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Assessment of Growth and Carbon Content of Teak (*Tectona grandis* Linn.) Plantation in Obubra, Cross River State, Nigeria.

[1]Ina(Jnr). O. U., [2]Egbuche C. T., [3]Aigbe H. I., [4]Ekwugha E. U., and [5]Duruanyim I. E.

Department of Forestry and Wildlife Technology; Federal University of Technology, Owerri Imo state

Correspondence email: utum.okoi@futo.edu.ng

Abstract

This study investigated the biomass and carbon content of Tectona grandis in Obubra Cross River State, Nigeria. The goal was to assess the amount of carbon stored in the Tectona grandis plantation (in Obubra located in Cross River State, Nigeria) by measuring its above-ground biomass (AGB). Eight temporary sample plots were set up in alternate directions, each measuring 25 m by 25 m, following a systematic line transect sampling method. A total of 225 trees were assessed. The study identified tree species with a diameter at breast height DBH ≥ 10 cm or larger in the sampling plots and measured their detailed growing stock, including outside bark diameters at various heights (base, middle, top), merchantable height, crown diameter, and total height. . The average number of tree stems, above-ground biomass (AGB), and carbon stock per hectare was 446, 829.05 kg, and 414.53 kg respectively.

Key words: Carbon content, Biomass, Tree volume,

Introduction: Forest ecosystems cover around 30% of the Earth's land area and have a crucial impact on the global carbon cycle and climate. Trees take in carbon dioxide and act as a significant carbon reservoir by storing carbon in the form of fixed biomass. Hence, evaluating tree carbon in forest ecosystems is crucial for understanding forest carbon storage capacity. Biomass assessment is instrumental in determining the carbon stock of a tree, and this can be achieved through both destructive and non-destructive methods. The estimation of forest biomass facilitates the evaluation of forest productivity, structural attributes, carbon sequestration potential, and carbon stock values across various tree species and forest stands (Bora *et al*., 2013). Various factors influence forest biomass and carbon stocks, including ecological variations, geographical features, climatic conditions, species composition, soil composition, sampling methods, and seasonal variations in forest structure and tree density (Rosenfield & Souza, 2013; Timilsina *et al*., 2014). Additionally, tree size, tree height, wood density, stand age, distribution frequencies, and generalized allometric models for biomass estimation impact forest biomass and carbon stocks (Rosenfield & Souza, 2013).

Materials And Method: **Study Area:** This study was carried out at Cross River State University of Technology, Cross Rivers State`s twenty-four-year-old **teaching** and research *Tectona grandis* plantation in Obubra Local Government Area, Cross River State (Figure 1). The plantation has an area of 205,000 m^2. Obubra is located between latitude 6° 05′ and 8° 20′ N and longitude 6° 08′ and 8° 33′ E. Sampling Procedure and Data Collection

Plots were laid using a systematic sampling design (systematic line transect), with two transects placed at 500 m intervals in the centre of *Tectona grandis* stands. A systematic sampling design was adopted due to its wide coverage and providing representative samples. Plots measuring 25 m x 25 m (0.0625 ha) were placed along each transect at 250 m intervals, resulting in four sample plots per transect and eight sample plots in total. The following measurements were made within each temporary sample plot:

i. outside bark stump diameter (D_{st} /cm) at 15 cm above the ground (since a survey of past exploitation shows that no tree is cut below this point) (Akindele, 2003),
ii. merchantable height (MHT/m) (which is the point between ground level and the point of the first surviving whorl of living branches),
iii. total tree height (THT/m),
iv. outside bark diameters, at the base, middle and top positions of the tree (cm).
v. outside bark diameter at breast height (Dbh/cm) (taken at 1.3m from the ground) of trees whose diameter is greater than or equal to 10 cm.
vi. The crown diameter, was measured by projecting the diameter of the crown with ranging poles on the ground in four different directions and taking the distance between the ranging poles using distance tape (Niva *et al.*, 2014).

