



Above-Ground Carbon Estimation of *Khaya Senegalensis*, *Tectona Grandis* and *Gmelina Arborea* in Nasarawa State University Forestry Plantations, Lafia

Clement, S. A., Egbewole, Z. T. and Ibrahim, A. A.
Faculty of Agriculture, Nasarawa State University, Keffi
*Corresponding authors' email: clementsegun2016@gmail.com

Clement, S. A., Egbewole, Z. T. and Ibrahim, A. A. (2021). Above-Ground Carbon Estimation Of *Khaya Senegalensis*, *Tectona Grandis* And *Gmelina Arborea* In Nasarawa State University Forestry Plantations, Lafia. *Nigerian Journal of Forestry* 51 (1):1 -10.

Abstract

Carbon dioxide is the primary greenhouse gas emitted by human activities, caused global warming and subsequently climate change. This study therefore assessed aboveground biomass and carbon stock of eight (8) year old stands of *Khaya senegalensis*, *Tectona grandis* and *Gmelina arborea* in Nasarawa State University Forestry Plantations, Lafia. The study also developed height-diameter models, for the management of these three tree species. Data were collected from ten (30) temporary sample plots of 0.01 ha size randomly located in each of the stands of the three tree species. The statistical selection indices for the height diameter models revealed that model two (2) with AIC (26.83489), BIC (31.03848) and RSE (0.3544) of *Khaya Senegalensis*, model one (1) with AIC (71.06), BIC (75.27) and RSE (0.74) of *Tectona grandis* and model five (5) with AIC (-212.0001), BIC (-206.3953) and RSE (0.00652) of *Gmelina arborea* were the best and grand models for predicting tree heights of the three forest plantations in the study area. The results also showed that *Gmelina arborea* has the highest biomass of 2501.8054145kg/ha, Carbon Stored of 1250.9027072kg/ha, CO₂ of 4590.8129357kg/ha when compared to *Khaya senegalensis* biomass of 1436.0432204kg/ha, Carbon Stored of 718.0216102kg/ha, CO₂ of 2635.1393092kg/ha and *Tectona grandis* biomass of 1514.7782607kg/ha, Carbon Stored of 757.3891304kg/ha, CO₂ of 2779.6181083kg/ha. Therefore, *Gmelina arborea* has the highest potential to capture and store Carbon (C) in form of wood, provide substantial oxygen to sustain living organisms, balance the earth ecosystem to avert severe global warming and climate change among the three tree species in the study area.

Key words: Height Diameter model, CO₂, Aboveground Biomass, Carbon stock, Climate Change.

INTRODUCTION

Carbon dioxide is the primary greenhouse gas emitted by human activities, caused global warming and subsequently climate change. Anthropogenic emissions of CO₂ originate primarily from the burning of fossil fuels and deforestation in tropical regions. CO₂ concentration in the atmosphere has increased by 31% since the beginning of the industrial era, from 280 to 360 ppm (IPCC, 2001). Therefore, it is necessary to keep temperature rise below 1.5°C within this century in order to reach net-zero emissions by 2050 (IEA, 2020). It would be abysmal not to use the forestry potential to mitigate climate change, since it is not a linear phenomenon, and there undoubtedly exist critical threshold levels beyond which the climate system would change unpredictably and timing of reduction measures counts (Pederson, 2000).

Trees are without a doubt the best carbon capture technology in the world. When it performs

photosynthesis, it pulls carbon dioxide out of the air, bind it up in sugar, and release oxygen. Trees use sugar to build wood, branches, and roots. Wood is an incredible carbon sink because it is made entirely of carbon; it lasts for years as a standing tree, and takes years to break down after the tree dies. While trees mainly store carbon, they do release some carbon, such as when their leaves decompose, or their roots burn sugar to capture nutrients and water. Trees survive by performing a process called photosynthesis, in which the tree actually consumes or store Carbon dioxide (CO₂). Being absorbed by trees is just one way that carbon moves through forests as part of the carbon cycle. This cycle is the process by which carbon travels from the atmosphere into the Earth and its organisms, and then travels back into the atmosphere (Luyssaert *et al.*, 2017).

Carbon sequestration is the process by which carbon dioxide is captured from the atmosphere by trees for long-term storage and in its lifetime. The amount of

carbon stored in forests is important because a net change in forest biomass can indicate whether forest ecosystems are stable, growing, or declining. Carbon storage is closely related to other vital ecological processes such as primary productivity (U.S. EPA, 2018).

Forests capture and store different amounts of carbon at different speeds depending on the average age and the number of trees in the stand. Young forests have many trees and are excellent at capturing carbon. Young trees grow quickly and are able pull in carbon rapidly. Not every small sapling becomes a large tree due to competition for light, resources, and growing space, but when it dies and decompose little carbon is released. The trees that remain continue to grow and sequester more carbon as the forest matures. The extent to which populations will respond to climate change is thought to depend upon variation in geographic distribution, phenotypic variation, response to CO₂ fertilization, strength of selection, fecundity, and degree of biotic interactions (Franklin *et al.*, 2016).

Mature forests are made up of middle-aged trees, which are medium to large, healthy, and have a large root system. Middle-aged trees grow slower than young trees, but the amount of carbon captured and stored is relatively greater. Some of large trees occasionally die, but they are quickly replaced by younger trees who take advantage of the new space. Since more trees are growing compared to those that are dying, the overall net productivity is positive and carbon capture is enhanced. Forest growth has a more fixed, less dynamic carbon cycle within live and dead trees and the soil. In old growth forests, large trees dominate by shading out small saplings, so recruitment of young trees and net productivity is zero (Franklin, 2010).

