



Development and Application of Allometric Models for Predicting Aboveground Biomass of *Eucalyptus camaldulensis* at Dayi Plantation, Katsina State, Nigeria

¹Saka M. G., ²Osho J. S. A., ^{2*}Magaji K. and ⁴Yakubu M.

¹Department of Forestry and Wildlife Management, Modibbo Adama University, Yola, Adamawa State, Nigeria.

²Department of Social and Environmental Forestry, University of Ibadan, Ibadan, Nigeria.

³Department of Forestry, Ministry of Environment, Katsina State, Nigeria.

⁴Department of Forestry and Environmental Technology, Hussaini Adamu Federal Polytechnic Kazaure, Jigawa State, Nigeria.

*Corresponding Author: kmagaji44@gmail.com, +2348069230606

ARTICLE HISTORY

Received: 28/04/2025

Accepted: 16/06/2025

Article Type:

Research Paper

Volume: 13

Issue: 1

Pp: 1 – 11

ABSTRACT

This study was carried out to develop Allometric Equations for aboveground biomass of *Eucalyptus camaldulensis* species at Dayi Plantation. Non-destructive sampling method was adopted in which five (5) sample plots of 50 x 50m were laid across each series (1989, 1990 and 1991) of the plantation. All trees in each plot were marked, numbered, and tree attributes (Diameter at breast height (DBH), diameter at the bottom (DB), diameter at the middle (DM), diameter at the top (DT) and tree height (HT)) were measured and recorded. The constant arithmetic mean wood density values of 0.58kg/m³ obtained from the web were used to estimate the biomass. Sixty eight (68%) percent of the data set were used for the data calibration, while the remaining thirty two (32%) percent was used for validating the developed equation. Coefficient of determination (R²), Standard error of estimate (SEE) were used to evaluate the equations. A paired sample T-test was also used to authenticate the developed models. A total number of 1,349 tree stands were recorded, the total quantity of 25,294 kg/m³ AGB was estimated for the plantation, all the tree growth variables measured showed a strong correlation with the species aboveground biomass at the 0.01 probability level. Model XII was chosen as the best equation due to its highest R² and lower SEE value of 98.1 and 0.1215 respectively.

Keywords: Calibration, Validating, Wood Density, Predicted, T-test and Statistics

INTRODUCTION

Plantation forest is one of the world's largest renewable ecosystems providing different products for human demands (Forest Stewardship Council (FSC), 2024). Forest provides income generation, it serves as habitat for animals, watershed protection and climate change mitigation through sequestering atmospheric carbon dioxide (CO₂) and store as a biomass (FSC), 2024). Since the beginning of

life, trees have furnished man with two of life's essentials namely food and air (oxygen). As man evolved, trees provided additional necessities such as shelter, medicine and tools. Presently, the values of trees are still increasing as more of their potential are being discovered and their roles are expanding to satisfy the needs created by our present-day lifestyles (Tree, 2024). Plantation forestry is increasingly based on successive rotation of plantations or

the establishment of new forests on degraded land (Weiskittel *et al.*, 2011). This approach distinguishes plantation forests from native forests, which are natural assets with inherent ecological value. In contrast, plantation forests are deliberately grown, often described as tree farms, for specific purposes such as timber production, carbon sequestration, or ecosystem services (CIFOR, 2019).

Plantation forest in Nigeria involves the establishment and management of tree plantations for various purposes, including timber production, pulpwood, and non-timber forest products. Nigeria has a long history of plantation forestry, dating back to the colonial era, Federal Ministry of Environment (2019). Allometric equations provide biomass estimates from tree measurements such as diameter at breast height (DBH), height, and/or wood density (Anthony *et al.*, 2020). Therefore, accurate measurements of biomass and other forest biophysical variables to determine the quantity of biomass in a forest are imperative and it is a useful measure for assessing the changes in forest structure. Widely used allometric equations must be independently evaluated using tree biomass datasets to identify error and bias (Duque *et al.*, 2017). Estimating the stocked carbon in forest trees is very important to assess the mitigation effect of forests on regional and global bases and to predict the potential mechanisms to reduce the emission of carbon that goes into the atmosphere (FSC, 2024). Determining the biomass of forests is a useful way of providing estimates of the quantity and quality of these components. The quantity of biomass in a forest is the net result of production through photosynthesis minus losses due to respiration, mortality, decomposition, and removal through harvest or other disturbances.

The need to estimate forest biomass, carbon stocks and stock changes, has become very important for different or various applications such as timber extraction, estimating the African type which follows the pattern of rainfall distribution and it falls within Sudan

amount of CO₂ that can be absorbed from the atmosphere by the stands, tracking changes in the carbon stocks of the stand and that of global carbon cycle (Alefu *et al.*, 2015). However, limited number of studies is available regarding carbon stock for the different forest types, the soils underneath and plantations of various species of which *Eucalyptus cameldulensis* is the major one (Alefu *et al.*, 2015). Only few activities about carbon sequestration potential have been published recently (Alefu *et al.*, 2015). The accurate quantification of forest attributes, mainly related to biomass are basically determined by the precise measurement at the individual tree level (Altanzagas *et al.*, 2019).