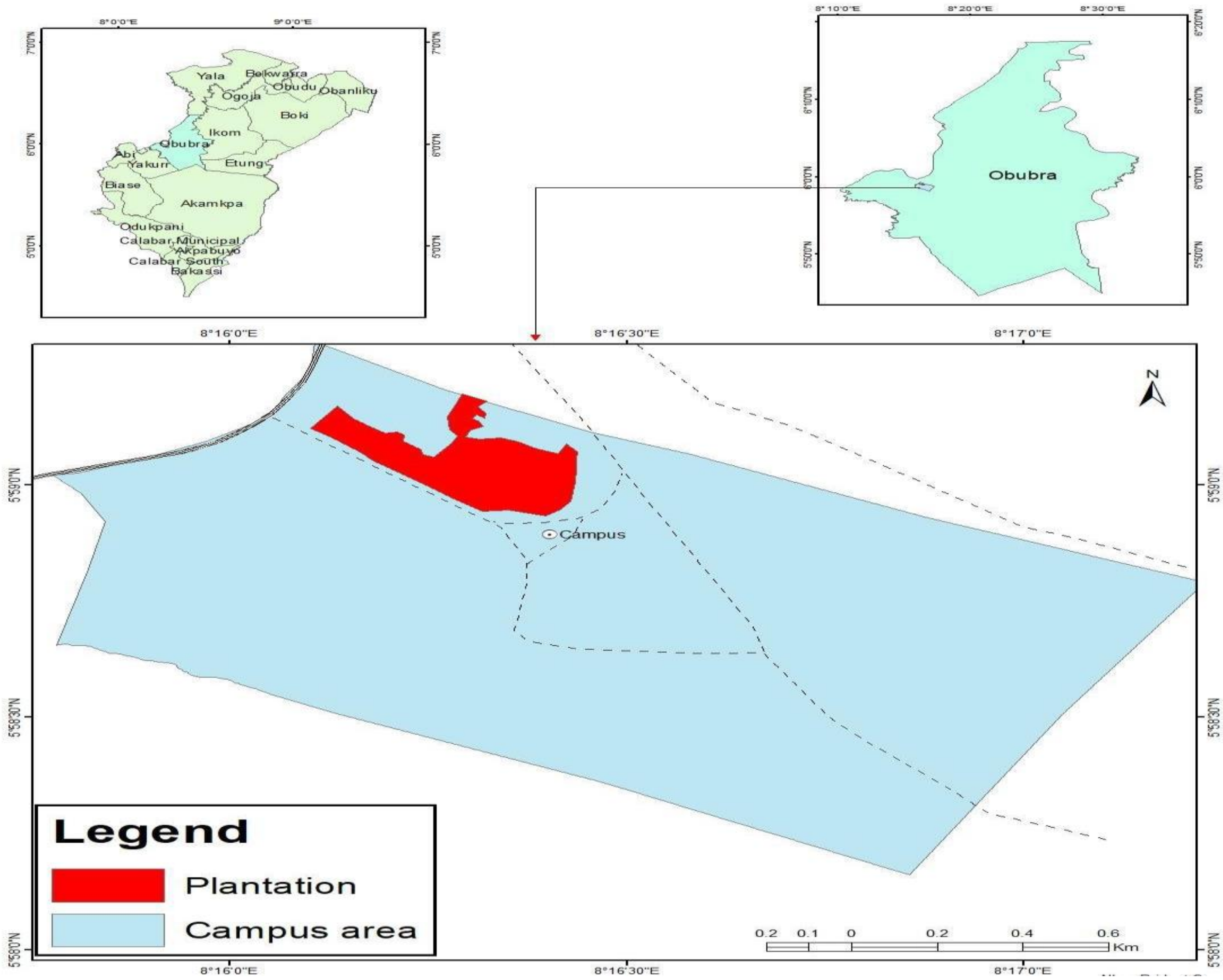

Figure 1: Map of the study area.

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xii. The crown diameter, was measured by projecting the diameter of the crown with ranging poles on the ground in four different directions and taking the distance between the ranging poles using distance tape (Niva *et al.*, 2014).

Data Analysis: Preliminary Data Analysis:

The preliminary analysis of the data involved the computation of individual tree volume and biomass from the raw data and their extrapolation to per-hectare estimates. The individual tree volumes were computed for the merchantable portion of the tree stem. The individual tree crown diameters were equally computed. The computation procedures included the following steps:

1. The volume of individual trees in each plot was computed using Newton's formula ($V = {}^{h}/_{6}(A_b + 4A_m + A_t)$) (Husch *et al*, 2003). Newton's formula was favoured because it is accurate, manages taper well, and has less bias—especially when predicting volumes of logs with unusual shapes.