Trees species are uniquely pertinent to human and other organisms' survival within the earth ecosystem. It has economic importance of providing timber for furniture, roofing, constructions and social value of providing sanctuary, aesthetics, microclimate, carbon sequestration, among others (Olufunke, 2015). Therefore, three tree species: *Khaya senegalensis*, *Tectona grandis* and *Gmelina arborea* are being investigated for their capability to convert life threatening carbon from the atmosphere to form timber for economic purposes.

Tectona grandis is an important species for its durable wood products (Chayaporn *et al.*, 2020). Also, many countries in the tropics raised it to restore their deforested lands (Kimambo and Michael, 2014).

Gmelina arborea is also known as a medicinal plant and all parts like stem, leaves, fruits, roots and flowers are used for medicinal purpose since ancient times in India (Veeranjaneyulu, 2006). This tree species is found throughout larger part of India at the range of altitude up to 1,500 meters and also occurs in Asia, Bangladesh, Pakistan, Myanmar, Sri Lanka, Thailand, Cambodia and Vietnam.

Khaya senegalensis is an important multipurpose tree in its natural range in sub-Saharan Africa. It is particularly valued for timber and medicinal purposes as well as being a popular shade and amenity tree (CAB International 2000). In its natural habitat it is a medium-sized to large tree (up to 30 m) with a wide crown. In cultivation as an exotic, it can grow up to more than 35m high and up to 1½ m in diameter (Jøker and Gaméné, 2003).

Over the years, the average carbon and other heavy gases in the atmosphere kept on soaring high at an alarming rate thereby trapping more energy than required to warm the earth leading to global warming and ultimately climate change. The consequences of climate change are floods, drought, diseases, food scarcity, unpredictable seasons and others. The major causes of this rate of increase are fossil fuel and bush burning. Green plants, particularly, trees serve as a major store of these gases and the rate of carbon sink differs among species due to tree features. Therefore, examining the carbon storage capacity of *Tectona grandis*, *Gmelina arborea* and *Khaya senegalensis* would lead to mitigating the effects of climate change.

Therefore, the main objective of this study is to estimate carbon sequestration potential of *Tectona grandis*, *Gmelina arborea* and *Khaya senegalensis* stands in Nasarawa state university plantations as a way of mitigating climate change. The study also developed height-diameter models for the three tree species. The research is apt as it focuses on tree biomass and carbon estimation, serve as mechanisms to estimate CO₂ greenhouse gas sequester by the three tree species. It will also provide information on the growth attributes of the plantations for their management, decision making and sustainability.

Methodology

Study Area

This study was carried out at Department of Forestry, Faculty of Agriculture, Shabu-Lafia Campus, Nasarawa State University's *Tectona gradis*, *Gmelina arborea* and

Khaya senegalensis Plantations, established eight (8) years ago. The plantations are located between longitude 8° 34'N and latitude 8° 32'E, in guinea savannah zone of North Central Nigeria at an altitude of about 175m above the sea level. The mean maximum and minimum temperature range between 35.06°C to 36.40°C and 20.16°C to 20.25°C respectively while the mean monthly

relative Humidity and rainfalls are 74.67% and 168.90mm respectively. Tropical ferruginous soils make up the major soil units found in Lafia Local Government Area. The parent material for the soils are from basement complex and sedimentary formations in the area (Lyam, 2000).