Estimation of Aboveground Biomass and development of biomass, volume and specific-wood density model is important for assessing the productivity and sustainability of the plantation (Liu *et al.*, 2014). Therefore, this study provides insights about the tree volume, estimated biomass of *Eucalyptus cameldulensis*, for sustainable plantation management in the study area.

MATERIALS AND METHODS

Study Area

The study area was Dayi plantation (Figure 1), it is located along Malumfashi - Gidan Mutum Daya road in Dayi village, Malumfashi Local Government Area, Katsina State Nigeria. The study site has a geographic position at Latitude 11° 93'486'' to 11° 94'469'' N and Longitude 007° 67'363'' to 007° 68'784'' E on elevation of 645m. It has total area of 100 ha with several compartments and the plantation was established between the years 1989 and 1991 by the Katsina State Government of Nigeria. The plantation comprises of three different age series, the 1989 plantation, 1990 and 1991 and are of equal size (30 hectares). The study site experiences a tropical continental climate characterized by distinct wet and dry seasons. The vegetation type of the study site is the West Savanna zone of Nigeria. (Katsina State Department of Forestry, 2020).

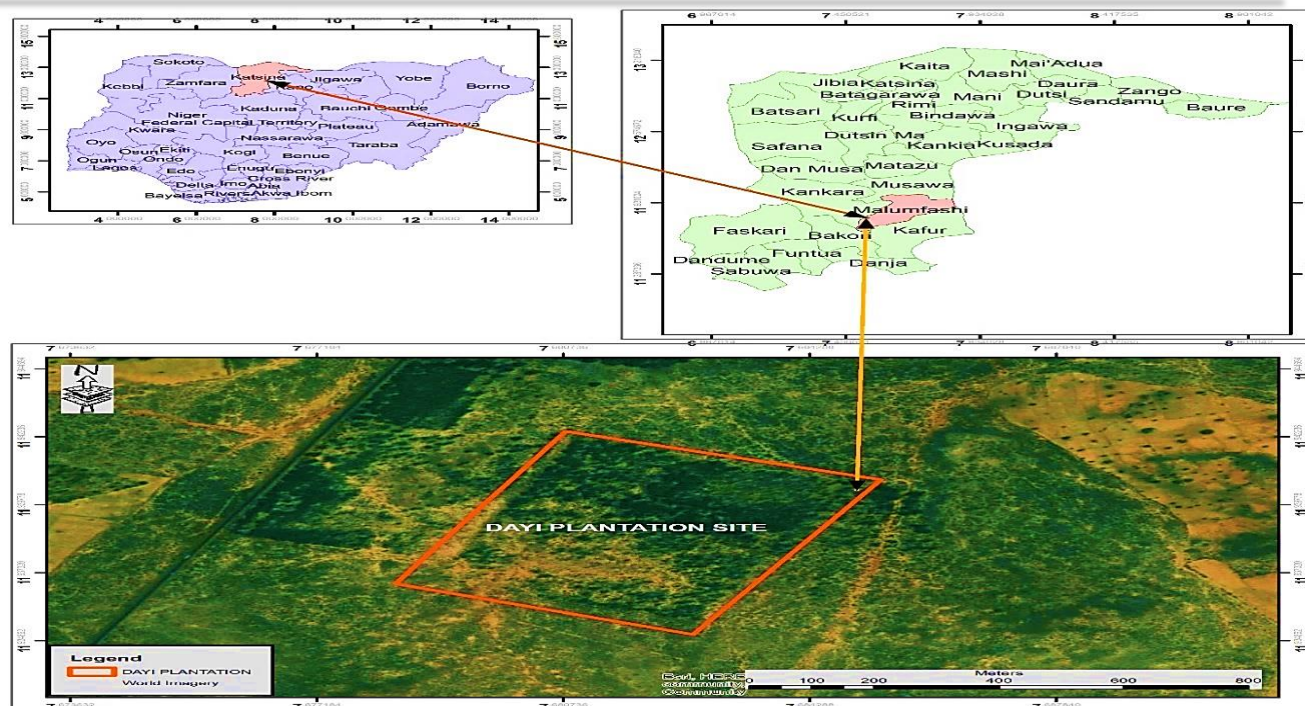


Figure 1: Map of Dayi plantation, Katsina State.

Source: <https://earth.google.com/blue/imagery>.

Computation of Tree Variables for Above Ground Biomass Estimation

Basal area

$$BA = \frac{\pi D^2}{4} \quad 1$$

Where: BA = individual tree basal area (m), D = diameter at breast height (cm), π = constant (3.142)

Volume Estimation

The volume of the species was calculated using Newton's formula adopted by Saka, 2021.

$$V = \left(\frac{A_b + 4A_m + A_t}{6} \right) H \quad 2$$

Where: V = Volume, H = Tree height, A_b = Cross sectional area at the base, A_m = Cross sectional area at the middle and A_t = Cross sectional area at the top

Biomass Estimation

The aboveground biomass was obtained as a product of the estimated tree volume and the specie's wood density.

$$AGB = VOB \times \rho \quad 3$$

Where: AGB = biomass estimation (kg), VOB = estimated volume (m^3) and ρ = wood-specific density which is $0.58 (t/m^3 \text{ or } kg/m^3)$, adopted by (Brito et al., 2020)

$$AGB = a \times (DBH)^b \quad 4$$

$$AGB = \exp(\alpha) \times \rho dbh^2 H \quad 5$$

Where: AGB = the total above-ground biomass, DBH = the diameter at breast height, a = intercept of allometric relationship and b = Slope of allometric relationship