Where: V = tree volume (m^3), h = tree height (m), Ab = Cross-sectional area at the base (m^2), Am = Cross-sectional area at the middle (m^2), At = Cross-sectional area at the top (m^2).

The volume of each tree within a plot was added to determine the total volume of that plot. The entire volume of each sample plot chosen from the plantation was then added up, and the result was divided by the total number of sample plots chosen from the plantation to determine the mean plot volume. The mean plot volume was then multiplied by the number of sample plots per hectare to determine the volume per hectare.

Biomass and Carbon Stock Estimation

The estimation of biomass was done using the non-destructive method. The estimation of tree biomass (Above Ground Biomass) was divided into two sections according to tree morphology:

- calculation of biomass for trunk or stem;
- calculation of biomass for canopy or crown.

- Above Ground Biomass (AGB) = Stem biomass + Crown Biomass

  Equation (2)
- Stem Biomass = Volume of Tree Stem x Wood Density

  Equation (3)

Wood density was obtained through core sampling. The core sample volume was determined using the displacement method and Oven-dry weight was determined by subjecting the sample to drying in a well-ventilated oven until a constant weight was achieved. This process typically requires a duration of 48 to 72 hours.

Results and Discussions: Results: Summary of Tree Growth Attribute: Summary of Tree/Stand Growth Parameters:A total of 223 individual trees were measured in the 8 sample plots from the *Tectona grandis* Plantation. The results indicated that the average number of trees per hectare in the study area was 446. (Table 1). The average above-ground biomass (AGB) is 829.05 with a standard error of 40.49. This indicates the typical amount of biomass in the above-ground portions of trees in the study. (Table 1). The average carbon stock is 414.53 kg with a standard error of 20.24. This represents the typical amount of carbon stored in the trees in the study. The smallest carbon stock observed is 55.70 kg, indicating trees with low carbon content. while the largest carbon stock observed is 1809.48 kg, indicating trees with high carbon content. Carbon stock quantifies the contribution of trees to carbon sequestration and is of significance in carbon offset and climate change mitigation studies.

Table 4.1. Summary of Tree Growth Attribute

Variables	Mean ± SE	Minimum	Maximum
DBH (cm)	21.96 ± 0.0052	13.50	47.50
THT (m)	21.02 ± 0.34	3.49	36.72
Volume (m^3)	1.37 ± 0.067	0.01	5.96
AGB (kg)	829.05± 40.49	111.40	3618.96
Carbon Stock (kg)	414.53± 20.24	55.70	1809.48

Source: Field Data, 2023

DBH = Diameter at Breast Height, THT = Total Tree Height, AGB = Above Ground Biomass, SE = Standard Error

Table 4.2 provides a summary of tree stand variables on a per-hectare basis. These variables represent the characteristics of a forest stand or plantation and are important for assessing the overall forest health and its ecological and environmental contributions. The average number of tree stems per hectare was 446. The smallest and largest number of stems observed per hectare was 336 and 592 respectively, indicating areas with lower and higher tree density. This variable quantifies tree density in the forest stand. The average tree volume per hectare is 609.15 m^3 (Table 2). The average tree volume per hectare was 609.15 m^3. The average above-ground biomass (AGB) per hectare was 369,755.88 kg. The range of above-ground biomass observed per hectare was 267,938.40 to 476,489.44 kg, indicating areas with lower and higher biomass respectively. AGB per hectare quantifies the total biomass production in the forest stand.

The average carbon stock per hectare was 184.88 tons. The smallest carbon stock observed per hectare was 133.92 tons, indicating areas with lower carbon storage. The largest carbon stock observed per hectare was 238.24 tons, indicating areas with higher carbon storage. Carbon stock per hectare quantifies the forest's contribution to carbon sequestration (Table 2). The average CO_2 sequestered per hectare was 678.50 tons. The minimum and maximum CO_2 sequestered per hectare were 491.52 and 874.24 tons respectively. These variables measures the forest's role in mitigating atmospheric CO_2 levels (Table 2).