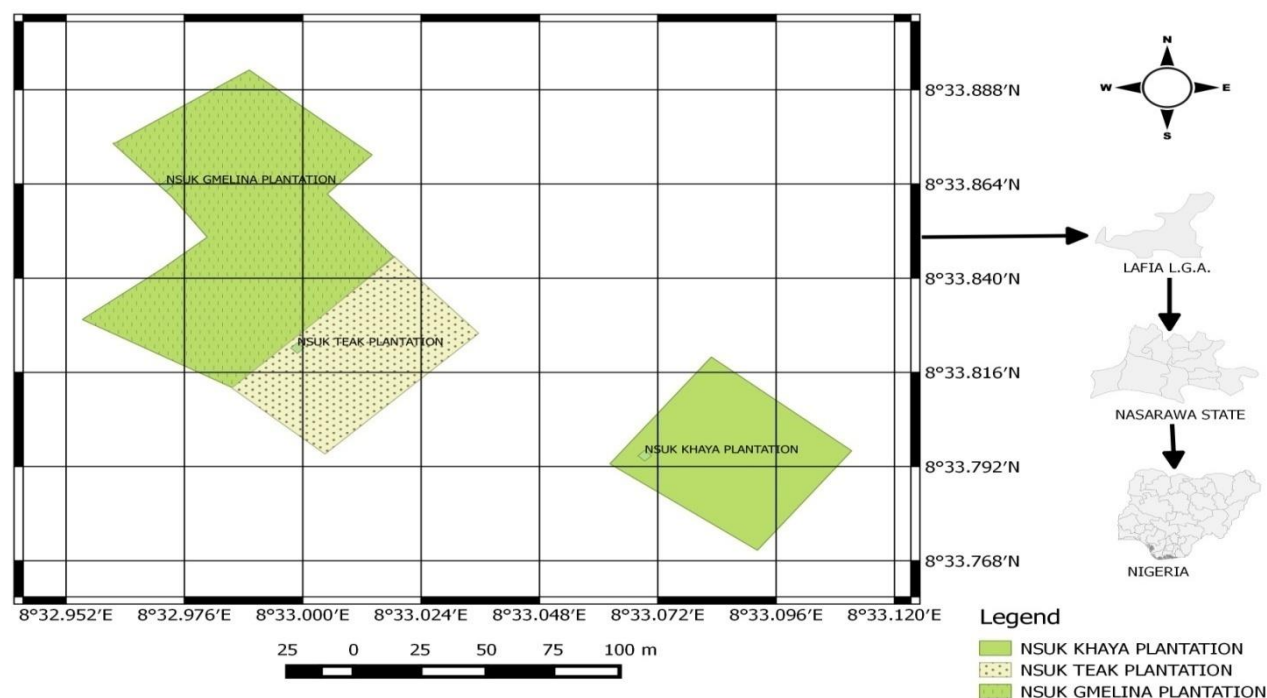


Fig. 1: Map of the *Tectona grandis*, *Gmelina arborea* and *Khaya senegalensis* Plantations.

Data collection

Thirty (30) temporary sample plots of 0.01 ha size were randomly selected from the sampling frame in each of the three plantations with 30% sampling intensity. Tree total heights and diameter at breast height (DBH) of individual trees within each plot were measured. Also, coordinates of the study area were collected. Instruments and materials that were used during this research include; Haga altimeter, diameter tape, ground survey tape, ranging pole, lines, marker and tags.

Tree Height-diameter Models for the three tree species

$$\text{MODEL 1} = bh + \frac{Dbh^2}{(a+bDbh)^2} + \varepsilon \quad (\text{Mehtatalo et al., 2015}) \quad \text{Equation [3]}$$

$$\text{MODEL 2} = bh + \frac{a}{1+be^{-Dbh}} + \varepsilon \quad (\text{Ogana, 2018}) \quad \text{Equation [4]}$$

$$\text{MODEL 3} = bh + ae^c - be^{(-Dbh)} + \varepsilon \quad (\text{Mehtatalo, et al., 2015}) \quad \text{Equation [5]}$$

$$\text{MODEL 4} = bh + \frac{aDbh}{(b+Dbh)} + \varepsilon \quad (\text{Haung, et al., 1992}) \quad \text{Equation [6]}$$

$$\text{MODEL 5} = bh + a\left(\frac{Dbh}{1+Dbh}\right)^b \quad (\text{Haung et al., 1992}) \quad \text{Equation [7]}$$

Criteria for Model Selection (Model Assessment Criteria)

Akaike information criterion (AIC)

$$\text{AIC} = 2k - 2\ln(\hat{L})$$

Where:

k = Number of estimated parameters in the model and $\hat{L}$ = maximum value of the likelihood function for the model

Bayesian Information Criterion (BIC)

$$-2 \times \log - \text{likelihood} + n \times \log(\text{nobs}),$$

Where,

Npar = represents the number of parameters and Nobs = the number of observations in the fitted model (Stricevic, 2015).

The Residual Square Error (RSE)

$$RSS = \sum_{i=1}^n (y^i - f(x_i))^2$$

Where:

y^i = The i^{th} value of the variable predicted, $f(x_i)$ = Predicted value of y^i and n = Upper limit of summation (Tohyama, 2020).

Method of Bole Carbon Stock Estimation

The procedure for bole carbon stock estimation involves the determination of the total green weight of trees, the dry weight of the tree, the weight of carbon in the tree and the weight of carbon dioxide sequestered in the tree (Jayakumar, 2012).

Determination of the total green weight of trees

The green weight is the weight of a tree stand. Therefore, the green weight of the above-ground weight was calculated as follows:

$$W_{\text{above-ground}} = 0.15 D^2 H \text{ (for trees with } D \geq 11)$$

$$W_{\text{above-ground}} = \text{Above-ground weight in kilograms}$$

D = Diameter at breast height in cm, H = Height of the tree in meter (Brain, 2004).

Determination of the dry weight of the tree

The average tree is 72.5% dry matter and 27.5% moisture. Therefore, to determine the dry weight of the tree, multiply the total green weight of the tree by 72.5%.

$$W_{\text{dry weight}} = 0.725 * W_{\text{total green weight}} \text{ (Potadar, 2016)}$$

Determination of the weight of carbon in the tree

The average carbon content is generally 50% of the tree's dry weight total volume. Therefore, in determining the weight of carbon in the tree, multiply the dry weight of the tree by 50%.

$$W_{\text{carbon}} = 0.5 * W_{\text{dry weight}} \text{ (Ostertag, 2000)}$$

Determination of the weight of carbon dioxide sequestered by the tree

CO_2 has one molecule of Carbon and 2 molecules of Oxygen. The atomic weight of Carbon is 12 (u) and the atomic weight of Oxygen is 16 (u). The weight of CO_2 in trees is determined by the ratio of CO_2 to C is $44/12 = 3.67$. Therefore, to determine the weight of carbon dioxide sequestered in the tree, multiply the weight of carbon in the tree by 3.67.

$$W_{\text{carbon-dioxide}} = 3.67 * W_{\text{carbon}} \text{ (Brain, 2004)}$$

Results

The results of table 1 showed height-diameter (H-D) models' parameters and model selection indices of *Tectona grandis* from the forest Teak plantation. Based on the model selection indices, model one (1) has the lowest AIC (71.06), BIC (75.27) and RSE (0.74), followed by model (4) with AIC (74.97), BIC (79.17) and RSE (0.79), model five (5) with AIC (79.76), BIC (83.96) and RSE (0.86), model two (2) with AIC (90.16), BIC (94.36269) and RSE (1.018) while model three (3) had the highest values of AIC (98.20), BIC (102.41) and RSE (1.16) respectively. All the models were tested and revealed to be highly significant, with model coefficients (parameters).

