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EVALUATION OF HEIGHT-DIAMETER MODELS FOR COMMUNITY *Parkia biglobosa* Jacq B. PLANTATION IN WASANGARE, OYO STATE.

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ABSTRACT

Forest growth and yield models are fundamental tools for sustainable forest management planning and future inventory assessments. In order to quantify the growing stock of *Parkia biglobosa* in Wasangare, Oyo state, reliable height-diameter (H-D) models are required. Therefore, the aim of this study was to evaluate 2-parameter H-D models for the prediction of heights of *Parkia biglobosa* tree which are consistent with current forest management practices in the country. Measured 1,196 pairs of height and diameter data were subjected to six (6) 2-parameter H-D models viz Naslund, Meyer, Curtis, Modified Log Logistic, Michaelis-Menten and Wykoff. Model fitting and validation was done in ratio 75:25. With the use of R software tools, the fitting and validation was done. Root mean square error (RMSE), mean absolute bias (MAB), Akaike information (AIC) and Bayesian information criterion (BIC) were used to assess the models. The result showed that all the models were significant but based on the goodness-of-fit statistics, Meyer H-D model had the least rank value, followed by the Modified log logistics H-D (M. LogL) model. The Meyer H-D model had RMSE, MAB, AIC and BIC of 2.996, 2.389, 4520.263 and 4524.660 respectively while M. LogL H-D model had 2.999, 2.421, 4522.082 and 4536.480 respectively. Therefore, it was concluded that Meyer H-D model and M. LogL model written as $H = 1.3 + 10.948\,(1 - e^{-0.057D})$ and $H = 1.3 + \left(\frac{0.425}{D}\right)^{0.516^{-1}}$, respectively were selected as the best candidate models for H-D relationships of *Parkia biglobosa* plantation especially in the savanna zone of Oyo state.

Keywords: Community plantation, Growth model, H-D functions, *Parkia biglobosa*

Introduction

Forest growth and yield models are fundamental tools for sustainable forest management, planning and future inventory assessments (Ige, 2018; Onilude *et al.*, 2019). Tree height and diameter are the two important factors that are very useful for these forest growth and yield models. Tree Diameter (D) and height (H) are very important in forest inventories; in the production and management of forest resources as well as research on forest ecosystems (Vargaslaretta *et al.*, 2009). Accurate tree height and diameter at breast height are necessary conditions for evaluating biomass and are of great importance for the research of forest growth models based on physiological ecology. These variables are also important for the development of forest management plans.

Tree diameter can be determined easily with high accuracy at low cost while tree height is more difficult to measure particularly in mixed tree species forest and due to canopy closure as well as in uneven terrain (Mehtatalo *et al.*, 2017; Özçelik *et al.*, 2018). This makes tree height measurement restricted to few samples. However, there exist a biological relationship between tree diameter and the height and this relationship is even stronger in even-aged forests of planted trees (Sileshi, 2014). In the event of estimating tree basal area and volume, the tree diameter is being used. In addition, forest administrators use the relationship to predict the height from the diameter (Özçelik *et al.*, 2018, Ogana, 2019).

The H-D relationship is either linear or nonlinear depending on the tree species and location, and is used to test the hypothesis that D predicts H (Mensah *et al*., 2018; Chai *et al*., 2018). The nonlinear models yield morerealistic height predictions and are frequently used in forestry thanlinear models (Mehtätalo *et al*., 2017; Mensah *et al*., 2018). Based on nonlinear models, H increases with D and attainsa maximum value (i.e. asymptote H) and an inflection point alongthe stand height curve (Laar and Akça, 2007;Mahanta and Borah, 2014).This is consistent biologically with a basic principle of tree growth. However, in order to develop H-D models in forestry, non-linear theoretical functions commonly use in quantitative forestry include Chapman-Richards, Exponential, Korf, Curtis and Logistic among others (Huang *et al*., 1992; Lumbres *et al*., 2013). These non-linear theoretical functions are of different forms. There are 2-parameter form functions; 3 parameter form functions as well as 4-parameter formfunctions (Chai *et al*., 2018; Mehtätalo *et al*., 2017; Ogana 2019). It is important that a flexible theoretical base function with reliable and proven mathematical properties is adopted in developing more efficient models for the specific tree species (Ferraz Filho *et al*., 2018; Ngandwe *et al*., 2019).

