Journal of Research in Forestry, Wildlife & Environment Vol. 10(4) December, 2018
http://www.ajol.info/index.php/jrfwe
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E-mail: jfewr@yahoo.com
ISBN: 2141 – 1778
Ebeniro, 2018

HEIGTH-DIAMETER MODELLING OF MIXED TREE SPECIES IN IBADAN

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ABSTRACT

Accurate tree height and diameter at breast height (dbh) are important input variables for growth and yield models. Height-Diameter models adequately describe the relationship between both tree characteristics at stand level. This study was carried out to model height-diameter relationships of mixed tree species in and around the departments of Forest Resources Management and Wildlife and Ecotourism, University of Ibadan. Five commonly used non-linear growth functions were selected as candidate base models and were fitted to individual tree height-diameter data of mixed tree species. The study area hosts about 24 tree species dominated by Eucalyptus camaldulensis, Eucalyptus tereticornis, Nauclea diderichi, Terminalia superba, and Terminalia randii. Complete enumeration was carried out in the study area. A total number of 115 trees were identified and measured. The sampled trees were used to estimate the 5 nonlinear model parameters for about 24 species of trees pooled together. Model 1 had a RMSE, SEE, AIC and R^2 value of 4.256, 4.295, 122.8979, and 0.920 respectively. Model 2; 4.083, 4.122, 122.4568 and 0.927 respectively. Model 3; 4.096, 4.135, 172.8217 and 0.926. Model 4; 5.194, 5.239, 123.2952.and 0.881 and model 5; 4.088, 4.127, 122.8179, and 0.926 respectively. Among the Five models, Shreuder model (M2) demonstrated the best fit and accounted for the greatest proportion of total height variations (R^2 = 92.7%).Residual plots were plotted for each model as a means of verifying the validation of the equation.

Keywords: Height-Diameter Models, Mixed Tree Species, University of Ibadan.

INTRODUCTION

The information's required for decision making in forestry are acquired by means of forest inventories, systems for measuring the extent, quantity, and condition of forests (Penman *et al.*, 2003). Tree volume, site index and other important variables in forest growth and yield models are estimated by essential inventory measures such as; trees height and diameter at breast height (dbh). Tree diameter can be measured easily with little cost while tree height however, is more difficult and costlier to measure (Colbert *et al.*, 2002). More often, only a subset of trees in the sample plots with measured dbh is also measured for height. Therefore, quantifying the relationship between total tree height and dbh is required for predicting heights of the remaining trees.

Height growth of trees is one of the most characteristic biological features. It is generally accepted that tree height depends not only on age, diameter, species, and species mixture but also on the quality of the site where the trees grow. Information on tree heights is essential in forest inventories for computing tree volumes. Also, growth and yield simulators usually need information on tree height, either at the individual tree, plot, or stand level, to predict forest dynamics, dominant height, and site index (e.g., Huang *et al.*, 2000). However, field measurement of tree height is rather tedious compared to measuring tree diameter. That is why many forest inventories save time and effort by predicting tree heights using height–diameter (H–D) models instead of direct measurements. Height measurements from a subsample of trees on each sample plot or sample plot cluster may be utilized for improved prediction of the local H–D curve. The accurate information of tree height is required for both forest management and research.

Diameter at breast height is one of most fundamental external characteristics or measured variables from forest trees which may be studied from various aspects. Diameter distribution and related statistical models plays an important role such as in growth modeling. Growth modeling has been an intrinsic part for forest management planning and research. Therefore, it is necessary to know the type of diameter distribution function and its parameters to identify the appropriate model for characterization (Mohammed *et al.*, 2009). A basic planning for natural resources requires qualitative and quantitative information, which is usually obtained by measuring the characteristics of stands (Zobeiry, 1994). One way of obtaining this basic information is the tree distribution in diameter classes, which allows the tree marker to interfere in stands more confidently to reserve the stand structure (Martaji*et al.*, 2000).