Table 1: Height Diameter Model Indices for *Tectona grandis* Plantation

Models	Coefficients	AIC	BIC	RSE	Pr(> t)
[1]	a = 0.076759 b = 0.942019	71.06201	75.26561	0.7408	<2e-16 *** <2e-16 ***
[2]	a = 2.642e+02 b = 3.166e-02	90.15909	94.36269	1.018	<1.07e-11 *** < 2e-16 ***
[3]	a = 4.546e+03 b = 7.975e-02	98.20323	102.4068	1.164	<6.51e-10 *** < 2e-16 ***
[4]	a = 0.0236818 b = 3.0453604	74.96767	79.17126	0.7906	< 2e-16 *** <4.94e-16 ***
[5]	a = 0.0046379 b = 8.3673327	79.76132	83.96491	0.8563	< 2e-16 *** <1.58e-14 ***

Where: AIC=Akaike information criterion; BIC=Bayesian information criterion; RSE=Root Mean Square Error; Pr= p-value; ***=significant at 0.001; a and b = model parameters.

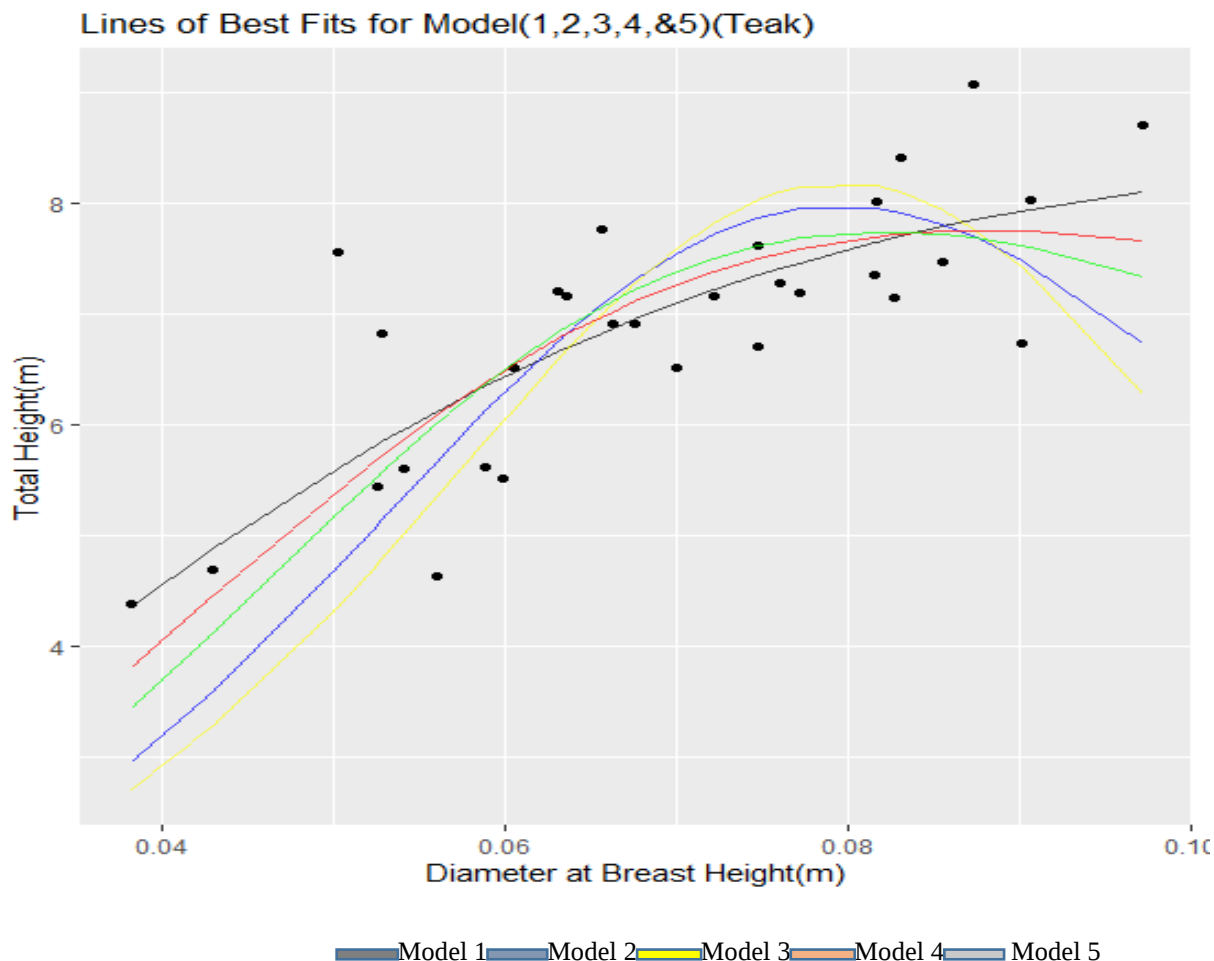


Figure 2: Lines of Best Fits for H-D Models (1-5) under Teak Plantations

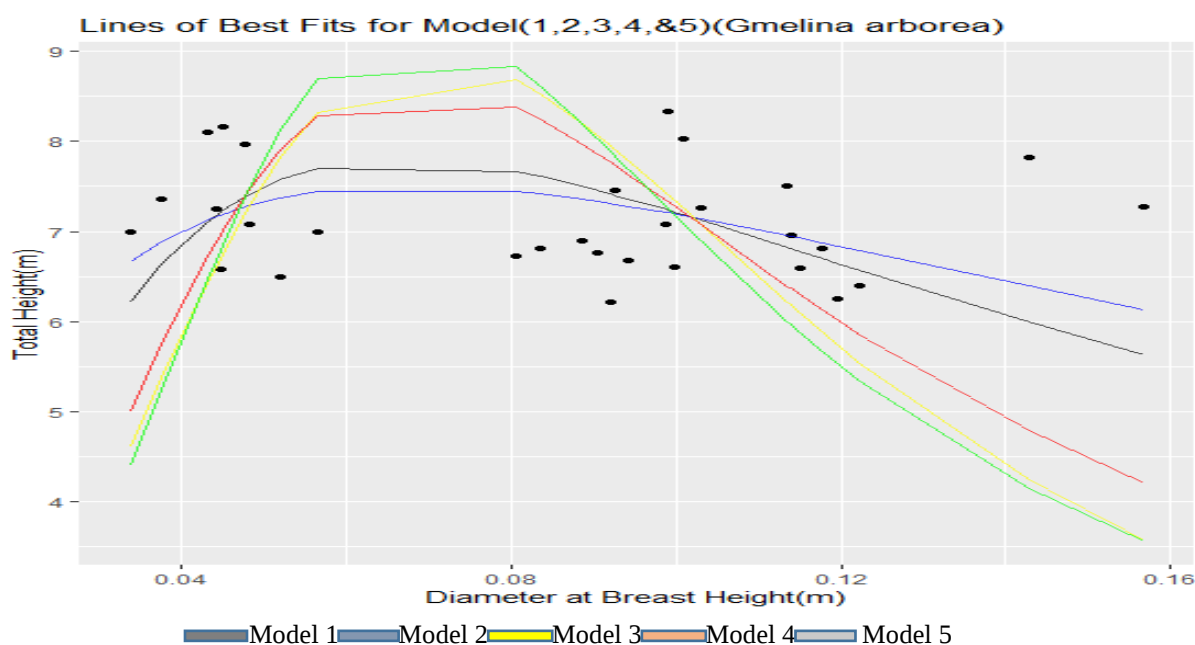
The result of figure 2 showed that the total height of trees was plotted against diameter at breast height. Also, five models were used to estimate the line of best fit for the *Tectona grandis* stand. Model 1 indicated increasing trend and has many data points on and around the line of best fit and so it is better than other four (4) regression models. In table 2, the result showed the height-diameter (H-D) model indices for *Gmelina arborea* in the study area. The results indicate that model five (5) has the lowest model selection indices of AIC (-212.0001),

