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HEIGHT DIAMETER MODEL FOR SELECTED TREES WITHIN UNIVERSITY OF IBADAN, OYO STATE, NIGERIA

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ABSTRACT

For growth and yield prediction models, tree height and diameter at breast height (Dbh) are essential input variables. The relationship between the two tree characteristics at the stand level is satisfactorily explained by height-diameter models. This study was carried out to model the height-diameter relationship of Terminalia radii Plantation at Heritage Park and Tectonagrandis at Teak Plantation, University of Ibadan. Ten non-linear growth functions were chosen as potential base models, and they were then fitted to the height-diameter information for each individual tree. Complete enumeration was carried out at Heritage Park while stratified sampling technique was employed using two transect lines at 50 meters apart with 10 sample plots. A total number of 277 trees were identified and measured with 146 trees from Heritage Park and 131 trees from Teak plantation. The ten (10) non-linear model parameters for trees in the study area were estimated using the sampled trees. Among the ten models, Curtis demonstrated the best model with smallest RMSE, AIC, BIC, high R^2 and small sum rank of 5.356499, 815.4638, 824.0894, 0.3800086, and 7 respectively; Logistic showed the best model with smallest RMSE, AIC, BIC, highest R^2 and small sum rank of 2.884578, 728.6374, 740.5718, 0.1058006, and 10 respectively with other h-d models for Teak plantation and Heritage Park respectively. For estimating tree height in the study locations, the two models are recommended.

Keywords: Height-diameter Model, Teak, Plantation, Height, Logistics

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INTRODUCTION

Information on tree height and diameter is important for efficient management of trees in various ways. For example, tree height and diameter are greatly used as an important input variables to estimate the volume, the height of the trees in the forest which is the pointer to evaluate the site quality (productivity of the site) and provides information on the competition of trees for nutrient, light and space within a stand (West, 2015).

The height measurement of trees is relatively difficult, time consuming, expensive when it is compared to the measurement of diameter at breast height (DBH) taken at 1.3m above the ground level (Ozçelik, *et al*., 2018; Corral-Rivas *et al*., 2019). For this reason, only sub-sample of tree heights are always measured; and height prediction models are employed to know the height of the trees that its diameter has been measured (Kalbi *et al*., 2018). Up to date, many height prediction models like Chapman-Richards (Richards, 1959), Korf (Lundqvist, 1957), Meyer (Meyer, 1940),Näslund (Näslund, 1937), Schumacher (Schumacher,

1939),Ratkowsky (Ratkowsky, 1990) etc. have been developed and applied to forestry with varying degree of great outcome.Growth modeling has been an important part of forest management planning and research. . To determine the best model for characterization, it is important to understand the type of diameter distribution function and its parameters (Mohammed *et al*., 2009). A basic planning for natural resources needs qualitative and quantitative information, which is usually derived by measuring the characteristics of stands (Zobeiry, 1994).

Several models have been implemented to predict height-diameter relationships for different species and in different regions across the world. The techniques used to create the height-diameter model ranged from simple to complex, linear to nonlinear (HaruniKrisnawati *et al*., 2010). There is no superiority among the models. The effective of the model depends on different stand variables used as predictors and also the forest stand with the forest conditions. It is very important to know that different models have their distinctiveness in predicting height and other stand variables for volume estimation.

Numerous studies have used the height-diameter relationship, resulting in the development of both local and generalized models. (Temesgen, 2004; Lei *et al*., 2001), as well as purely deterministic (Schröder*et al*., 2001; López-Sanchez *et al*., 2003.) and mixed-effects models (Calama, R. *et al*., 2004;Saunders, 2008). Local height-diameter models, when derived from a sufficiently representative sample of diameter height measurements, effectively describe the relationship between both tree characteristics at the stand level, and are frequently used in forest inventories for forest management and planning. Although height-diameter models for other species have been around for a while in other regions and are important for predicting forest growth and yield, mixed tree species height-diameter models have received relatively little attention in the literature. Hence, the objective of this study is to predict tree height of *Terminalia radii* in the Heritage Park and *Tectona grandis* in Teak plantation using height-diameter model.