The community plantation of *Parkia biglobosa* consists 7-ha plantation with espacement of 4 m X 4 m. Since establishment, the community has been adequately protecting the forest with little interference. However, there is lack of study on the H-D relationship for this indigenous plantation since establishment and also there is lack of adequate information on the growth pattern and characteristics of the *Parkia biglobosa* plantation in Wasangare, Oyo state. Therefore, the aim of this study was to assess the growth characteristics and evaluate appropriate 2-parameter H-D models for *P. biglobosa* with the view to begin to prepare for forest management practices of indigenous plantations species in the country.

Materials and Methods

Study site

The study was conducted in the *Parkia biglobosa* plantation in Wasangare village located in the Savannah belt of Oyo state. It lies on Lat. 8.8558°N and 8.8573°N and Long 3.42353°N and 3.42519°E(Fig. 1). 10-ha plantation at espacement of 4m X 4m was established by the World Bank in the year 1995 to study the growth pattern of the *P. biglobosa* and handed over to FRIN for proper and adequate management. However, during the reconnaissance survey for this study, a total of 7 ha plantation of *P. biglobosa* was estimated to remain in the study location.

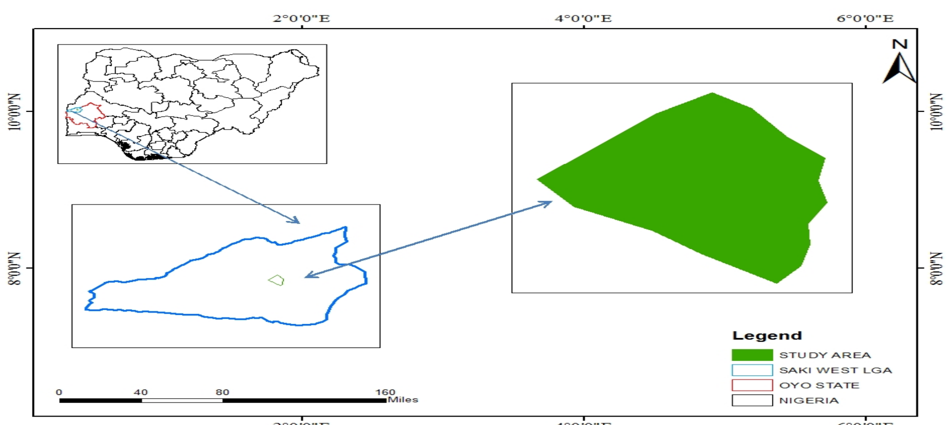

Fig 1: Study map of *Parkia biglobosa* plantation, Wasangare, Oyo state

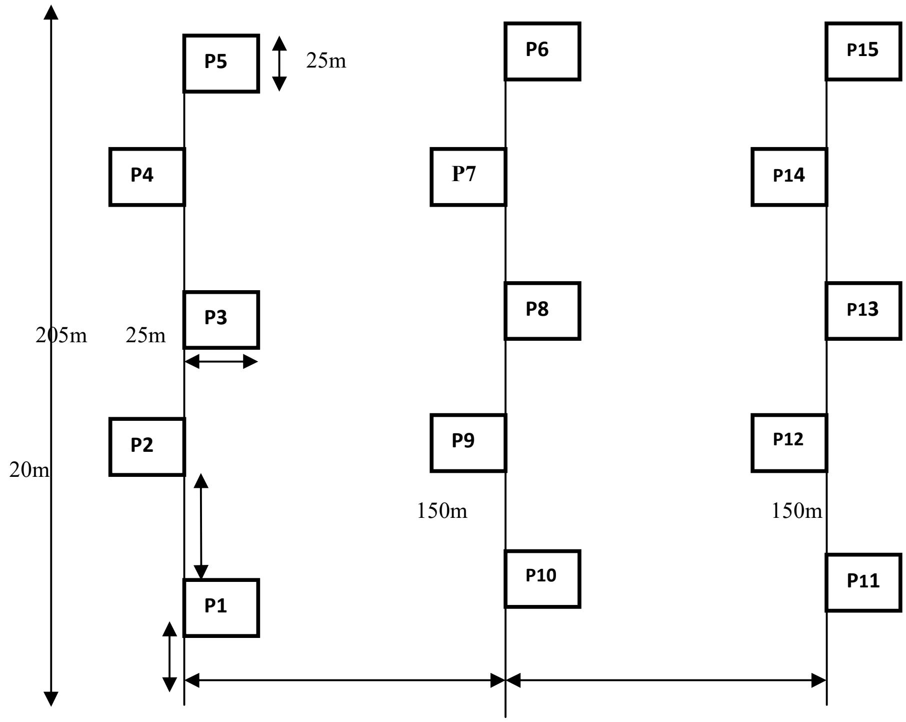

Fig. 2: The transect lines used for the plot sampling

Sampling procedure and data collection

A systematic line transect was adopted for this study. A total of 15 plots of size 25 m × 25 m spaced at 20 m to each other and laid alternatively to each other were obtained from two transect lines of 205 m each at 150 m from each other. An edge effect of 20 m was established before laying the plots (Figure 2). In each of the established temporary sample plot, measurement and information on all tree diameters (for example, diameter at breast height at 1.3 m from the base of the tree, diameter at the base, middle and top of the tree)and height were collected for each *Parkia biglobosa* tree. With this information, all diameter sizes of trees would have been captured. Diameter and height were measured to the nearest 0.1 cm and 0.1 m with diameter tape and a lacer ace hypsometer respectively.

H-D model development for *Parkia biglobosa* in Wasangare

