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Aboveground biomass estimation models for *Tectona grandis* Linn f. plantation in Nnamdi Azikiwe University, Awka, Nigeria

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Abstract: Tree biomass is considered a useful indicator of structural and functional attributes of forest ecosystems across a wide range of environmental conditions. The aboveground biomass (AGB) refers to the living vegetation above the soil, including stems, stumps, branches, bark, seeds, and foliage. Teak (*Tectona grandis* Linn f.) is a popular exotic tree species in Nigeria; it is widely grown in large-scale and small community woodlots. The objective of this study was to develop models for the estimation of biomass content of Teak plantation in Nnamdi Azikiwe University, Awka, Nigeria for sustainable management. Data on the diameter at breast height (DBH), stump diameter (Ds), and total height (TH) of all teak stands in the plantation were recorded. A non-destructive method using an existing equation was used to estimate the AGB of the individual stands from Ds. The data was subjected to descriptive statistics, bivariate correlation analysis and fitted to six (6) linear regression functions. A total of 295 trees were measured with a mean AGB of 18.61 kg. Out of the AGB prediction models developed for the study area, the Semi Log 3 (B5) model had the best predictive ability; with the highest adjusted coefficient of determination (0.984) and the lowest standard error of estimate (0.308), and Akaike information criterion (-690.974). Model B5 is therefore recommended for future inventory and management of the plantation.
Keywords: Carbon stocks, Forest inventory, Forest modelling, Regression, Tree growth variables

Nnamdi Azikiwe Üniversitesi, Awka, Nijerya'daki *Tectona grandis* Linn f. plantasyonunun yerüstü biyokütle tahmin modelleri

Özet: Ağaç biyokütlesi, çok çeşitli çevresel koşullarda orman ekosistemlerinin yapısal ve işlevsel özelliklerinin önemli bir göstergesi olarak kabul edilir. Toprakūstü biyokütle (TÜB), gövde, kütük, dal, kabuk, tohum ve yapraklar dahil olmak üzere toprağın üstündeki canlı bitki örtüsünü ifade etmektedir. Tik (*Tectona grandis* Linn f.), Nijerya'da popüler bir egzotik ağaç türü olup büyük ve küçük topluluklar halinde ormanlık alanlarda yaygın olarak yetiştirilmektedir. Bu çalışmanın amacı, sürdürülebilir yönetim için Nijerya Awka'daki Nnamdi Azikiwe Üniversitesi'nde bulunan tik plantasyonundaki biyokütle miktarının tahmini için modeller geliştirmektir. Plantasyondaki tüm tik ağaçlarının göğüs yüksekliği çapı (DBH), kütük çapı (Ds) ve toplam ağaç boyu (TH) ölçülmüştür. Kütük çapını bir değişken olarak kullanan bir denklem yardımıyla tüm ağaçların toprakūstü biyokütle miktarları tahmin edilmiştir. Verilere ait tanımlayıcı istatistikler belirlenmiş, iki değişkenli korelasyon analizi yapılmış ve altı (6) doğrusal regresyon fonksiyonu geliştirilmiştir. Toplamda 295 ağaç ile gerçekleştirilen bu çalışmada, ortalama toprakūstü biyokütle miktarı 18.61 kg olarak belirlenmiştir. Çalışma kapsamında geliştirilen modeller arasında en başarılı model, en yüksek düzeltilmiş belirleme katsayısı (0,984), en düşük tahminin standart hatası (0,308) ve en düşük Akaike bilgi kriteri (-690,974) ile Semi Log 3 (B5) modeli olmuştur. Bu nedenle, Model B5, plantasyonun gelecekteki envanteri ve yönetimi için önerilmektedir.
Anahtar kelimeler: Karbon bütçesi, Orman envanteri, Orman modelleme, Regresyon, Ağaç büyüme değişkenleri

1. Introduction

Tree biomass is considered a useful indicator of structural and functional attributes of forest ecosystems across a wide range of environmental conditions (Brown et al., 1999), it is the accumulated mass, above and below ground. Aboveground biomass (AGB) is the living vegetation above the soil, including stems, stumps, branches, bark, seeds, and foliage. Forest ecosystems play an important role in climate change mitigation by sequestering carbon from the atmosphere (Baccini et al., 2017; Mitchard et al., 2018;), as such, about 50% of global carbon is stocked in tropical forests, while a majority (60%) of the carbon is found in the AGB of the forests (Pan et al., 2011) and are considerable carbon sink (Brown, 1997). Hence, accurate assessment of biomass estimate of a forest is important for many applications like timber extraction, tracking changes in the carbon stocks of forests, and the global carbon cycle.