MATERIALS AND METHODS

Study Area

The study was carried out at the University of Ibadan which lies between latitude 7°26'35''N to 7°27'33''N and longitude 3°53'57''E to 3°54'06''E. University of Ibadan is characterized by dry and rainy season.

Climatic Conditions

The rainy season start from late March to late October with a mean annual rainfall of about 1220 mm and a double maxima rainfall with a peak in June and interrupted by a short break and the second peak is reached in September.

Study Site

Heritage Park and the Teak Plantation were chosen as study site inside the university grounds.

(i) Heritage Park

This is the first park situated almost immediately after the university's main gate (entrance) with *Terminalia radii* Plantation which was established so as to serve as a recreation, relaxation and beautification purpose. This plantation also serves as habitat for birds around the university. The plantation is a relative flat surface with loamy/clayey soil and a gradual slope surface. There are little outcrops of rocks scattered within the plantation.

(ii) *Teak Plantation*

This is located beside the University of Ibadan international Conference Centre (UIICC) and extends through to the Distance Learning Centre along Ajibode Road Ibadan in Akinyele Local Government area of Oyo State. It lies between Latitudes 7°45.106'N to 7°45.834'N and longitudes 3°90.942'E to 3°90.508'E.University of Ibadan Teak plantation was established over a period of three years (1951-1953) and managed by the Department of Social and Environmental Forestry and Department of Forest Production and Products).

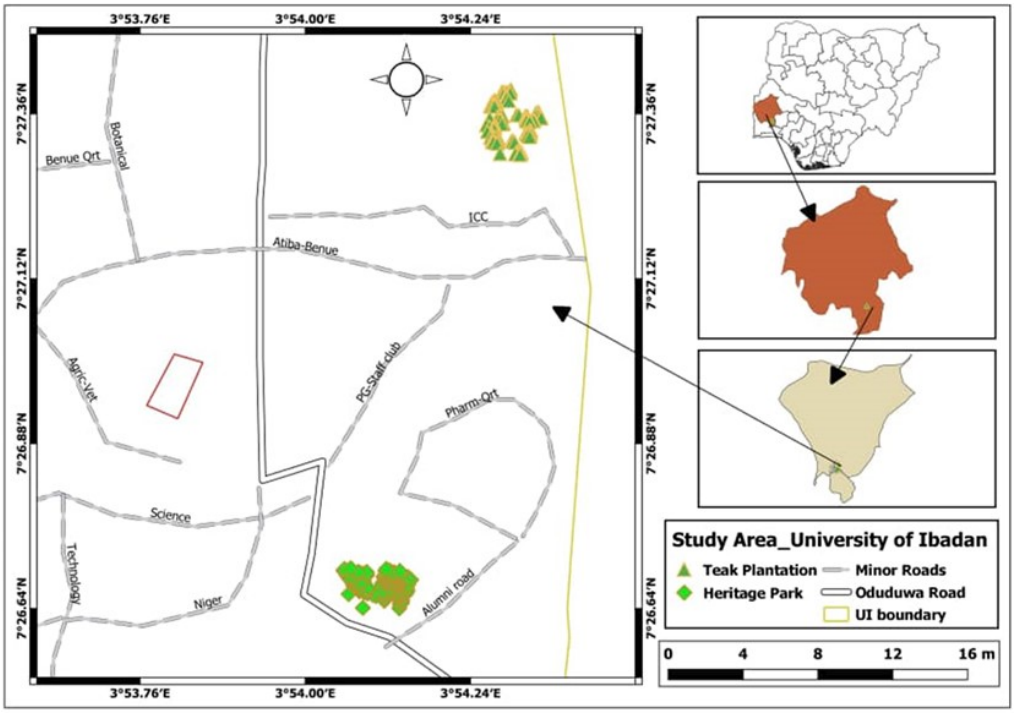

Figure 1. Map of the Study Area

Data Collection

Sampling Procedure

The data for this study came from Heritage Park and Teak plantation located in University of Ibadan. At Heritage Park, 146 trees (*Terminalia randii*) were identified and measured. Data were obtained from 10 temporary sample plots (TSPs) of size 0.04 ha i.e. 20m by 20m plots using systematic sampling with 10 m interval between each plot and 131 trees were recorded for modelling at Teak plantation.