In order to develop the H-D models for *P. biglobosa* in Wasangare, six (6) 2-parameter theoretical functions that are widely used in forestry modeling based on the precision of their predictive ability, simplicity and logic were selected from literature searches. Although, there have been several height-diameter models that have been applied to forestry with varying degree of success (Ogana, 2018, 2019). Although, no single height-diameter model is suitable for all data structure. For this study, six (6) 2-parameter height-diameter models were fitted to the data for this study. The models evaluated included Curtis H-D model, Naslund H-D model, Modified log logistics (M. LogL) H-D model, Michaelis-Menten H-D model and Wykoff H-D model and Meyer H-D model as presented in table 1.

H-D model assessment for *P. biglobosa*

The model assessment for the study was based on root mean square error (RMSE), mean absolute bias (MAB), Akaike information criterion (AIC) and Bayesian information criterion (BIC). The use of adjusted coefficient of determination (Adj.R^2) as goodness-of-fit for linear models has beenwell reported by authors in forestry (Lumbres *et al*., 2013; Chai *et al*., 2018, Ogana, 2019). However, its use in evaluating non-linear models has been criticized mainly because its value may lie outside the limits (0–100%), the total variance sometimes exceeded and may also increase type II error (Ogana, 2020). For this study, Adj.R^2 as a metric for evaluation was not used.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{n}} \quad \ldots\ldots (1)$$

$$MAB = \frac{\sum_{i=1}^{n}(\hat{Y}_i - Y_i)}{n} \quad \ldots\ldots (2)$$

$$AIC = n\ln\left(\frac{RSS}{n}\right) + 2P \quad \ldots\ldots (3)$$

$$BIC = n\ln\left(\frac{RSS}{n}\right) P\ln n \quad \ldots\ldots (4)$$

$$t = \frac{\bar{X}_A - \bar{X}_B}{\sqrt{\frac{S_d^2}{n}}} \quad \ldots\ldots (5)$$

Where: RSS = residual sum of square, n = number of sample size/units, P= number of parameters; Yi is the observed value;$\hat{Y}_i$= the theoretical value predicted by the model.$\bar{X}_A$ *and* $\bar{X}_B$ are the predicted and observed values for each model to be compared, $\frac{S_d^2}{n}$ is the variance of the individual differences in $\bar{X}_A$ *and* $\bar{X}_B$.The models were also validated using independent data set (that is, data not used in calibrating the models). The predicted and observed values from each model were compared using paired sample t-test at 5% probability level.