Statistical Analysis

Both descriptive and inferential statistics were used, using Statistical Package for Social Sciences (SPSS Version 25), 34-bite edition produced by IBM (2010). Correlation coefficient and linear Regression analysis were used to compared and predict the tree variables against the estimated aboveground biomass of *Eucalyptus camaldulensis*

Allometric Equations for Aboveground Biomass of *Eucalyptus camaldulensis*

The construction or development of an allometric equation comprises (3) stages: Model development, model evaluation and model validation

Model Development

Almost 912 stems (68%) of the data collected from the field were fitted to twelve (12) linear regression equations for the model development for this research, based on measurable tree variables and other parameters as primary predictors of the aboveground biomass. Both transformed and untransformed variables were used as dependent and predictor variables. The

twelve models developed focus on structure, accuracy, applicability, and practicality in forestry management (Chave et al., 2005). The models developed for estimating biomass on *Eucalyptus camaldulensis* plantation are of the form:

- I. $B = \alpha + \beta_1 BA$
- II. $B = \alpha + \beta_1 BA + \beta_2 HT^2$
- III. $B = \alpha + \beta_1 BA + \beta_2 HT^2 + \beta_3 BA^2$
- IV. $B = \alpha + \beta_1 BA + \beta_2 HT^2 + \beta_3 BA^2 + \beta_4 LnBA$
- V. $B = \alpha + \beta_1 BA + \beta_2 HT^2 + \beta_3 BA^2 + \beta_4 LnBA + \beta_5 HT$
- VI. $B = \alpha + \beta_1 BA + \beta_2 HT^2 + \beta_3 BA^2 + \beta_4 LnBA + \beta_5 HT + \beta_6 DBH$
- VII. $LnB = \alpha + \beta_1 LnBA$
- VIII. $LnB = \alpha + \beta_1 LnBA + \beta_2 LnHT$
- IX. $LnB = \alpha + \beta_1 LnBA + \beta_2 LnHT + \beta_3 BA^{-1}$
- X. $LnB = \alpha + \beta_1 LnBA + \beta_2 LnHT + \beta_3 BA^{-1} + \beta_4 BA$
- XI. $LnB = \alpha + \beta_1 LnBA + \beta_2 LnHT + \beta_3 BA^{-1} + \beta_4 BA + \beta_5 BA^2$
- XII. $LnB = \alpha + \beta_1 LnBA + \beta_2 LnHT + \beta_3 BA^{-1} + \beta_4 BA + \beta_5 BA^2 + \beta_6 DBH$

Note: B – Aboveground Biomass; BA – Basal Area; HT – Tree Height; DBH – Diameter at the breast height; Ln – Natural Logarithm

Source: Field work (2024)

Model Evaluation or Selection Criteria

This involved examination of the structure and properties of the models. It implicitly means comparing and evaluating candidate models. The models developed in this study were verified using the following statistical criteria.

The Coefficient of determination (R^2).

$$R^2 = 1 - \left(\frac{RSS}{TSS} \right) \quad 6$$

Where: RSS = the Regression Sum of Squares, TSS = the Total Sum of Squares.

Standard Error of Estimate (SEE).

$$SEE = \sqrt{\frac{SSE}{n-p}} \quad 7$$

Where:

SEE = Sum of Squares Error, y = Observed variable, x = Predicted variable, n = Number of Observation and p = Number of parameters

Model Validation

Model validation was achieved by dividing the collected data into two sets; one set (68%) of the data, which comprises of 912 stems, was used for model development, while the remaining (32%) was used for validating the predicted equations, which comprises of 437 stems. The models were validated via t-test (Equation 6) to test for the significance

difference between the predicted and the observed aboveground biomass of *Eucalyptus camaldulensis*.

$$t = \frac{\bar{O} - \bar{P}}{\sqrt{SP_{OP} \left(\frac{1}{O_b} + \frac{1}{P_r} \right)}} \quad 8$$

Where:

t = Paired sampled t-test, O_b = Observed Biomass, P_r = Predicted, $\bar{O}$ = Observed Biomass mean, $\bar{P}$ = Predicted Biomass mean, SP_{OP} = Pooled Variance

Correlation of Aboveground Biomass with Tree Variables

Pearson's Correlation Coefficient was used to determine the degree of association existing between the aboveground biomass and the tree variables.

$$r = \frac{\sum XY - \frac{(\sum X)(\sum Y)}{n}}{\sqrt{\left(\sum X^2 - \frac{(\sum X)^2}{n} \right) \left(\sum Y^2 - \frac{(\sum Y)^2}{n} \right)}} \quad 9$$

Where:

X = Predict; Y = Observed variable and n = Number of Observation.

RESULTS AND DISCUSSION

Estimation of the Above-ground Biomass of *Eucalyptus camaldulensis* at Dayi Plantation

Prediction of tree aboveground biomass requires a certain number of tree stem for calibration and validation of the equations. For this study, a total number of 1,349 stems were used for both the calibration and validation. The number of trees per plot ranged from 67 to 117, while the number of trees per hectares, ranged from 268 to 468 across the three sampled age series as presented in table 1. The higher number of tree stems obtained in this study is higher than that recorded by Saka et al., (2020) their work who recorded a total number of 395 stems. This variation may be as a result of environmental factors and different in operational management (Sanquetta et al., 2020).