BIC (-206.3953) and RSE (0.00652) when compared with model two (2) of AIC (67.63595), BIC (71.83954) and RSE (0.82), model one (1) of AIC (77.16133), BIC(81.36492) and RSE(0.82), model three (3) of AIC(115.0268), BIC (119.2304) and RSE(1.541) and model four (4) of AIC(118.0046), BIC(122.2082) and RSE (1.62). All the models were found to be highly significant except model five (5) with slope moderately significant while the intercept was not significant.

Table 2: Height-Diameter Model Selection Indices of *Gmelina arborea*

Models	Coefficients	AIC	BIC	RSE	Pr(> t)
[1]	a 0.054073 b 1.220109	77.16133	81.36492	0.82	<2e-16 *** <2e-16 ***
[2]	a 1.092223 b 0.147777	67.63595	71.83954	0.6996	<2e-16 *** <2e-16 ***
[3]	a 6.46796 b 0.05156	115.0268	119.2304	1.541	<2e-16 *** <2e-16 ***
[4]	a 0.0031528 b 9.9053247	118.0046	122.2082	1.62	< 2e-16 *** 1.74e-14 ***
[5]	a -0.279711 b 0.177420	-212.0001	-206.3953	0.00652	0.45551 0.00129 **

Where: AIC=Akaike information criterion; BIC=Bayesian information criterion; RSE=Root Mean Square Error; Pr= p-value; ***=significant at 0.001; a, and b= model parameters.