However, to decide on the candidate models, a rank was assigned to each H-D model based on each fit index (Tewari and Singh 2018, Ogana 2019). The smaller the rank, the better the model. These ranks were thereafter summed up to reach a final fit rank for each model which shows the individual model performance with respect to all fit indices considered in this study. All statistical analyses including model fitting and all other analysis were carried out using nonlinear regression procedure from nlstoolspackage in R software tools (R Core Team, 2017).

Table 1: 2-parameterH-D functions used in the evaluation of H-D models for *P. biglobosa* in Wasangare, Nigeria

Eq/N	Model Name	Functions	References
6	Curtis	$H = 1.3 + \beta_1\left(\frac{D}{1+D}\right)\beta_2$	Mensah *et al*, (2018); Ogana, 2019
7	Naslund	$H = 1.3 + \frac{D^2}{(\beta_1 + \beta_2 D)^2}$	Näslund (1937), Mehtatalo *et al*, (2017); Ogana, 2019
8	M. LogL	$H = 1.3 + \left(\frac{\beta_1}{D}\right)^{\beta_2^{-1}}$	Ogana 2018
9	Michaelis-Menten	$H = 1.3 + \frac{\beta_1 D}{(\beta_2 + D)}$	Michaelis-Menten (1913), Ogana 2019
10	Wykoff	$H = 1.3 + e\beta_1 + \beta_2/(D+1)$	Wykoff *et al*. (1982) , Ogana 2019
11	Meyer	$H = 1.3 + \beta_1(1 - e^{-\beta_2 D})$	Meyer, 1940, Ogana, 2019

Note: H is the tree height in m, D is the diameter at breast height in cm, and the model parameters are β1and β2, 1.3 is a constant used to indicate that DBH is measured at 1.3m above the ground, e, is the base of the natural logarithm

Result and Discussions

Total enumerations of trees were carried and the result indicated that 1,196 trees of *Parkia biglobosa* were enumerated. The result of descriptive statistics for the whole stands is presented in Table 2. The mean height of the plantation was 8.14±0.10 m while the minimum and maximum values were between 1.80 m and 21.0 m respectively. The diameter at breast height in cm was 18.66±0.25 while the minimum and maximum values were between 2.0 cm and 61.7 cm respectively. The minimum value, Dbh of 2cm was as a result of the growth of young trees growing out of the fallen seeds from the parent tree (Table 2).

Table 2: Descriptive statistics for *P. biglobosa* in Wasangare, Oyo State

Growth variables	Values	
	Mean± S.E	Min and Max
Height (m)	8.14±0.10	(1.80; 21.0)
DBH (cm)	18.66±0.25	(2.0; 61.7)

Note: DBH- Diameter at breast height, Min and Max- Minimum and Maximum values

Height-Diameter relationship

The result showed that all the H-D models tested for the *Parkia biglobosa* data were all significant and performed well based on the fit indices (Table 3). The Meyer H-D model was ranked first with rank summation value of 4 (Table 3) while M. LogL H-D model with summation value of 8 (Table 3) was next to the Meyer H-D model, followed by MM H-D model, Naslund H-D model, Wykoff H-D model and Curtis H-D model. However, the best candidate models and their fit statistics were: Meyer H-D model with the least RMSE, MAB, AIC and BIC of 2.996, 2.389, 4520.263 and 4524.660 respectively and M. LogL H-D model with 2.999, 2.421, 4522.082 and 4536.480 respectively (Table 3).The order of ranking for the models is presented below:

Meyer H-D > M. LogL H-D > MM H-D > Naslund H-D >Wykoff H-D > Curtis H-D models.

Furthermore, according to Ogana, (2018, 2019) and Ng'andwe et al. (2019), as a common rule of thumb, two models are the same if the difference of their AICs (that is, ΔAIC) value is less than two (2). For this study, the difference between the Meyer H-D model and M. LogL H-D model isless than 2, (Table 3), therefore the two models are regarded as similar. However, the difference between other models and these two best models are far more than the value of 2. Thevalidation of the models with independentdata set indicated that the predicted values from all the models were not significant from the observed tree height at 5% probability level (Table 3)

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Table 3: Model Parameter estimates and their statistic fits for H-D models for *Parkia biglobosa* in Wasangare, Oyo state