Measurement of Tree Growth Variables

Total height (m), merchantable height (m), diameter at breast height over bark, base, middle, and top were all measured (cm). The following tools were used to gather the data. They include the Spiegel Relascope, which is used to measure height and diameter at various points, and the Diameter Tape, which is used to measure diameter at breast height (dbh).

Model Specification

A scattered plot diagram of height against Diameter at Breast Height (Dbh), as shown in Figure 2 for the two locations, confirmed the non-linear relationship between height and diameter. To fit the height-diameter relationship, ten different nonlinear models (Table 1) were used. The models are of the following form as shown in Table 1.

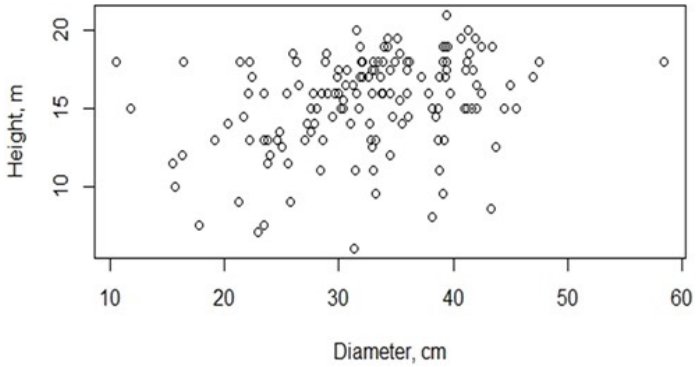

Figure 2.*Scattered plot diagram of height against Diameter at breast height.*

Table 1: Model considered.

Model name	H-D Model	References	Equation
Naslund	$H = bh + \frac{D^2}{(a+bD)^2}$	(Näslund, 1937)(Mehtätalo *et al*., 2015)	(5)
Wykoff	$H = bh + e^{a+b/(D+1)}$	(Wykoff*et al*., 1982)	(6)
Curtis	$H = bh + a(D/(1+D))^b$	(Curtis, 1967)(Mehtätalo*et al*., 2015)	(7)
Meyer	$H = bh + a(1 - e^{-bD})$	(Meyer, 1940)	(8)
Michaelis-Menten (MM)	$H = bh + \frac{aD}{(b+D)}$	(Menten 1913)(Huang *et al*., 1992)	(9)
Richards	$H = bh + a(1 - e^{-bD})^c$	(Richards, 1959)(Mehtätal *et al*., 2015)	(10)
Ratkowsky	$H = bh + ae^{-b/(D+c)}$	(Ratkowsky, 1990) (Mehtätalo *et al*., 2015)	(11)
Korf	$H = bh + a(e^{-bD^{-c}})$	(Lundqvist, 1957)(Krisnawati *et al*., 2010)	(12)
Logistic	$H = bh + \frac{a}{1+be^{-cD}}$	(Mehtätalo*et al*., 2015) (Ogana, 2018)	(13)
Gompertz	$H = bh + ae^{(-be^{(-cD)})}$	(Gompertz, 1825) (Mehtätalo*et al*., 2015)	(14)

Note: a, b, c = model parameters; bh = 1.3 (a constant used to account that DBH is measured at 1.3m above the ground); H = height (m); D = diameter (DBH); e= base of the natural logarithm.