Table 4.2: Summary of Tree Stand Variables on Per Hectare Basis

Variables	Mean	Standard Error	Minimum	Maximum
No. of Stem/ha	446	33	336	592
Volume/ha (m^3)	609.15	47.06	441.44	784.96
AGB/ha (kg)	369,755.88	28567.35	267938.40	476489.44
Carbon Stock/ha (tons)	184.88	14.29	133.92	238.24
CO_2 Sequestered/ha (tons)	678.50	52.42	491.52	874.24

Source: Field Data, 2023.

Tree Variables Distribution

The distribution pattern of the THT (Total Height of Tree) of trees in the plantation is negatively skewed (-0.2329) (Figure 3). A negative skewness value means that the distribution is skewed to the left (negatively skewed), with the tail on the left side longer or more pronounced than the right side. The distribution kurtosis is 0.2871, which is slightly positive. A high kurtosis indicates that the distribution has thicker tails and a sharper peak in the centre than a standard distribution.

The distribution pattern of the DBH of trees in the plantation is positively skewed (0.242644) (Figure 4). This means that the tail on the right side of the distribution (the larger DBH values) is longer or fatter compared to the left tail. Skewness measures the asymmetry of a probability distribution. The distribution kurtosis is -0.62744, which is negative. Kurtosis measures the "tailedness" of a probability distribution. A negative kurtosis, as in your case, indicates that the distribution has thinner tails and is less peaked than a normal distribution.

The result of the volume distribution pattern (Figure 5) shows a positive skewed pattern. A positive skewness value of 1.4302 indicates that the volume distribution is skewed to the right, meaning it is skewed to the right. This suggests that there may be more Teak trees with lower volumes and a relatively small number of trees with very high volumes on the plantation. The correlation coefficients between the various individual tree growth variables (Table 3) show positive and strong linear relationships between different growth variables and weak ones between other growth variables.