Model	Parameters		RMSE	MAB	AIC	BIC	$\sum Rank$	VALIDATION Pred. Vs Obs T. test	
	β_1	β_2						T-value	P-value
Meyer	10.948	0.057	2.996(1)	2.389(1)	4520.263(1)	4524.660(1)	4	0.022	0.982
Naslund	1.777	0.276	3.029(4)	2.436(4)	4539.556(4)	4553.953(4)	16	0.030	0.976
M.LogL	0.425	0.516	2.999(2)	2.421(2)	4522.082(2)	4536.480(2)	8	0.219	0.827
MM	15.503	21.659	3.011(3)	2.422(3)	4529.333(3)	4543.731(3)	12	0.098	0.922
Wykoff	1.457	-8.626	3.096(6)	2.460(6)	4555.624(6)	4570.021(6)	24	0.094	0.925
Curtis	11.874	9.230	3.049(5)	2.455(5)	4551.589(5)	4565.986(5)	20	0.053	0.957

Note: β1,β2 are estimated parameters for each of the developed model; Adj.R^2- adjusted coefficient of determination; RMSE- root mean square error; MAB- mean absolute bias; AIC- Alkaike information criterion; BIC- Bayesian information criterion

Although, Ngandwe *et al*., (2019) reported RMSE value of 3.31 for Naslund and 3.86 for Curtis theoretical functions in their study of height and diameter relationship of planted *Pinus kesiya* in Zambia while Liu *et al*., (2017) reported RMSE value of 1.8277 for the native Chinese metasequoia trees. Also, Ogana (2018), reported RMSE value of 3.343 and 3.302 for M. LogL and Logistics theoretical functions respectively in his study of comparison of M. LogL functions to other already established model used for height prediction in forestry. However, for this study, there is no basis for comparing the goodness of fit indices values with others already reported in forest modeling. This is because the parameters of the models are site specific and can only be used for *P. biglobosa* plantations with similar ecological characteristics.

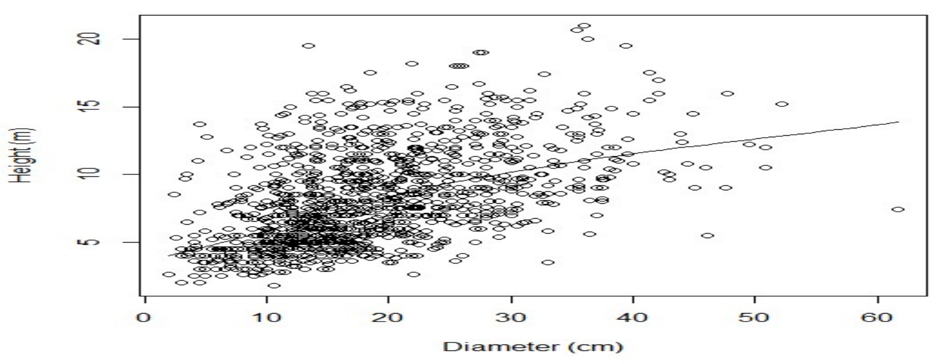

Fig 3: Scatter plot of all measured tree heights and diameter of *Parkia biglobosa* plantation

(a) (b)

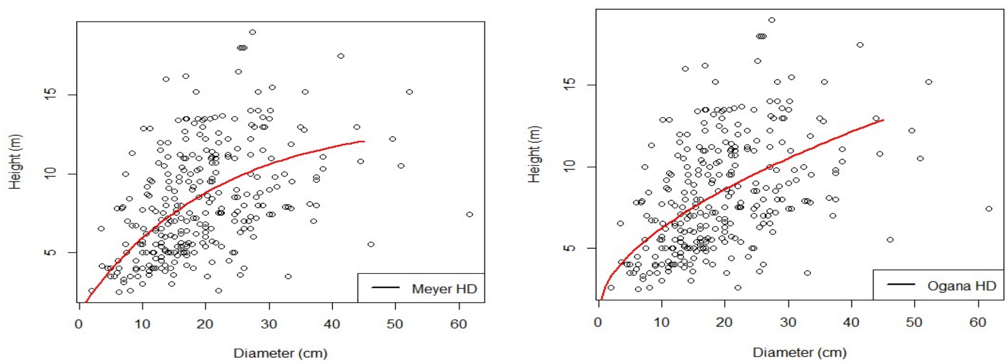

Fig. 4: The fitted curves as produced by the Meyer H-D model (a) and Ogana H-D model (b)