Data Analysis

Model Evaluation

The parameters were estimated using a non-linear least-squares procedure in R software version 4. The fitted models were then evaluated using all of the following criteria: Significant parameter estimates, Akaike information criterion (AIC), Root mean squared error (RMSE), Bayesian information criterion (BIC), and Coefficient of determination (R^2). Model resulting with the highest (R^2), the least RMSE, and the smallest values of AIC were selected as the best model.

Akaike information criterion (AIC): To compare models with various parameter values, this is one of the most reliable criteria. The smaller the AIC value, the better the model. It is defined as:

$$AIC = n\ln(\frac{RSS}{n}) + 2P \quad \text{..... (1)}$$

$$BIC = n\ln(\frac{RSS}{n}) + P\ln n \quad \text{..... (2)}$$

$$RMSE = \sqrt{\frac{RSS}{n-p}} \quad \text{..... (3)}$$

$$R^2 = \frac{RSS}{TSS} \times 100 \quad \text{..... (4)}$$

Where: n = Number of observation, RSS = Regression sum of squares, P = Parameter, R^2 = Coefficient of Determination, TSS = Total Sum of Square, AIC = Akaike information criterion, BIC = Bayesian information criterion, RMSE = Root mean squared error.

Height-Diameter Models

Each H-D model was given a rank based on each fit index before the models were chosen (Tewari *et al*., 2018).The lower the rank, the better the model. Normality test of the residual was carried out using Shapiro-Wilk at 5% level. All statistical analyses, including model fitting and the normality test, were performed in using R software (R Core Team, 2017).

There are several height-diameter models that have been applied to forestry with varying degree of success. No single height-diameter model is suitable for all data structure. In this study, ten height-diameter models were fitted to the data from Teak Plantation and Heritage Park (Table 1).

RESULTS

The experimental plot for this study consisted of 277 sampled trees measured from two locations in the university of Ibadan, specifically; Heritage Park consist of one species of tree (*Terminalia radii*) with 146 trees and Teak plantation with 131 trees as shown in Table 2.The diameter at breast height showed the highest value for standard deviation (7.760851) while merchantable height show the least value for standard deviation (2.132107) at Heritage Park, the diameter at breath height showed higher value for standard deviation at Teak plantation with and 9.124826 with the merchantable height that show least values of 4.224194.The average height, diameter at breath height and merchantable height for trees at Heritage Park, it was recorded as 15.40411, 32.52397, and 6.880137 respectively and recorded 30.39466, 38.83511, and 17.26565 respectively for teak plantation as shown in Table 2.

Table 2. Descriptive statistics of the measured variables

Location	Variable	Minimum	Maximum	Mean	Standard Deviation
Heritage Park n = 146	THT (m)	6	21	15.40411	3.029348
	DBH (cm)	10.6	58.4	32.52397	7.760851
	MHT (m)	0	13	6.880137	2.132107
Teak Plantation n =131	THT (m)	12.5	50	30.39466	6.776592
	DBH (cm)	13.5	65.8	38.83511	9.124826
	MHT (m)	3.3	28	17.26565	4.224194

n= Number of Trees. THT = Total Height, DBH = Diameter at Breast Height, MHT = Merchantable Height.