Tree biomass can be quantified by either harvest (direct method) or allometric equations (indirect method) (Chave et al., 2005). Conversion of data collected from the field to usable AGB requires the use of allometric models. These equations use tree variables like tree stem; diameter at breast height (DBH), total height (TH) and, sometimes, wood

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density (WD) of the species to estimate tree biomass (Brown et al., 1989). Studies have shown that information about AGB is necessary for estimating and forecasting ecosystem productivity, carbon budgets, nutrient allocation, and fuel accumulation (Brown et al., 1999; Kurz and Apps, 1999). Most studies of biomass employ allometric models to quantify AGB because harvesting and weighing trees is destructive and expensive. Although allometric modeling has been used since the development of regression analyses in the first half of the 20th century (Machado and Figueiredo, 2003), only a few allometric models are available to estimate AGB of tropical forests (Cole and Ewel, 2006), especially for Teak plantation in Nnamdi Azikiwe University, Awka, Nigeria.

Teak (*Tectona grandis* Linn f.) is a deciduous tree from the Lamiaceae family, and it is a valuable wood due to its resistance to weather and elastic fiber (Tsoumis, 1991). It was introduced to several countries before 1900 (Verhaegen et al., 2010) and it is known to perform well in plantations under favorable conditions. It has been gathered that the Teak plantation in Nnamdi Azikiwe University Awka was raised to serve as a shelterbelt to the School of Postgraduate Studies' building to counteract soil degradation by restoring vegetation cover while decreasing the existing pressure on native forests and increasing soil carbon (C) and nitrogen (N) pools. Quantification of Biomass is considered a time-consuming activity, especially the measurement of variables like foliage or branch biomass. Therefore, there is a need to develop useful, indirect methods for estimating the variables that are difficult to measure (AGB). The main objective of this study is to develop aboveground biomass estimation models to determine the best-suited model for the Teak plantation in Nnamdi Azikiwe University, Awka, Nigeria.

2. Materials and methods

2.1. Study site

The study was carried out in the 7-year-old Teak plantation at the College of Postgraduate Studies (CPGS), Nnamdi Azikiwe University (NAU), located in Awka South Local Government Area, Anambra State, Nigeria (Figure 1). The University is within the tropical rainforest zone and lies from latitude 6°10'N to 6°17'N and Longitudes 7°2.4'E to 7°7.2'E (Chukwu and Emebo, 2020; Chukwu et al., 2020).

2.2. Data collection and data analysis

This study utilized secondary inventory data from the Teak plantation by Emebo (2019) in the College of Postgraduates, Nnamdi Azikiwe University, Awka. Tree growth variables used were the total height (m), stump diameter, and the diameter at breast height (cm) (i.e., Ds and DBH measured at 0.3 m and 1.3 m, respectively). The data were processed and subjected to descriptive statistics.

The AGB of *Tectona grandis* stands in the plantation was estimated using the AGB model developed by Chukwu and Ezenwenyi (2020) for *Tectona grandis* Linn. f. plantations within the Nigerian Tropical Rainforests.

The model is expressed as:

$$\ln AGB = 2.403 + 0.026Ds \quad (1)$$
$$AGB = e^{2.403+0.026Ds} \quad (2)$$

Where, AGB= aboveground biomass (kg), ln =natural logarithm, e= exponential and Ds= stump diameter (cm)

Six (6) linear regression functions were then fitted to the data with the computed AGB as the dependent variable and DBH and TH as independent variables. The least squares method was used to estimate the regression parameters. The linear biomass functions used for this study are presented in Table 1.