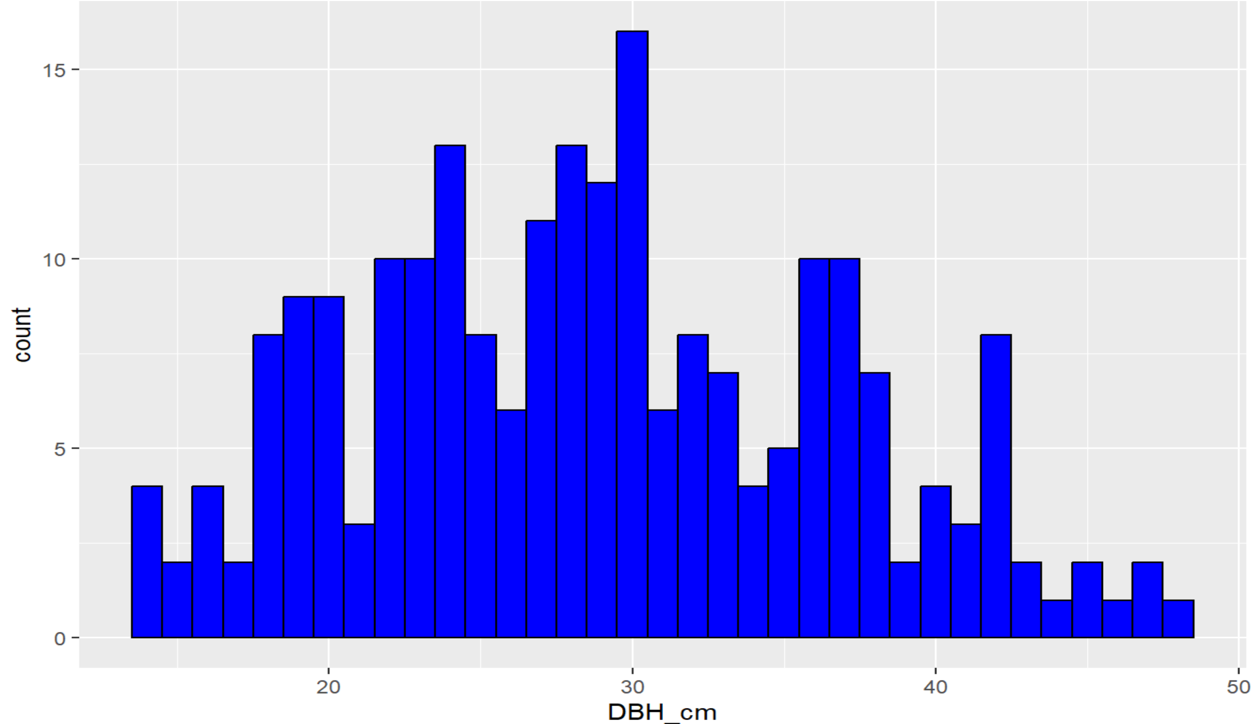

Figure 3: DBH Distribution Pattern of *Tectona grandis* Plantation

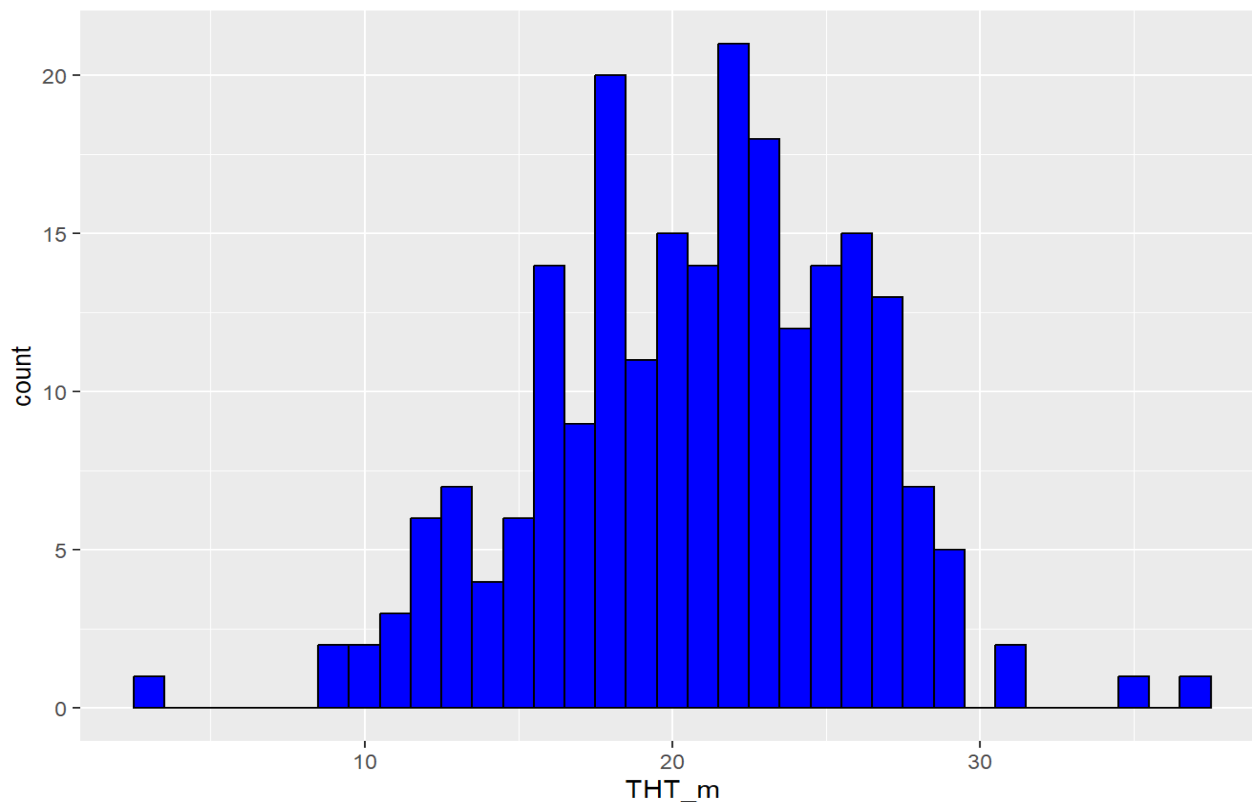

Figure 4: THT Distribution Pattern of *Tectona grandis* Plantation

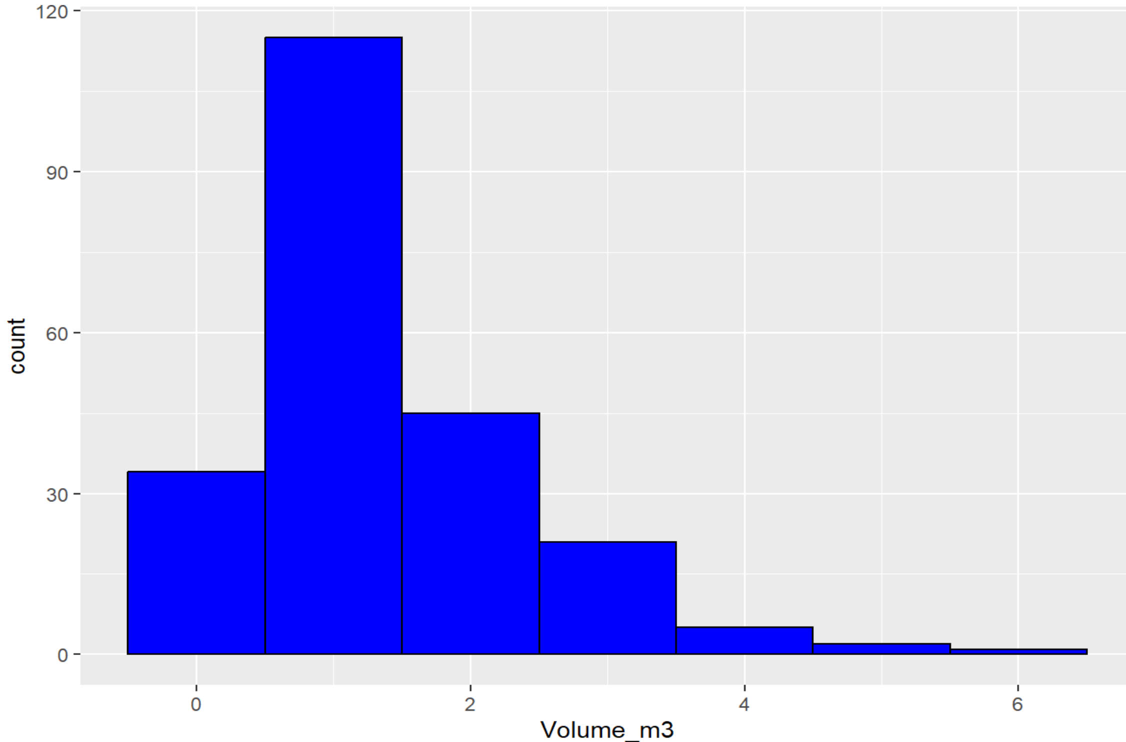

Figure 5: Volume Distribution Pattern of *Tectona grandis* Plantation

Discussion; Summary of Tree Growth Attribute:; Measuring teak biomass and carbon stock involves obtaining tree growth attributes such as DBH, tree height, and tree volume. The range of volumes for the study area, from 1.37 to 5.96 m3, differs from the findings of Ojo *et al.,* (2020) for the *Tectona grandis* plantation at the Federal College of Forestry, Ibadan, which reported volumes ranging from 4.81m3 to 8.79m3. The amount of trees observed indicated an average of 446 trees per hectare in the study area (Table 1). This value shows how many trees are present in the stand. A higher number of tree trunks indicates a more crowded forest, which can impact the amount of light and tree competition. This influences biodiversity, wildlife habitat, and timber production.

The average number of trees per hectare in the study area is the reason for the higher tree density in the plantation, which is greater than the 100 to 300 tree species per hectare reported in rainforests by Onyekwelu *et al.*, (2008). Nwoboshi (1982) reported that in extremely lush rainforests, the density of tree species per hectare could reach up to 400. The study area plantation stocking is higher than 297/ha reported for *Nauclea diderrichii* stand in Akure Forest Reserve by Fuwape *et al*, (2008) but lower than 632/ha reported for *Gmelina arborea* stand in Akure Forest Reserve by Fuwape *et al*, (2021); 997/ha and 1540/ha for *Tectona grandis* in Puerto Libertador and Toluvejo site respectively in commercial plantation of Colombia by Usuga *et al.*, (2010).