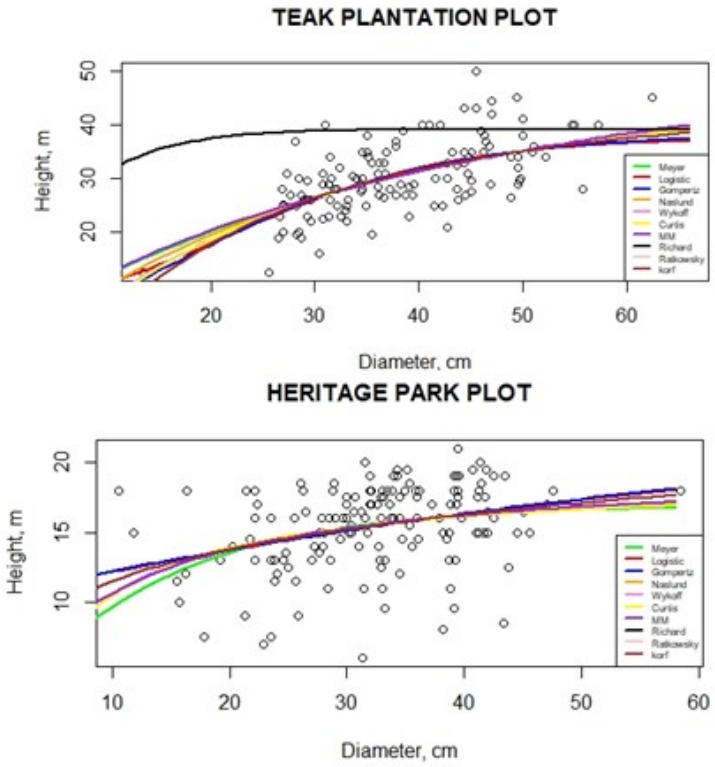

Figure 3: Fitted height-diameter curves of the ten models for Heritage Park and Teak Plantation.

Table 3: Model parameter estimates and fit statistics for Teak Plantation and Heritage Park

Model	Parameters Estimate			Fit Statistics					
Name	**a**	**b**	**c**	**RMSE**	**AIC**	**BIC**	**R^2**	***Rank***	***S-W***
Teak Plantation	n = 131								
Meyer	46.744082	0.025797		5.376419	816.4364	825.062	0.3753886	23	0.7489
Naslund	2.089771	0.129905		5.368115	816.0314	824.657	0.3773166	16	0.783
Wykoff	3.99009	-23.8073		5.357165	815.4964	824.122	0.3798545	8	0.7813
Curtis	53.617	23.169		5.356499	815.4638	824.0894	0.3800086	7	0.7811
MM	70.47	53.94		5.388694	817.0339	825.6594	0.3725334	32	0.7419
Richard	37.91411	0.06211	2.48079	5.361371	816.6826	828.1833	0.3836952	19	0.7046
Gompertz	37.29716	3.42802	0.07129	5.358871	816.5604	828.0612	0.3842697	17	0.6897
Ratkowsky	51.583	20.283	-1.852	5.37578	817.3858	828.8866	0.3803779	30	0.7753
Korf	-46.9353	47.0390	1.2696	5.373332	817.2664	828.7672	0.3809421	29	0.7533
Logistic	36.26697	7.61834	0.09344	5.35843	816.5388	828.0396	0.384371	17	0.7033
Heritage Park	n = 146								
Meyer	15.65772	0.07631		2.918517	731.0703	740.0211	0.078234	36	0.000479
Naslund	0.941211	0.235705		2.906529	729.8684	738.8192	0.08579113	23	0.0002079
Wykoff	2.87259	-7.16662		2.909353	730.152	739.1028	0.08401363	26	0.0001856
Curtis	17.562	6.829		2.911415	730.3589	739.3097	0.08271489	28	0.0001872
MM	18.655	9.996		2.900375	729.2495	738.2004	0.08965803	16	0.0002171
Richard	4.333e+01	4.86e-04	2.688e-01	2.892957	729.4844	741.4188	0.100598	19	0.0001126
Gompertz	21.17056	0.82480	0.02204	2.885311	728.7115	740.646	0.1053462	11	7.783e-05
Korf	-86.7035	2.9696	0.1424	2.895552	729.7462	741.6806	0.0989838	12	0.0001189
Ratkowsky	38.51	113.36	80.59	2.886003	728.7816	740.716	0.1049171	22	7.09e-05
Logistic	19.22662	1.07848	0.03394	2.884578	728.6374	740.5718	0.1058006	10	8.254e-05

a,b,c: Regression parameters, AIC: Akaike Information Criterion, RMSE: Root Mean Square Error, BIC: Bayesian Information Criterion, R^2: Coefficient of Determination. $\sum$ ***Rank****: Sum Rank, S-W: Shapiro-Wilk.*