**Figure 3: Lines of Best Fits for H-D Models (1-5) for *Gmelina arborea* Plantations**

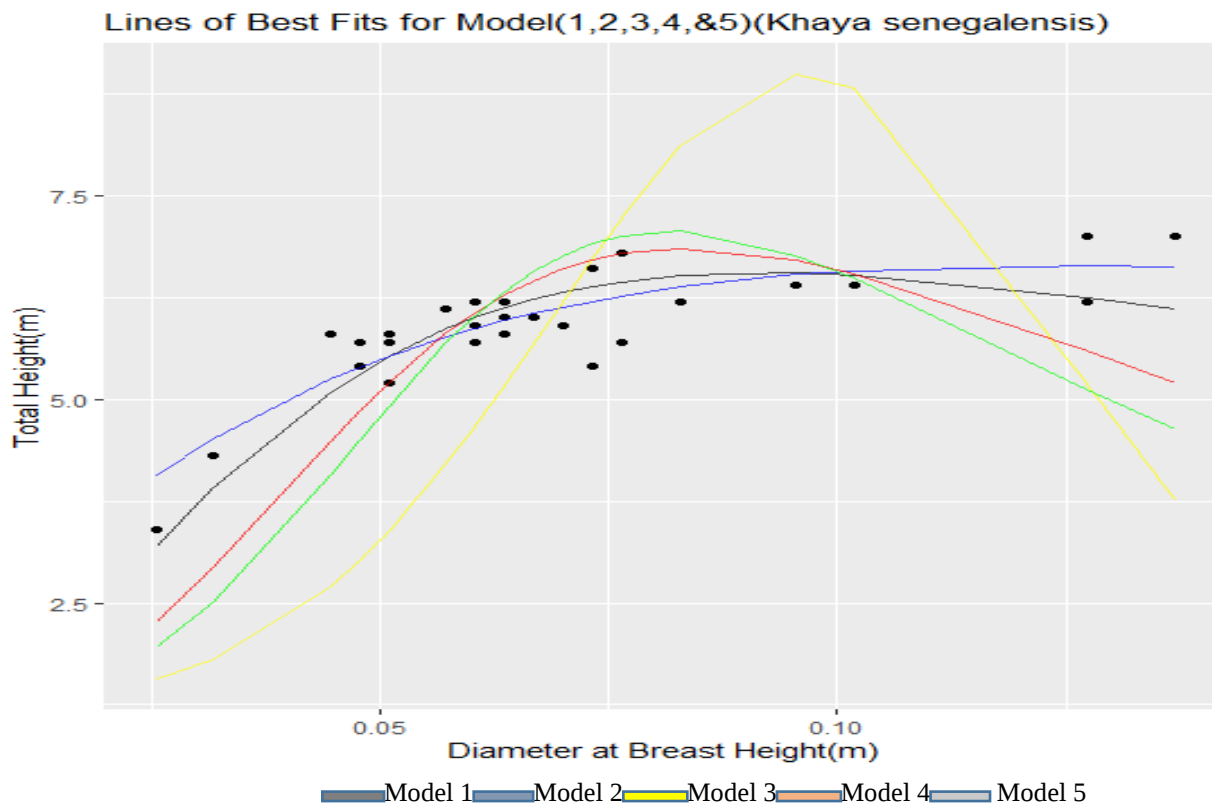
The result of figure 3 showed that the total height of trees was plotted against diameter at breast height. Also, five models were used to estimate the line of best fit for *Gmelina arborea* Plantation. Model five (5) indicated an increasing trend and the line of best fit passes through the center of the data. This revealed that it is better than the other four (4) regression models. The result of table 3, showed the height-diameter (H-D) model indices for *Khaya senegalensis* stand in the study area. The result

indicates that model two (2) has the lowest model selection indices of AIC (26.83, BIC (31.04) and RSE (0.35) when compared with model one (1) of AIC (36.94), BIC (41.14) and RSE (0.42), model four (4) of AIC (75.07), BIC(79.27) and RSE(0.79), model five (5) of AIC (91.83), BIC (96.03) and RSE (1.05) and model three (3) of AIC (128.11), BIC(132.32) and RSE (1.92). All the models were found to be highly significant.

Table 3: H-D Model Selection Indices for *Khaya Senegalensis*

Models	Coefficients	AIC	BIC	RSE	Pr(> t)
[1]	a =0.06883 b =1.11575	36.93772	41.14131	0.4194	<2e-16 *** <2e-16 ***
[2]	a =0.765956 b=0.190202	26.83489	31.03848	0.3544	< 2e-16 *** <5.74e-16***
[3]	a=1.995e+03 b=8.969e-02	128.1134	132.317	1.917	< 2e-16 *** <3.17e-06***
[4]	a=0.0235841 b=3.3800026	75.07035	79.27394	0.7919	<2e-16 *** <2e-16 ***
[5]	a=8.9043473 b=0.0048703	91.82886	96.03245	1.047	<4.59e-13*** < 2e-16 ***

Where: AIC=Akaike information criterion; BIC=Bayesian information criterion; RSE=Root Mean Square Error; ACT= Achieved convergence tolerance; Pr= p-value; ***=significant at 0.001; a, and b= model parameters.

Figure 4: Lines of Best Fits for H-D Models (1-5) for *Khaya senegalensis* Plantations

The result of figure 4 showed that the total height of the trees was plotted against diameter at breast height. Also, five models were used to estimate the line of best fit for the *Khaya senegalensis* Plantation. Model two (2) indicated increasing trend and has many data points on and around the line of best fit better than other four (4) regression models. The result of table 4 shows the

highest mean biomass (2501.8054145 kg/ha), carbon stock (1250.9027072 kg/ha) and carbon dioxide (4590.8129357 kg/ha) in *Gmelina arborea* when compared to *Tectona grandis* biomass (1514.7782607 kg/ha), carbon (757.3891304 kg/ha) and CO₂ (2779.6181083 kg/ha) and *Khaya senegalensis* biomass (1436.0432204 kg/ha), carbon (718.0216102 kg/ha) and

CO₂ (2635.1393092 kg/ha) from forest plantations in the study area. The result of table 5 showed the biomass, carbon stock and carbon dioxide of the three tree species were examined for significant difference. The result

shows that there was a significant difference between the tree species in terms of tree biomass (0.00435 **), carbon (0.00435 **) and carbon dioxide (0.00435 **) at 0.05 probability level.