The stand parameters as shown in Table 2 are estimated on a per hectare basis. The mean volume per hectare, which is 609.15 m^3, is central for understanding the potential biomass estimates, timber yield and forest productivity. A higher volume indicates a greater potential for biomass production, which can have economic implications for alleviating poverty. The mean volume of the study area is high when compared with the result of the study carried out by Fuwape *et al.*, (2021), that the average volume per hectare of *Nauclea diderrichii* stand was 265.18 m^3 *in* Akure Forest Reserve and lower than 721.40 m^3 as reported by Fuwape *et al*., 2021 for *Gmelina arborea* in Akure Forest Reserve. The above-ground biomass (AGB) is a product of volume and wood density. The average above-ground biomass per hectare is 369.75 kg/ha as shown in Table 2. AGB is an important measure for assessing carbon storage and overall ecosystem health in forests. It has implications for carbon sequestration, biodiversity, and long-term forest management. The 369.75 kg/ha AGB value of Tectona grandis in the research region differed from other studies in Thailand

(Hiratsuka *et al*. (2005), Meunpong *et al*. (2010); Yoneda *et al*., (2017); Ojo *et al*., 2020). The difference in data between now and previous studies could be due to variations in age, tree size, stand density, and site quality.

The carbon stock in the current study utilizes 50% of the tree biomass which gives 184.88 tons/ha on average. Carbon is predicted to account for almost half of the living biomass contained in aboveground and belowground plant components (Malhi *et al*., 2009). According to Hiratsuka *et al*. (2005), a conversion factor of 0.50 was employed in various research to estimate carbon stock in biomass for teak trees since the carbon content ranged from 45% to 52% of the biomass in teak (Kraenzel *et al*. 2003; Jha 2005; Muenpong *et al*. 2010). Above-ground carbon stock in the current study ranged from 133.92 to 238.24 tons/ha (Table 2). This is in contrast with the study of Yonenda *et al*, (2017), who reported 1.3 to 67.7 Mg/ ha. The stand-level carbon stock in the current study also disagrees with the value in Teak stand, Thailand (Hiratsuka *et al*. 2005; Meunpong *et al*. 2010) and in mangrove stand, Karawang Regency, West Java (Trissanti *et al*, 2022). The biomass and carbon content of *Tectona grandis* plantations increases with plant age and the quality of the plantation's growth location. This is related to increasing plant age as a result of larger plants and better growth spaces, which give a superior nutritional element (Chanan and Iriany, 2014). The average diameter of the tall trees at the site of study has an impact on large carbon stock (Trissanti *et al*, 2022). According to Wahyudi *et al*. (2018) and Azzahra *et al.* (2020), a stand with bigger trees suggests that the biomass in the stand is substantial, and hence the carbon store is considerable.

Rahma (2011) reported that the growth in tree density and diameter contributes significantly to determining the amount of biomass and carbon sequestration. Moreover, any element causing a reduction in biomass potential will also affect the carbon sequestration process because they are closely linked. The amount of CO_2 sequestered in the current study ranges from 491.52 to 874.24 tons/ha. This variable represents the forest's capacity to remove carbon dioxide from the atmosphere, offering significant climate benefits. Carbon sequestration, also known as carbon fixation, is the semi-permanent uptake of CO_2 by plants during photosynthesis from the atmosphere into the interior of organic components (Hairiah *et al*., 2000). Sequestration of carbon refers to the increase in carbon storage that forests contain in the context of forestry expansion (Murdiyarso and Herawati, 2005).

Conclusion: Each tree's volume was determined using Newton's formula, and the results were extrapolated to per-hectare estimations. The average carbon stock, average number of tree stems per hectare, and above-ground biomass (AGB) were determined to be 446, 829.05, and 414.53 kg, respectively. Allometric regression methods were used to predict biomass. Model evaluation criteria (high R^2 adj., low SEE, high significant F-ratio, low AIC, AICc and BIC), were used to adjudge the most suitable model to estimate the biomass and carbon stock of the *Tectona grandis* plantation. The best-adjudged model was the logarithmic model [lnAGB = 6.04 + 0.97[ln (DBH^2THT)]. This study evaluated the above-ground biomass (AGB) and carbon stock (CS) contained in the *Tectona grandis* plantation in Obubra, Cross River state, Nigeria. Understanding possible biomass estimates, timber yield, and forest productivity all depend on the mean volume per hectare, which was 609.15 m^3. A larger volume suggests a higher possibility for biomass production, which may have financial ramifications for reducing poverty. The study assessed 829.05 kg of AGB and 414.53 kg of CS per hectare.

Recommendation: It is critical to implement a sound management method for proper plantation supervision and monitoring in order to reverse the deterioration in Obubra's tree estate Cross River State University of Technology. These strategies will be used to promote effective forest management by preventing encroachment, deforestation, and forest degradation

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