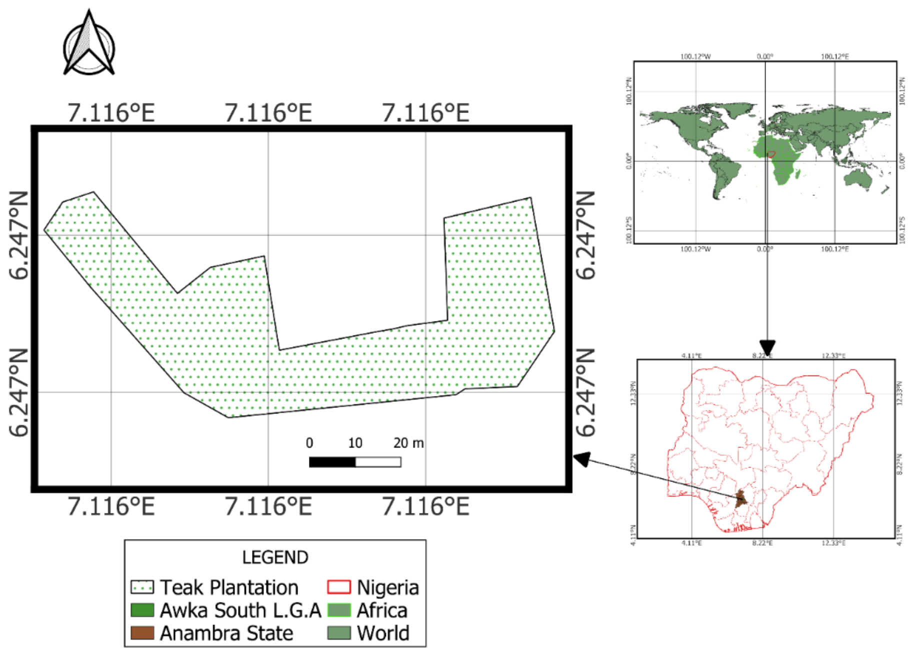

Figure 1. Map of the study area (Modified from Chukwu et al., 2020)

Table 1. Candidate biomass functions

Model code	Function name	Function form	Equation no.
B1	Simple linear	$AGB_i = b_0 + b_1 DBH_i$	3
B2	Semi Log 1	$ABG_i = b_0 + b_1 lnDBH_i$	4
B3	Multiple linear	$ABG_i = b_0 + b_1 DBH_i + b_2 TH_i$	5
B4	Semi Log 2	$ABG_i = b_0 + b_1 lnDBH_i + b_2 TH_i$	6
B5	Semi Log 3	$ABG_i = b_0 + b_1 DBH_i + b_2 lnTH_i$	7
B6	Semi Log 4	$ABG_i = b_0 + b_1 lnDBH_i + b_2 lnTH_i$	8

Where ABG_i = individual tree aboveground biomass, DBH_i = individual tree diameter at breast height, TH_i = individual tree total height, b_0, b_1 and b_2 = regression parameters.

The best model was selected using statistical goodness of fit indices; coefficient of determination (Adj.R^2), standard error of estimate (SEE), and Akaike information criterion (AIC). A model with the lowest value of SEE and AIC, and the highest value of Adj.R^2 was regarded as best. The goodness of fit indices are expressed as:

$$Adj.R^2 = 1 - \frac{(1-R^2)(n-1)}{n-p} \quad (9)$$

$$SEE = \sqrt{\frac{\sum(Y_i-\hat{Y}_i)^2}{n-p}} \quad (10)$$

$$AIC = 2p + nln\left(\frac{RSS}{n}\right) \quad (11)$$

Where, Adj.R^2 = adjusted coefficient of determination, SEE = standard error of estimate, AIC = Akaike information criterion, Y_i = observed value of Y for observation i; $\hat{Y}_I$= predicted value i, n = the total number of observation Y_i (trees) used to fit the model, and p = the number of model fixed parameter.

3. Results and discussion

3.1. Data summary

A total of 295 trees were used and the summary statistics can be seen in Table 2. The distribution of DBH from minimum to maximum ranged from 3.4 cm to 18.0 cm, TH ranged from 1.8 m to 17.3 m, and the AGB ranged from 14.410 kg to 27.110 kg. The results show the existence of a strong relationship between AGB and DBH. This agrees with the result from Ige (2018), which shows a strong relationship between DBH and AGB, with an Adj.R^2 value of 0.911. Pearson correlation analysis with DBH and AGB was also having the highest correlation; this implies that biomass and diameter at breast height have a linear relationship (Figure 2), this means that as DBH increases, AGB also increases. This also agrees with Ige (2018), who recorded a strong relationship between AGB and all tree growth variables. The TH and DBH also show a strong relationship which also means that an increase in the TH also yields a corresponding increase in the DBH.

Figure 2 shows a straight linear relationship between AGB and DBH while a curved linear relationship between AGB and TH. They showed that as DBH and TH increase, the AGB increases.

3.2. Biomass estimation models

The results of the individual tree-level models developed for predicting biomass (AGB) from DBH and TH are shown in Table 3. DBH often is used to predict AGB for tropical trees and shrubs (Chave et al., 2014; Ali et al., 2015). The results revealed that model B5 (Semi Log 3) gave the lowest values of SEE (0.308) and AIC (-690.974), and the highest value of Adj.R^2 (0.98). However, Simple linear (B1), Semi Log 1(B2), Multiple linear (B3), Semi Log 2 (B4), and Semi Log 4 (B6) have Adj.R^2 values of 0.98, 0.90, 0.98, 0.90 and 0.901 respectively, SEE values of 0.311, 0.776, 0.310, 0.777 and 0.772 respectively and AIC values of -687.816, -147.632, -688.700, -145.931 and -149.718 respectively. All parameters were found to be significant at 95% level of probability. This result also agrees with the findings by Chave et al. (2014), which announced the Semi Log to be the best model for estimating the AGB of tropical trees.