Figure 3 showed the scatter plot of all the measured tree heights and diameter in the plantation. Furthermore, the result of validation test revealed that all the models were not significantly different at probability level of 5%(Table 3). That is, the independent dataset used for the validation are not significantly different from the fitting dataset. Furthermore, only the height curves and the residual plots for theMeyer and the M. LogL H-D models were presented for the study shown in figure 4a:4b and 5a:5b respectively. The height curves produced by the Meyer and the M. LogL H-D models followed tree height pattern (that is,monotomic increment and inflection point). Although, the pattern showed that the plantation is still in its active growing stage. Also the plots of residual and predicted values for the Meyer H-D model and M. LogL H-D model were presented in figure 5a and 5b respectively. The plots revealed that there is minimal or no systematic bias towards over or under estimation of tree height.

According to Huang *et al*. (1992) and Ogana, (2019), they asserted that for a good h-d candidate model, the asymptotic t-statistic for each coefficient should be significant and the residual plot should approximate homogeneous variance over the full range of predicted values. The Meyer H-D model and M. LogL H-D model met these criteria.

(a) (b)

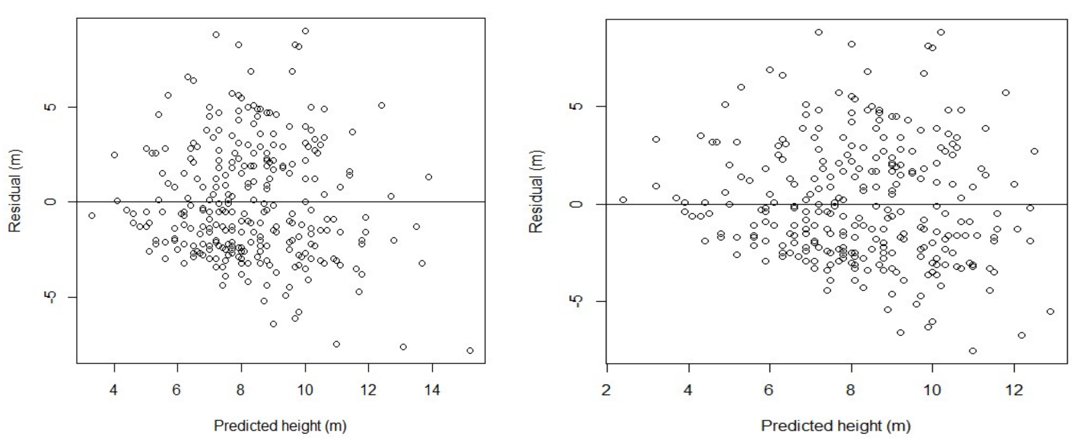

Fig.5: Residual plots for the Meyer H-D model (a) and Ogana H-D model (b)

Conclusion and Recommendation

The use of nonlinear model for fitting height-diameter relationship is an effective and efficient method for improving the estimation of tree height. Out of the evaluated and tested 2-parameter H-D models, Meyer H-D model and M. LogL H-D model were selected as the best fitting models that can be applied in the estimation of tree height for the *Parkia biglobosa* trees in Wasangare, Oyo state based on the fitting indices.

The models are best written as:

1. Meyer H-D model :

$$H = 1.3 + 10.948\,(1 - e^{-0.057D})$$

2. M. LogL H-D model:

$$H = 1.3 + \left(\frac{0.425}{D}\right)^{0.516^{-1}}$$

These 2-parameter H-D models may be used to predict the height of *Parkia biglobosa* in Wasangare, Oyo state. However, these models may be tested on other tree species from different ecological zones. Furthermore, there is need to develop a country wide model for this species that will incorporate local condition such as site quality, stand age, stand density and other variables to increase its specificity and accuracy in order to satisfy the demands of the forestry industry to have an accurate H-D models that are simple to use during inventories and forest management planning.

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