Table 4: Estimation of Biomass (kg/ha), Carbon Stock (kg/ha) and CO₂ (kg/ha)

T. Species	Biomass (kg/ha)	Carbon (kg/ha)	CO ₂ (kg/ha)
Gmelina	2501.8054145	1250.9027072	4590.8129357
Teak	1514.7782607	757.3891304	2779.6181083
Khaya	1436.0432204	718.0216102	2635.1393092

Table 5: Analysis of Variance on Biomass, Carbon and Carbon dioxide

BIOMASS						
Source of variation	of	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Biomass		2	2116	1058.1	5.792	0.00435 **
Residuals		87	15893	182.7		
CARBON						
Source of variation	of	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Carbon		2	529	264.53	5.792	0.00435 **
Residual		87	3973	45.67		
CARBON DIOXIDE						
Source of variation	of	Df	Sum Sq	Mean Sq	F value	Pr(>F)
CO2		2	7126	3563	5.792	0.00435 **
Residuals		87	53515	615		

The result of table 6 showed the least significant difference of the three tree species for mean biomass, carbon and carbon dioxide was compared in order to ascertain the tree species that contribute more to tree biomass, carbon and carbon dioxide. The result shows that in tree biomass, there was a significant difference between the mean value of *Gmelina arborea* (25.01805^a) when compared to *Tectona grandis* (15.14778) and *Khaya senegalensis* (14.36043) but no significant difference between *Tectona grandis* (15.14778) and *Khaya senegalensis* (14.36043). In carbon stock, there was a significant difference between

the mean value of *Gmelina arborea* (12.509027^a) when compared to *Tectona grandis* (7.573891^b) and *Khaya senegalensis* (7.180216^b) but no significant difference between *Tectona grandis* (7.573891^b) and *Khaya senegalensis* (7.180216^b). In carbon dioxide (CO₂), there was a significant difference between the mean value of *Gmelina arborea* (45.90813^a) when compared to *Tectona grandis* (27.79618^b) and *Khaya senegalensis* (26.35139^b) but no significant difference between *Tectona grandis* (27.79618^b) and *Khaya senegalensis* (26.35139^b).

Table 6: LSD Statistics of Comparison of Biomass, Carbon and CO₂

Tree Species	Biomass (kg)	Carbon(kg)	CO ₂ (kg)
Gmelina	25.01805 ^a	12.509027 ^a	45.90813 ^a
Teak	15.14778 ^b	7.573891 ^b	27.79618 ^b
Khaya	14.36043 ^b	7.180216 ^b	26.35139 ^b

Discussion

Nonlinear height diameter (H-D) models were applied on the three tree species to assess the tree heights in the study areas. It was highly difficult and time consuming to measure tree heights in the field directly due to tree canopy closure observed in the three plantations. It is based on this premise that model one (1) is selected to be the best model and appropriate for predicting tree heights in the plantation. It is abysmal to engage in measuring total height of all trees in a given plantation in the course of carrying out a project due to the difficulties in visibility and fatigue posed by canopy cover (Clement, 2023). Tree heights modeling was necessary as it was an integral part of tree carbon modeling in the study area. The result of (H-D) models showed that the models fitted well with minimum residuals and an increase in the line of best fit but varied across the three tree species. It implies that the trees are in their competition zones where they strive for growth resources such as water, sun light, soil nutrients and space for survival and maximum productivity. In individual-based forest dynamics models, effects of competition are typically included (Fyllas *et al.*, 2014). Competition is an important driver of community structure and dynamics in forests worldwide (Kunstler *et al.*, 2016).

Based on the performance of model selection indices, model one fitter better in predicting tree heights of *Tectona grandis*, model five performed better in predicting tree heights of *Gmelina arborea* and model two performed better in predicting tree heights of *Khaya senegalensis*. This variation observed showed that different tree species response to the same model differently due to different requirement of growth resources, resource availability and environmental factors. Therefore, the three models were apt and suitable for predicting tree heights in the study areas.

The result of carbon dioxide (CO₂) showed a significant difference between the mean value of *Gmelina arborea* (45.90813) when compared to *Tectona grandis* (27.79618) and *Khaya senegalensis* (26.35139) but no significant difference between *Tectona grandis* (27.79618) and *Khaya senegalensis* (26.35139). It implied that *Gmelina arborea*, in relative to *Tectona grandis* and *Khaya senegalensis* tree species produces more biomass, store more carbon, carbon dioxide and released more oxygen in the study area. There is a need to properly raise, manage and harness the potential of *Gmelina arborea* tree species in the study area. It has the potential to reduce carbon dioxide which is one of

the primary greenhouse gasses in the atmosphere responsible for global warming and climate change in the study area. It also has the potential to arrest the impacts of climate change such as floods, drought, diseases, food scarcity, and unpredictable seasons among others in the study area. The result is also in line with the findings of Gunlu *et al.* (2014), who noted that deforestation and forest degradation in tropical regions are major contributors to global warming. As CO₂ is released quickly into the atmosphere, it traps the heat produced when sunlight strikes the earth's surface during the day. Out of all carbon reservoirs, tree biomass makes up the majority, and deforestation and forest degradation have a significant impact on tree above-ground biomass (Gibbs *et al.*, 2007).

Conclusion

The results of the height-diameter model shows that model one (1), five (5) and two (2) are the grand and suitable models for predicting *Tectona grandis*, *Gmelina arborea* and *Khaya senegalensis* tree heights in the Nasarawa State University Forestry plantations. It also shows that *Gmelina arborea* in relative to *Tectona grandis* and *Khaya senegalensis* tree species produces more biomass, store more carbon and carbon dioxide in the study area. Therefore, there is a need to raise, manage and harness the potential of *Gmelina arborea* tree species in the study area. It has the potential to reduce carbon dioxide which is one of the primary greenhouse gases in the atmosphere responsible for global warming and climate change in the study area. It also has the potential to curb the impacts of climate change such as floods, drought, diseases, food scarcity, and unpredictable seasons among others in study area. Out of all the carbon reservoirs, tree biomass makes up the majority, and deforestation and forest degradation have a significant impact on tree above-ground biomass. By engaging in afforestation, forest regeneration and sustainably management of the current forests, carbon reserves could be preserved and expanded.