The result from this study also disagrees with the findings of Basuki et al. (2009) where the DBH-only model proved more accurate in biomass estimation. Claesson et al. (2001) and Aabeyir et al. (2020) argued that using only one response variable in allometric models to estimate biomass was less accurate; hence, out of the 6 models fitted, model B3 (Equation 5) performed best based on the data set, with DBH and TH as the response variables and showed a fair error distribution in a scattered plot (Figure 3). The AGB models developed in this study showed high Adj.R^2 and low SEE. A low SEE value is an indication of a model's good fit and suggests a good predictive ability of such a model (Adekunle et al., 2004). The high Adj.R^2 results from this study suggested that a very large proportion of the variation in tree AGB was explained by DBH and TH for the stands.

$$AGB_i = 12.058 + 0.764\, DBH_i - 0.105 lnTH_i \quad (12)$$

Table 2. Summary statistics of tree growth variables for model calibration

Growth variables	Min.	Max.	Mean	Std. error	Std. dev.	Skewness
DBH (cm)	3.4	18.0	8.9	0.19	3.23	0.29
THT (m)	1.8	17.3	10.6	0.23	3.93	-0.41
AGB (kg)	14.41	27.11	18.61	0.14	2.46	0.60

Total number of trees=295, DBH=diameter at breast height, TH=total height, AGB=aboveground biomass

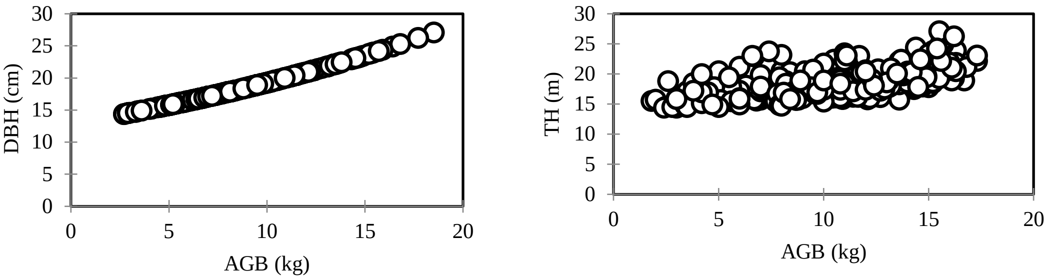

Figure 2. Relationship between AGB, and DBH and TH

Table 3. Model parameters and goodness of fit indices for biomass estimation

	Model parameters			Fit indices			
M/Code	b_0	b_1	b_2	Adj. R^2	SEE	AIC	Rank
B1	11.900	0.755		0.98	0.311	-687.816	3
B2	6.172	5.890		0.90	0.776	-147.632	5
B3	11.939	0.763	-0.010	0.98	0.310	-688.700	2
B4	6.148	5.942	-0.008	0.90	0.777	-145.931	6
B5	12.058	0.764	-0.105	0.98	0.308	-690.974	1
B6	6.336	6.073	6.073	0.90	0.772	-149.718	4

M/Code= Model code, B1=Simple Linear, B2= Semi Log 1, B3= Multiple Linear, B4= Semi Log 2, B5= Semi Log 3, B6= Semi Log 4. SEE= standard error of estimate, and AIC= Akaike information criterion.

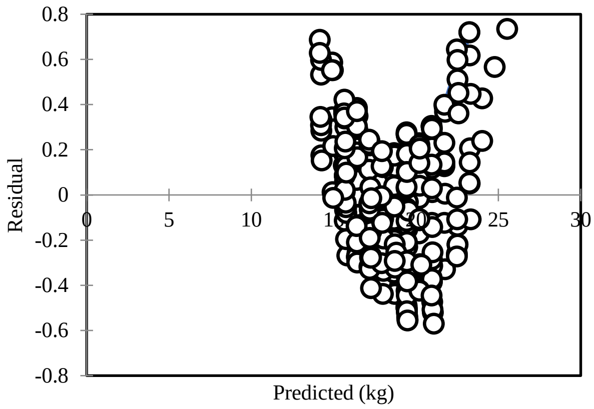

Figure 3. Residual Plot for Semi Log 3

The graphical analysis for the models indicated an even spread of residual above and below the zero mean, with no systematic trend. The positive and negative sides of the plot have a constant breadth and are horizontal. The derivation of the predicted values from the observed values could be said to be random. This indicates that the assumption of normality and homoscedasticity in the distribution was not violated. This agrees with the report of Yang et al. (2019) for linear regression.

4. Conclusion

In conclusion, this study developed a dependable model for estimating the aboveground biomass for Teak plantation. Based on the evaluation of the models examined; the Semi Log 3 model was found to be the most suitable model fit for biomass prediction. The model provided a non-destructive method of predicting the AGB of the Teak stands and an input for estimating the carbon sequestered by the stand. Hence, the model was recommended as a basic tool for further management of the plantation.

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