Several model forms have been used in predicting height-diameter relationships for different species and in different regions. The approaches used for developing height-diameter models have varied from being simple to complex, including linear and nonlinear models (HaruniKrisnawati *et al. 2010*). For a given species, height-diameter relationship differs from stand to stand due to different stand densities and site qualities, sometimes even within the same stand, variation might be high (Calama and Montero, 2004). Also, height-diameter relationship may change over time (Curtis, 1967). For more comprehensive and accurate height-diameter models, additional variables describing stand density (e.g. basal area or number of stems) and site quality (e.g. site index) should be included into the models (e.g. Sharma and Zhang, 2004; Temesgen and Gadow, 2004; Sharma and Portan, 2007; Newton and Amponsah, 2007). However, getting information on such attributes demands a lot of resources, and therefore cannot be considered for general purpose models.Two kinds of H–D models have been reported in the literature: models that express the height as a function of tree diameter only and models that include additional stand-level predictors in the model. Soares and Tomé (2002) call these two model types local and regional H–D models, respectively, whereas others use the term "generalized" for the latter model type (Temesgen and von Gadow 2004; Paulo *et al.*, 2011). However, both these models can be fitted at the plot-level and regionally.

Height and diameter are among the most important tree characteristics and their relationship is not only used to characterize the vertical stand structure, but also is fundamental for elaborating and applying many growth and yield models. The height-diameter relationship has been the subject of numerous studies, resulting in the development of both local and generalized models (Temesgen Gadow 2004, Lei *et al.*, 2009), as well as purely deterministic (Schröder and Àlvarez González 2001, López Sánchez *et al.*, 2003) and mixed-effects models (Calama and Montero 2004, Saunders & Wagner 2008, Crecente-Campo *et al.*, 2010). Local height-diameter models adequately describe the relationship between both tree characteristics at stand level, if derived from a sufficiently representative sample of diameter height measurements, and are often used in forest inventories. However, expansion of the predictions to a wider region would probably lead to biased predictions, as the relationship is highly dependent on the growth conditions and stand characteristics (López Sánchez *et al.*, 2003). This has led to the elaboration of numerous generalized height-diameter models that include stand level variables such as density, age, basal area, site index, and mean and dominant heights and diameters.

Despite the importance of height-diameter model in forest growth and yield prediction systems and the period of time over which these models have existed for other species in other regions, relatively little has been published on height-diameter models for mixed tree species. Hence, the objective of this study which is to use height-diameter model in predicting tree height of mixed tree species in and around the department of Forest Resources Management and the department of Wildlife and Ecotourism.

MATERIALS AND METHODS

Study Area

The data for this study was extracted from an inventory carried out within and around the department of Forest Resources Management and department of Wildlife and Ecotourism, University of Ibadan for the purpose of updating its management plan. The study area is located between Longitudes 7^0 44' N and $7^0$46' Latitudes 3^0 89' E and $3^0$92'E at an altitude of 199 m above sea level and a total area of 216.3/km^2. The top soil of the study area is more or less sandy loam. The relief is undulating and the area is well drained.

The University of Ibadan is located in the northern limit of the lowland rainforest zone. It lies in a transitional zone between the rainforest and the derived savanna zone. The climate of the campus is relatively dry with two distinct seasons. The wet season is usually between March and November and the dry season usually between November and March.

Generally, the dry months of the year have relatively lower humidity than the wet months. Strong winds are usually experienced before and at the start of the rainy season.The vegetation is floristically dominated by trees, shrubs, and open grassland. Some of the exotic tree species found there are: *Eucalyptus camaldulensis*, *Eucalyptus tereticornis*, *Afzelia bella*, *Anogeissius leiocarpa*, *Azadirachta indica*, *Camelia sinensis*, *Cedrela odorata*, *Delonix regia*, *Khaya ivorensis*, *Khaya senegalensis*, *Mansonia altisima*, *Milicia excelsa*, *Nauclea diderrichii*, *Pentaclethra macrophylla*, *Pinus caribaea*, *Raphia palm*, *Roystonea regia*, *Senna fistula*, *Stereospermum tetragonum*, *Tectonia grandis*, *Terminalia randii*, *Terminalia superba*, *Treculia africana*,*Triplochiton scleroxylon*, .