The total tree volume per hectare varies with year of establishment; this is a reflection of the fact that, plantations tree growth variables vary with age. This is similar to the study conducted by Adekunle et al., (2011), who observed an

increase in stand growth with different age series in the Teak plantation in Omo Biosphere Forest reserve. This process has been described an inevitable especially where there are favourable environmental conditions and all other factors that support tree growth.

The specific wood density used in this research is 0.58 t/m^3 , which is an arithmetic mean and the most common specific wood density values 0.58 t/m^3 , g/cm^3 for tropical tree species such as *Eucalyptus camaldulensis* (Brito et al., 2020; Junior et al., 2020). This value is also consistent with the range of specific wood density values reported for Eucalyptus species, which typically vary between $0.55\text{-}0.65 \text{ g/cm}^3$ (Kumar et al., 2017; Sanquetta et al., 2020).

The total estimated aboveground biomass for *Eucalyptus camaldulensis* in Dayi plantation across the three age series ranges is between 2,410 and $2,905 \text{ kgm}^{-3}$ (Table 1), indicating a significant increase in forest biomass over the three-year period. This result obtained is higher than that of Dongs et al., (2024), who reported a total biomass of 256.5 kgm^{-3} in their work carried out in Jos Wildlife Park, Plateau State. Also, Tegene, (2018) reported a total biomass of 342.09 kg/ha , 339.03 kg/ha and 257.44 kg/ha along the lower, middle and upper elevation gradients respectively in Minjarn District of Northern Ethiopia. The variation with other findings might be also be from difference in management of the forest plantations, difference in tree ages, difference in environmental conditions and difference in stocking density (Mekuria et al. 2018).

Correlation Analysis

The strong positive correlation of the AGB with tree basal area (BA), Diameter at breast height (DBH) and tree height (TH) indicated that they are all good predictor of AGB as presented in table 2. Similar findings were reported by Chave et al. (2014), who found a strong positive correlation between AGB and BA in tropical forests. Feldpausch, (2012) also

reported a moderate positive correlation between AGB and DBH in tropical forests.

Predicted Allometric Equations for the Aboveground Biomass of *Eucalyptus camaldulensis* in Dayi plantation

The results in Table 3 revealed that, the Coefficient of determination (R^2) value ranged from 83.8 to 98.1 with the highest R^2 value in model 12 (M12) and lower R^2 value in model 1 (M1). While standard error of estimate (SEE) values ranged from 0.1215 to 1.6393 with highest SEE value in M1 and lowest SEE value in M12 as presented in table 3. The result obtained on the developed equations for this study, are in line with that of Paul, (2015) and Chave et al. (2014) who reported a R^2 values ranging from 0.85 to 0.95 for their allometric models of tree biomass in *Eucalyptus* plantations in Australia.

The results also revealed the importance of evaluating multiple models and selecting the best model based on statistical criteria; this indicates that the precision level varies among the candidates' models. The results of this study have implications for the development of accurate models for predicting the response variable.

Validation of the Selected Equations

The selected models were validated using an independent dataset of 437 stems, representing 32% of the total 1,349 stems of the data set. This validation approach is consistent with previous studies, which have used similar proportions of their datasets for validation. For example, a study by Junior et al. (2022) used 30% of their dataset for validation, while a study by Liu et al. (2022) used 35% of their dataset for validation. The validation process involved comparing the estimated biomass obtained from tree growth variables (observed data) and the developed above-ground biomass equation (predicted biomass).

Table 1: Statistical Summary of Tree variables and the Estimated Aboveground Biomass

Age (years)	1989					1990					1991					Total
Plot No.	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	15
No. of Tree	83	92	107	74	84	113	79	79	67	69	106	115	78	117	86	1349
No. of Tree/Ha	332	368	428	296	336	452	316	316	268	276	424	460	312	468	344	33,725
Volume (m ³)	425.4	645.2	875.7	534.6	698.1	1252	637.5	805.1	544	566.6	1039	831	614.4	876	557.5	10902.4
Vol./Ha (m ³ /ha)	1702	2581	3503	2138	2793	5008	2550	3220	2176	2267	4155	3325	2458	3506	2230	43609.7
Specific Wood Density (kg/m ³)	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	
Biomass (kg/m ³)	987	1497	2032	1240	1620	2905	1479	1868	1262	1315	2410	1929	1425	2033	1293	25294
Total Biomass (kg/m³)	7376					8828					9090					25294

Source: Field work (2024)

Table 3: Predicted Allometric Equations for the Aboveground Biomass (AGB) of *Eucalyptus camaldulensis* in Dayi Plantation