References

- Brian, C. M., Bruce, A. M. and Heng-Chi L. B. C. (2004). Estimating Leakage from Forest Carbon Sequestration Programs . *Land economics* (80):109-124.
- CAB International, (2000). Forestry Compendium – a silvicultural reference. Global Module.

- Wallingford, UK: CAB International, 223-232Pp
- Clement, S.A (2023). Modeling Size-Density Relationship and Thinning Regime for the management of *Tectona Grandis* Stands In Ado Teak Plantation, Ekiti State, Nigeria. *FUDMA Journal of Science*. 6. (2) 275 - 282
- Chayaporn, D., Carl, L., Harold, N. M. and FAO, (2020). GRIN Taxonomy for Plants – *Tectona grandis*. <http://www.ars-grin.gov/cgi-bin/npgs/html/genus.pl?1>
- Franklin, R., Olufunke, O. and Popoola, L. (2015). Carbon Stock in Teak Stands of Selected Forest Reserves in Southwestern Nigeria. *Environment and Natural Resources Research*, 5(3). ISSN 1927-0488: E-ISSN 1927-0496Pp. Published by Canadian Center of Science and Education
- Fyllas, N. M. (2014). Analysing Amazonian forest productivity using a new individual and trait-based model (TFS vol. 1). *Geoscientific Model Development* 7: 1251– 1269.
- Gibbs, H. K., Brown, S., Niles, J. O. and Foley, J. A. (2007). Monitoring and estimating tropical forest carbon stocks: Making REDD a reality. *Environmental Research Letters* 2; 1-13
- Gunlu, A., Ercanli, I., Baskent, E. Z. and Cakır, G. (2014). Estimating aboveground biomass using Landsat TM imagery: a case study of Anatolian Crimean pine forests in Turkey. *Annals of Forest Research*, 57: 289-298
- HUANG, S., TITUS, S.J., and WEINS, D.P. (1992). Comparison of nonlinear height-diameter functions for major Alberta tree species. *Canadian Journal of Forest Research*. , 22, 1297-1304
- IEA, (2020). World Energy Investment, IEA, Paris, <https://www.iea.org/reports/world-energy-growth>
- IPCC, IEA, SongklanakarinOzgur, T. K. and Alipour, K.G. (2001). Estimation of carbon offset for teak plantation. *Journal of Science*, 41 (3): 580-586
- Jøker, D. and Gaméné, S. (2003). *Khaya senegalensis*. Danida Forest Seed Centre, Humlebaek, Denmark. Seed Leaflet No. 66.
- Kimambo, D. L. and Michael C. (2014). The Unseen Effects of Deforestation. *Biophysical Effects on Climate* 5 (10); 34-44
- Kunstler, G. (2016). Plant functional traits have globally consistent effects on competition. *Nature* 529: 204 – U174.
- Luyssaert A., Leverett, Robert T., Retzlaff, W. A., Handest, J. A., O'Malley, D. M., McKeand, S. E. and Topa, M. A. (2001). Whole-tree biomass and carbon allocation of juvenile trees of loblolly pine (*Pinustaeda*), 31-32pp.
- Lyam, A. A. (2000): Nigeria: A People United, A Future Assured. Survey of States; Volume (2), Gabumo Publishing, Calabar.
- Mehtatalo, L. (2015.). lmfor: Functions for Forest Biometrics. URL <http://cran.r-project.org/web/packages/lmfor/index.html>
- OGANA, F. N. (2018). Comparison of a modified log-logistic distribution with established models for tree height prediction. *Journal of Research in Forestry, Wildlife and Environment*, 10 (2): 49-55.
- Ostertag, J., Lehtonen, A., Makipaa, R., Heikkinen, J., Sievanen, R. and Liski, J. (2004). Biomass expansion factors (BEFs) for Scots pine, Norway spruce and birch according to stand age for boreal forests. *Forest Ecology and Management*, 188: 211-224
- Pederson, V. H., Dale, L. A. J., Steven, G. M., Ronald, P. N., Matthew, P. (2000). Climate Change and Forest Disturbances. *Biological Science*, 51 (9):723
- Potadar, H. Fisher, E., Stricevic, R., Dzeletovic, Z., Djurovic, N. and Cosic, M. (2015). Application of the Aqua Crop model to simulate the biomass of *Miscanthus giganteus* under different nutrient supply conditions. *GCB Bioenergy*, (7): 1203–1210pp.
- Tohyama, T., Mehtatalo, G., Nanos, N., Ogana, F., Haung, Y., Calama, R., Montero, G. and Gil, L. (2004). Geostatistical prediction of height/diameter models. *Forest Ecology and Management*, 195:221 –235.
- U.S. EPA (United States Environmental Protection Agency), (2018). Inventory of U.S. Greenhouse gas emission and sinks: (2016). EPA 430-R-18-003.<https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2016>
- Veeranjaneyulu, E., Onyekwelu, J. C., Mosandl, R. and Stimm, B. (2006). Productivity, site evaluation and state of nutrition of *Gmelina arborea* plantations in tropic rainforest zone in South-western Nigeria. *Forest Ecology and Management*, 229. 214-227.