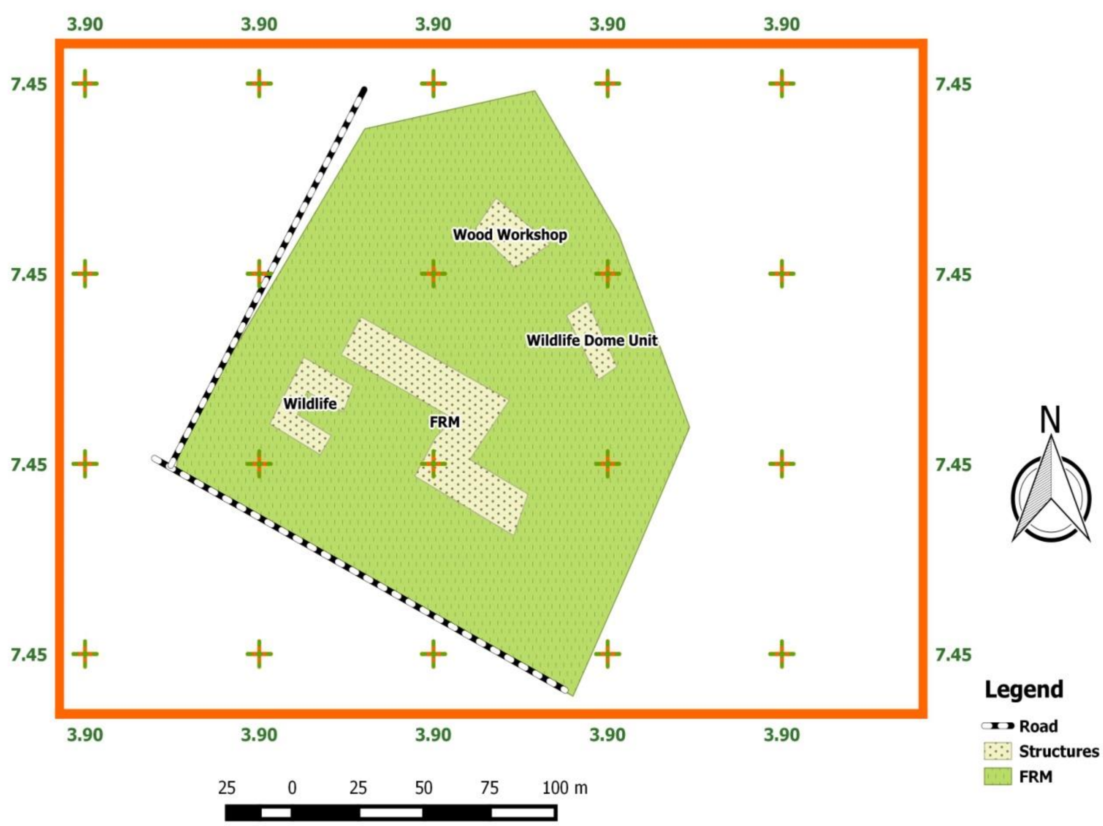

Fig 1. Map of the Study Area.

Data Collection

Sampling Procedure

Complete enumeration was carried out in the study area. The study area hosts about 24 tree species dominated by *Eucalyptus spp*, *Terminalia superba*, *Nauclea diderichi and Terminalia randii*. Trees with diameter at breast height less than 5 cm were neglected. A total number of 115 trees were identified and measured.

Measurement of Tree Growth Variables Required for H-D Modeling

The following tree growth variables where measured:

1. Total height (m).
2. Merchantable height (m)
3.Diameter at breast height over bark (cm)

The following instruments were used during the data collection;

1. Diameter tape: for measuring diameter at breast height (dbh)
2. Spiegel Relascope: for measuring height and diameter at various points.

Data Processing
The data processed includes:
Basal area.

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

Where:
D = diameter at breast height
π = 3.142

Model Specification

Non-linear relationship between height and diameter was confirmed with a scattered plot diagram of height against dbh. Five different non-linear models (Table 1) were used to fit height-diameter relationship. All those models were parsimonious (possessing few parameters) and therefore have been commonly used for modeling various trees and stand attributes (e.g. Hui and Gadow (1993), Shreuder et al., (1982), Wykoff *et al*., Meyer (1940). Loetsch *et al*., (1973)). The models are of the following form as shown in Table 1.

Data Analysis
Model Evaluation

The parameters were estimated using a non-linear least-squares procedure in SPSS version 20. The fitted models were then evaluated using all of the following criteria: Significant parameter estimates, Akaike information criterion (AIC), Root mean squared error (RMSE), Standard error of estimate (SEE), and Coefficient of determination (R^2). Model resulting with the highest (R^2) and the least RMSE, and SEE and the smallest values of AIC were selected as the best model.