MODEL	EQUATIONS	R ²	SEE	RANKING
M1	B = -0.725 + 8.619BA	83.8	1.6393	12
M2	B = -1.07 5 + 5.394BA + 0.009HT ²	97.3	0.6713	8
M3	B = -1.318 + 6.087BA + 0.009HT ² - 0.275BA ²	97.4	0.6569	7
M4	B = 2.445 + 7.886BA + 0.009HT ² - 0.569BA ² - 0.570LnBA	97.5	0.6419	6
M5	B = 1.973 + 7.599BA + 0.010HT ² - 0.590BA ² - 0.521LnBA - 0.052HT	97.5	0.6399	5
M6	B = -5.389 + 4.397BA + 0.011HT ² - 0.291BA ² - 1.262LnBA - 0.063HT + 0.057DBH	97.5	0.6382	4
M7	LnB = 1.986 + 1.165LnBA	84.0	0.3491	11
M8	LnB = -1.083 + 0.781LnBA + 1.069LnHT	95.4	0.8791	10
M9	LnB = -0.715 + 0.924LnBA + 0.948LnHT + 0.016BA ⁻¹	97.3	0.1446	9
M10	LnB = -0.466 + 1.131 LnBA + 0.988 LnHT + 0.020 BA ⁻¹ - 0.361BA	97.9	0.1250	3
M11	LnB = -0.394 + 1.170 LnBA + 0.993 LnHT + 0.021 BA ⁻¹ - 0.484BA + 0.030BA ²	98.0	0.1248	2
M12	LnB = -4.142 + 0.263LnBA + 0.996 LnHT + 0.014 BA ⁻¹ - 3.926BA + 0.267BA ² + 0.056DBH	98.1	0.1215	1

B – Aboveground Biomass; BA = Basal area; HT = Tree height; DBH = Diameter at Breast height Ln = Natural logarithm predicted biomass values for allometric models developed for estimating biomass in *Eucalyptus* plantations. For example, a study by Oliveira *et al.* (2022) reported non-significant differences between observed and predicted biomass values for allometric models developed for estimating biomass in *Eucalyptus spp.* in Brazil, using 32% of their dataset for validation.

The results showed that all the selected models, except Model VI, recorded non-significant differences ($p < 0.05$) between the observed and predicted biomass values Figure 2-4). This suggests that the selected models are valid and can be used to estimate above-ground biomass in *Eucalyptus camaldulensis* Dayi Plantation. Similar validation studies have reported non-significant differences between observed and