DISCUSSIONS

The growth models play an important role in describing the forest stocking. The tree variables such as height and diameter has been used by many authors to give information about the stocking of the forest and for future prediction. Scatter plot was done to ascertain the relationship that exist between the height and diameter of the tree in the study area as shown in figure 1. This gives insights about the models to be considered for the study. The scatter plot revealed a non-linear relationship (Figure 1). This study used ten non-linear models with the consideration of five models with 2- parameters and 3-parameters each. The results presented in Table 3 showed the performances of the ten models considered for this study. The coefficient of determination R^2 values from Ordinary Least Squares (OLS) are low for all the models considered for the two study areas used. Shamaki (2016) also observed low R^2 values for his study in height-diameter relationship models for teak plantation in Nimbia Forest Reserve, Nigeria. He reported that the results confirm the height-diameter relationship can be influenced by other factors such as stand variables like quadractic mean diameter, basal area, site quality and climatic variables. This implies that the use of diameter alone as the independent variable will not adequate predict heights accurately.

The result showed that 2-parameter Curtis and 3-parameter Logistic h-d models provided the best prediction of tree height in Teak Plantation and Heritage Park respectively.In teak plantation, Curtis showed as the best model with smallest RMSE, AIC, BIC, high R^2 and small sum rank of 5.356499, 815.4638, 824.0894, 0.3800086, and 8 respectively. In Heritage Park, Logistic

showed as the best model with smallest RMSE, AIC, BIC, highest R^2 and small sum rank of 2.884578, 728.6374, 740.5718, 0.1058006, and 10 respectively. According to Ogana (2018) and Tewari and Singh (2018), two models are the same provided the differences between their AICs are less 2. From the result, it is observed that the differences in the AIC values are less than 2. This mean that all the models used for this study behaved in the same manner in estimating heights.

Furthermore, Shapiro-Wilk (S-W) test of normality used to ascertain the assumption of normality for the ten h-d models used for the purpose this study. The results from the Table 3 above showed that all the h-d models in Teak plantation agreed with the assumption of normality at 5% level of significance with p-value > 0.05. All the ten h-d models in Heritage Parkviolated the assumption of normality at 5% level of significance with p-value < 0.05.Also, the models followed the expected h-d curve of monatomic increment, inflection point and asymptotic value for all the two locations.

These models (Table 3) were also used in the study carried out by Ogana (2019) to predict the tree height of Ikrigon and Cross River (CRS) Forest Reserve respectively. The result from his study showed that Gompertz and Meyer were the best models for the prediction of tree height for the two forest reserves. This contradicts the results found for this study as Curtis and Logistics areconsidered as the adequate models for predicting the heights in the two study areas. This implies that models used for height prediction might be location and species specific. This is as a result of the performance of the same models used in different location and tree species with different outcome.

Mehtätalo *et al.* (2015) reported that 2-parameter Curtis and Naslund were more consistent in predicting the tree height than other models. This is similar to the result for this study for Teak plantation but not in agreement with the result observed in the Heritage Park which considered 3-parameters Logistics as the best model for the study area. The graphs in figure 3 (qualitative results) as observed conform to the quantitative resultsrecorded for Teak Plantation and Heritage Park respectively (Table 3).

CONCLUSION

Based on a comprehensive data set, height-diameter functions were fitted for 277 trees from two locations, including 131 trees in Teak Plantation and 146 trees in Heritage Park, University of Ibadan. Ten height-diameter models were used in this study andthey gave useful precise estimates of the tree heights for accurate predictions.

RECOMMENDATIONS

Based on the results of this study it can be recommended that:

i. Curtis and Logistic can be used for predicting height of the tree species under consideration in the study area.These models are useful tools that inform the management of the university about the available forest resources for proper forest management and decision making.
ii. Caution should be taken when these models are being used beyond the university because of changes in the ecological factors. The model can be extended for further investigations that improve it flexibility to be used in other regions.

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