves were close. This might be a reflection of the dbh values obtained from the sites where most of the trees fell within the diameter class of 10-20cm whereas student's t-test already showed that the diameter values across the plots were not different from each other for the study locations. Olayode *et al.* (2015) reported carbon ha^{-1} for teak stands in Gambari, Osho and Shasha Forest Reserves, in southwestern Nigeria and the values are well above those obtained for the reserves used for this study. Information gathered through informal discussion indicated that no proper attention has been given to the management of these reserves. Also, it was gathered that taungya practice was used in raising most of the existing trees which have been seriously exploited. The results of this study is in consonance with the report of Ibimilua (2012) that physical impacts of deforestation were most felt in both Aramoko and Ikere Forest Reserves in comparison with some other Forest Reserves in Ekiti State.

Furthermore, Wang *et al.* (2003) reported that the most accurate method for the estimation of biomass is through cutting of trees and weighing of their parts whereas it can be deduced from this study that where existing equations of similar climatic conditions to the stands in which the carbon is to be estimated are available, these can be adopted to estimate carbon stock. The equation adopted in this study was developed from the data collected in some forest reserves located in southwestern Nigeria and with similar ecological conditions. However, some conditions that must have been satisfied include: similar species are used in developing such equations and the range of dbh in the stand for which carbon is to be estimated should fall within the range of dbh used in generating the equations. This will forestall carrying out destructive sampling again which is laborious, expensive and time consuming. Onyekwelu (2007) noted that all biomass components could be described by dbh alone with very low standard error of estimates while little improvements was achieved in the precision of the functions by including total height. Therefore, this study is in order by adopting an equation that used dbh alone, more so as it is an easily measurable parameter and where proper rules are followed, the same value could be obtained by different individuals irrespective of the number of times this is repeated (Olayode *et al.*, 2015) unlike a parameter like plant height. Diameter has been noted as a key parameter used in tree allometry (Zianis and Mencuccini, 2004). Basuki *et al.* (2009) noted that species-specific equations provide high accuracy in biomass estimation. The equation adopted for estimating carbon in this study is species-specific as it was generated from *Tectona grandis* trees from selected forest reserves in southwestern Nigeria. Henry *et al.* (2010) earlier stated that the accuracy of allometric equations for carbon accounting can be improved with the use local equations involving the range of tree diameter classes in that particular locality.

Conclusion

This study estimated carbon stock in Aramoko and Ikere Forest Reserves using existing allometric equation which has been developed from similar ecosystems. These data have contributed to a growing database of carbon stock for forest reserves in Nigeria and can form basis for comparison in the future. The carbon stock ha^{-1} values obtained in the two locations were small compared to some forest reserves in southwestern Nigeria. Therefore, in order to increase the carbon stock in these two locations, more trees which can either be exotic or indigenous need to be grown. This will foster many benefits on the immediate communities close to the Forest Reserves and help to sequester more carbon from the atmosphere to reduce the impact of rising carbon level on global climate.

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