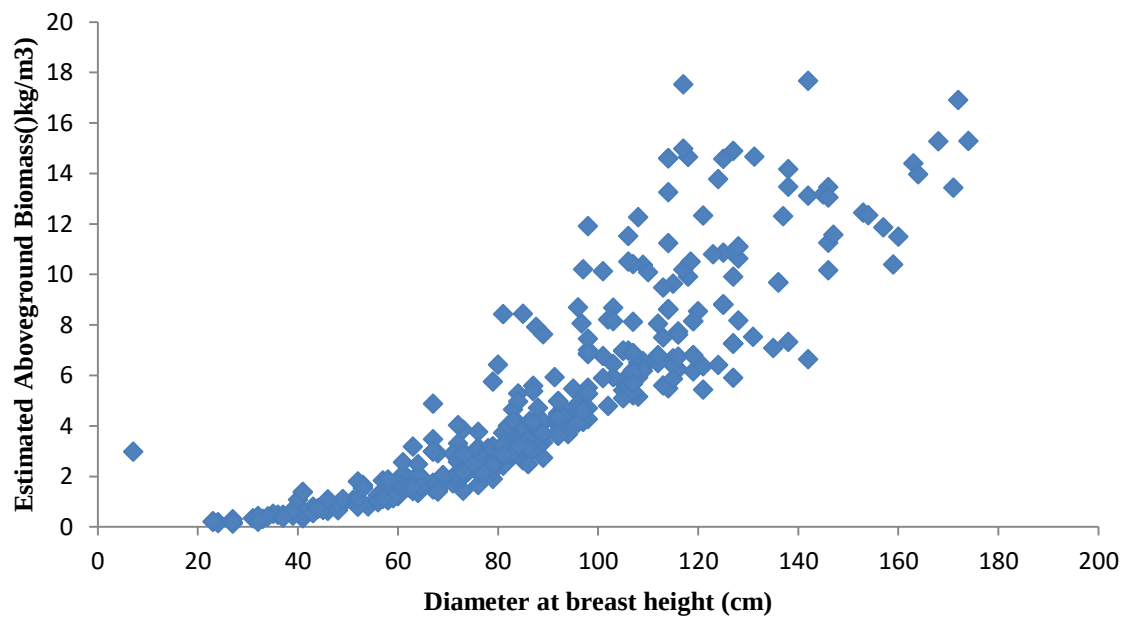


Figure 2: Observed Aboveground Biomass against tree Diameter at breast height

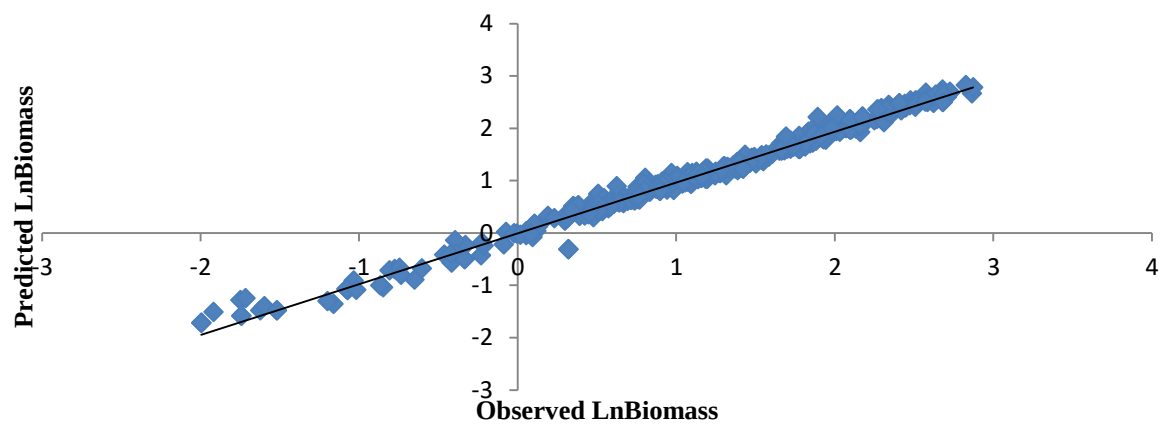


Figure 3: Predicted LnBiomass Versus Observed LnBiomass (Transformed)

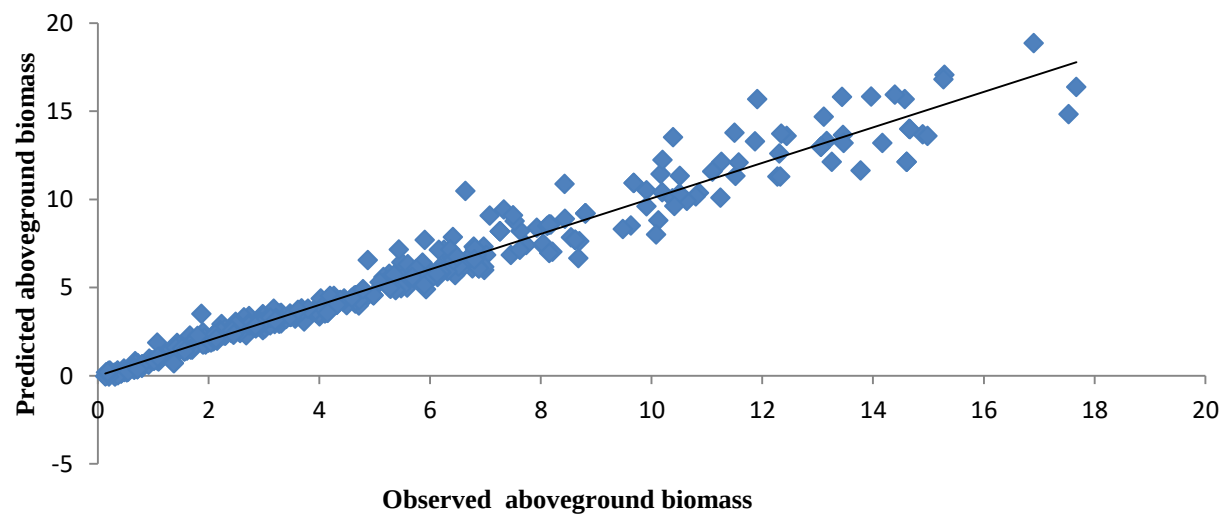


Figure 4: Relationship Between Predicted and Observed Biomass (Untransformed)

Comparison of Developed Models with Previous Models in the Literature

The study evaluated the performance of six existing models for predicting above-ground biomass (AGB) in *Eucalyptus camaldulensis*, and compared them with the newly developed model as presented in table 4. The results showed that the developed model outperformed the existing models, with a higher coefficient of determination (R^2) and lower standard error of estimate (SEE). The R^2 value of the developed model ranged from 97.5 to 98%, indicating that it explains 97.5-98% of the variation in AGB, compared to 76.4-95.8% produced by the existing models. This finding is consistent with previous studies, which have reported that newly developed models can outperform existing models due to their ability to capture site-specific characteristics (Oliveira et al., 2022; Wang et al., 2022; Kumar et al., 2020).

The evaluation metrics used to compare the performance of the developed model with the existing models included R^2 , SEE, and bias. The results showed that the developed model had a higher R^2 value, lower SEE value, and lower bias compared to the existing models. This suggests that the developed model is more

accurate and reliable for predicting AGB in *Eucalyptus camaldulensis*. Similar findings have been reported by other studies, which have used these evaluation metrics to compare the performance of different models (Alam et al., 2022; Mensah et al., 2020; Junior et al., 2022). The study highlighted the importance of including tree height (HT) and diameter at breast height (DBH) as predictor variables in the developed model (table 4). The results showed that the inclusion of HT and DBH improved the accuracy of the model, particularly for trees with varying growth patterns. This finding is consistent with previous studies, which have reported that HT and DBH are important predictor variables for estimating AGB in *Eucalyptus* species (Oliveira et al., 2022; Wang et al., 2022; Kumar et al., 2020). A study by Liu et al. (2022) also reported that the inclusion of HT and DBH improved the accuracy of a model for estimating AGB in a *Eucalyptus* plantation.

Table 4 Comparison of Developed Models with Previous Model in the Literature

Model	Developed Models			Previous Models from Literature			
	Equations	R ²	SEE	Equations	Authors	R ²	SEE
M12	LnB = - 4.142 + 0.263LnBA + 0.996 LnHT+0.014 BA ⁻¹ – 3.926BA + 0.267BA ² + 0.056DBH	98.1	0.1215	B = -13. 205 + 0.918LnDBH ²	Chave <i>et al.</i> , (2014)	95.8	0.7653
M11	LnB = - 0.394 + 1.170 LnBA + 0.993 LnHT+0.021 BA ⁻¹ - 0.484BA + 0.030BA ²	98.0	0.1248	B = -4.962 + 0.111DBH	Schnitizer <i>et al.</i> , (2006)	86.7	0.1505
M10	LnB = -0.466 + 1.131 LnBA + 0.988 LnHT + 0.020 BA ⁻¹ - 0.361BA	97.9	0.1250	B = -3.925 + 0.615HT	Bekam (1981)	84.0	0.1649
M6	B = - 5.389 + 4.397BA + 0.011HT ² - 0.291BA ² – 1.262LnBA - 0.063HT + 0.057DBH	97.5	0.6382	B = -3 534+ 0.312DBH ² + 0.379Ht	Putz (1983)	81.9	1.5838
M5	B = 1.973 + 7.599BA + 0.010HT ² - 0.590BA ² - 0.521LnBA - 0.052HT	97.5	0.6399	LogB = -3.708 + 2.212LogDBH	Gerwing and Farias (2000)	76.4	1.8046
M4	B = 2.445 + 7.886BA + 0.009HT ² -0.569BA ² – 0.570LnBA	97.5	0.6419	B = -1772 + 0.623LogDBH ²	Gehring <i>et al.</i> , (2004)	65.2	2.1949

B = Aboveground Biomass; BA = Basal Area; DBH = Diameter at Breast Height; Log = Logarithm; Ln = Natural logarithm

CONCLUSION

This study explores the use of allometric equations for predicting the aboveground biomass of *Eucalyptus camaldulensis* Dayi plantation. The total aboveground biomass for *Eucalyptus camaldulensis* in Dayi plantation in the study was estimated at 25,294 kg/m³, with each of the age series (1989, 1990 and 1991) having an estimated aboveground biomass of 7376, 8828 and 9090 kg/m³ respectively. The variability in tree aboveground biomass among each age series might be attributed to the number of tree stem and larger tree diameters in some of the sampled plots. This study has developed twelve allometric equations for estimating the aboveground biomass of *Eucalyptus camaldulensis* in Dayi plantation. The models developed showed clearly that all the allometric equations had a good fit only when DBH and HT are used as the explanatory variables. The comparison of the developed model and the six reported models in the literature shows that the reported models in the literature underestimated the aboveground biomass for *Eucalyptus camaldulensis* in the study area. For this study, Model 12 was selected as the best allometric equation for predicting aboveground biomass of *Eucalyptus camaldulensis* in Dayi plantation. The finding has proved that the inclusion of DBH and HT as the predictor variables always produces a good fit. This allometric equation developed for Dayi plantation will play a crucial role in sustainable forest management and climate change mitigation by enabling accurate, non-destructive estimation of tree biomass, which supports efficient forest inventory.

REFERENCES

Adekunle, V. A. J., Olagoke, A. O., and Ogundare, L. F. (2011). Rate of carbon sequestration in tree species

of the Omo Biosphere Reserve, Ogun State, Nigeria. *Journal of Environmental Management*, 92(3), 1046–1051.
<https://doi.org/10.1016/j.jenvman.2010.11.005>

Alefu Chinasho, Teshome Soromessa, Eyale Bayable. (2015). *Carbon Stock in Woody Plants of Humbo Forest and its Variation along Altitudinal Gradients: The Case of Humbo District, Wolaita Zone, Southern Ethiopia*. *International Journal of Environmental Protection and Policy*. Paper 99-103.

Altanzagas, B., Luo, Y., Altansukh, B., Dorjsuren, C., Fang, J., & Hu, H. (2019). Allometric equations for estimating the above-ground biomass of five forest tree species in Khangai, Mongolia. *Forests*, 10(8), 1–17.
<https://doi.org/10.3390/f10080661>.

Anthony, N., Adesoye, P. O., and Onyekwelu, J. C. (2020). Allometric models for estimating aboveground biomass of tree species in tropical rainforest ecosystem of Nigeria. *Southern Forests: A Journal of Forest Science*, 82(4), 303–312.
<https://doi.org/10.2989/20702620.2020.1727431>.

Bekam, G. (1981). *Silviculture of tropical hardwoods*. Commonwealth Forestry Institute, University of Oxford. pp. 123–125

Brito, J. O., Silva, J. R. M. and Santos, R. C. (2020). Wood Density of *Eucalyptus camaldulensis* in Brazil. *Cerne*, 26(1), 34-41.

Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., & Folster, H. (2005). Tree allometry and improved biomass estimates for

- African eucalyptus plantations. *Oecologia*, 145(1), 87-99. DOI: 10.1007/s00442-005-0100
- Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M. S., Delitti, W. B. C. and Malhi, Y. (2014). Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology*, 20(10), 3177-3190.
- CIFOR. (2019). *Plantation forestry: A review of the literature*. Bogor, Indonesia: Center for International Forestry Research (CIFOR). Pp. 45 - 48
- Dongs Y. D., Saka M. G. and Adedotun A (2024) Tree species diversity and carbo sequestration potentials in Jos wildlife park, Jos, Plateau state, Nigeria. *South Asian Journal of Agricultural Sciences* 2024; 4(1): 28-36
- Duque A, Saldarriaga J, Meyer V, Saatchi S. (2017): Structure and Allometry in Tropical Forests of Chocó, Colombia. *Forest Ecology and Management*. 405:309–18.
- FAO, (2020). Global forest resources assessment 2020: Main report. Rome: Food and Agriculture Organization of the United Nations. Pp. 45 – 48
- Federal Ministry of Environment, (2019). Nigeria's national forest policy. Abuja, Nigeria: Department of Forestry, Federal Ministry of Environment. Pp. 12 - 17
- Feldpausch, T. R., (2012). Height-diameter allometry of tropical forest trees. *Biogeosciences*, 9(8), 3111-3124.
- Forest Stewardship Council. (2024). Sustainable forestry certification and its role in plantation management. *FSC Reports*. Retrieved September 9, 2024 from <https://www.fsc.org>.
- Gehring, C., Denich, M., and Vlek, P. L. G. (2004). Resilience of secondary forest regrowth after agricultural abandonment in the Atlantic Forest, Brazil. *Journal of Tropical Ecology*, 20(3), 261-273. doi: 10.1017/S0266467403003179
- Gerwing, J. J., and Farias, D. L. (2000). Integrating liana abundance and forest stature into an estimate of above-ground biomass for an eastern Amazonian forest. *Journal of Tropical Ecology*, 16(3), 327-335. doi: 10.1017/S0266467400001459
- Google Earth. (n.d.). World imagery. Retrieved June 9, 2024, from <https://earth.google.com/world/imagery>
- Junior, R. A., Silva, G. F. and Péllico Netto, S. (2020). Allometric Equations for Estimating Biomass of Eucalyptus spp. in Brazil. *Cerne*, 26(2), 147-156.
- Katsina State Department of Forestry. (2020), Katsina State Forestry Sector Review and Plantation Records, 2020. Katsina, Nigeria: Katsina State Department of Forestry.
- Liu, X., Ekoungoulou, R., Loumeto, J.J., Ifo, S.A., Bocko, Y.E. and Koula, F.E., (2014). Evaluation of carbon stocks in above-and below-ground biomass in Central Africa: case study of Lesio-louna tropical rainforest of Congo. *Bio geosciences Discussions*, 11(7), pp.10703-10735
- Mekuria, W., Aynekulu, E. and Vågen, T. G. (2018). Above-Ground Biomass and Carbon Pools in Different Land Use

- Systems in Ethiopia. Forest Ecology and Management, 427, 73-85.
- Nigerian Conservation Foundation. (2020). *State of Biodiversity in Nigeria*. Retrieved on March 14, 2020 from [NCF Website](#)
- Paul, K. I., (2015). Biomass accumulation in Eucalyptus plantations in Australia. *Forest Ecology and Management*, 340, 142-153.
- Peng, D. L., (2020). Biomass accumulation and carbon sequestration in Eucalyptus plantations in Brazil. *Forest Ecology and Management*, 461, 117961.
- Putz, F. E. (1983). Treefall pits and mounds, buried seeds, and the importance of soil disturbance to pioneer trees on Barro Colorado Island, Panama. *Ecology*, 64(5), 1069-1074.
- Ribeiro, N. A., and Almeida, R. J. (2018). Allometric equations for estimating above-ground biomass of *Eucalyptus grandis* in Brazil. *Forest Ecology and Management*, 427, 123–132. <https://doi.org>
- Saka M. G., Osho, J. S. A. and Isa, H. D. (2020). Assessment of Biomass Contents and Carbon Stock of Plantation-Growth in Neem Specie (*Azadirachta Indica*) in Yola, Nigeria. *Journal of Research in Forestry, Wildlife and Environment* Vol. 12(1) March, 2020. <http://www.ajol.info/index.php/jrfwe> . Publications ISBN: 2141 – 1778
- Saka, M. G. (2021). Determination of mean annual increment and optimal rotation age for sustainable management of eucalyptus species in Afaka forest reserve, Nigeria. *International Journal of Forestry, Ecology and Environment*, 05(01), 187-194.
- Sanquetta, C. R., Behling, A. and Calegario, N. (2020). Allometric Equations for Estimating Biomass of *Araucaria angustifolia* in Brazil. *Forest Ecology and Management*, 473, 118262.
- Schnitzer, S. A., & Bongers, F. (2006). Lianas and logging in West Africa. *Journal of Tropical Ecology*, 22(5), 571-575. doi: 10.1017/S0266467406003359
- Tegene, T. (2018). Assessment of biomass and soil carbon stocks of *Eucalyptus globulus* in Grabocan plantations along elevation gradients in Minjar district, Northern Ethiopia Master's thesis, Hawassa University, Wondo Genet, Ethiopia. Pp. 27 – 29
- Tree Kisan. (2024). *Introduction of Eucalyptus and Its Benefits*. Retrieved June 6, 2024 from [\[https://treekisan.com/2024/04/02/introduction-of-eucalyptus-and-its-benefits/\]](https://treekisan.com/2024/04/02/introduction-of-eucalyptus-and-its-benefits/)