1. Akaike information criterion (AIC): This is one of the most reliable criteria to compare the models with different parameter numbers (Burnham and Anderson, 2002). The smaller the AIC value, the better the model. It is defined as:

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

Where:
N = Number of observations
RSS = Regression sum of squares
P = Parameter

2. Root mean squared error (RMSE): It is defined as:

$$RMSE = \sqrt{\frac{RSS}{n-p}} \ldots\ldots\ldots 3$$

Where
n = Number of observations.
RSS = Residual sum of squares.
P = Number of parameters

3. Standard Error of Estimate

$$SEE = \sqrt{\frac{SSE}{n-p}} \quad \ldots\ldots\ldots\ldots 4$$

Where:
SEE = Standard Error of Estimate
SSE = Sum of Square Error
n = Number of Observation

4. Coefficient of determination

$$R^2 = \frac{RSS}{TSS} \times 100 \quad \ldots\ldots\ldots\ldots\ldots 5$$

Where R^2 = Coefficient of Determination
RSS = Residual Sum of Square
TSS = Total Sum of Square

RESULTS

The results are presented in Table 4 and Figure 4 and 3. Different regression equations were derived for simple regression analysis. In Table 1, a total of five non-linear regression models were used i.e. tree height-diameter regression models. A total of 115 trees of varying species were sampled, the sampled trees were used to estimate the model parameters for about 24 species of trees pooled together.Not quite noticeable difference was found among four predictive abilities of the height-diameter equations (M1, M2, M3, and M5). Model 1 had a RMSE, SEE, AIC and R^2 value of 4.256, 4.295, 122.8979, and 0.920 respectively. Model 2; 4.083, 4.122, 122.4568 and 0.927 respectively. Model 3;

4.096, 4.135, 172.8217 and 0.926. Model 4; 5.194, 5.239, 123.2952.and 0.881 and model 5; 4.088, 4.127, 122.8179, and 0.926. All of which had closer value except for model 4 (Table 4)

As a means of verifying the validation of the equation, residual plots were plotted for each model, as presented in Figure 4. For model 1, the residual line lies a bit scattered along the horizontal line than not. This is also evident in model 2, 3, and 5 respectively. However, the case is not the same for model 4 which shows a more dispersed distribution along the horizontal axis.

Table 2 shows the descriptive statistics for the pooled data. A total of 115 different trees were measured in the study area. The diameter at breast height shows the highest standard error (2.4300), while merchantable heights have the least standard error value of 0.4320. The mean total height value of the trees shows that majority of their stems are tall trees. This may be because they are open grown trees with less or no competitive tree(s). *Eucalyptus camadulensis* has the highest number of occurrence (24) and followed by *Terminalia superba* (20) as shown in Table 3. Figure 2 shows that about 71 trees fall within the range of 11-20 cm diameter class which constitutes about 80% of the trees in the study area. The diameter class <10cm, 81- 90cm, 91-100cm, 121-130cm, ≥130cm has only one tree. Figure 3 shows that the relationship between total height and diameter at breast height is a nonlinear relationship hence the use of the nonlinear models to predict height from diameter at breast height.

Table 1: Models considered

No.	Models	References	
M1	$HT = 1.3 + aD^b$	Hui and Gadow (1993)	… (6)
M2	$HT = 1.3 + e^{a+b/(D+1)}$	Shreuder*et al.*, (1982)	… (7)
M3	$HT = 1.3 + aD/(b + D)$	Wykoff *et al.*, (1982)	… (8)
M4	$HT = 1.3 + D^2 + (a + bD^2)$	Meyer (1940)	… (9)
M5	$HT = 1.3 + ae^{b/D}$	Loetsch*et al*., (1973)	... (10)

H = Total height (m); D = Dbh (cm); a, b = Parameters; e = exponential

Table.2 Summary statistics of variables required for H-D modeling.

Variables	Minimum	Maximum	Mean	Std. Dev.	Std. error	Variance
DBH (cm)	9.50	143.20	29.9180	26.2207	2.4300	1023.093
THT (m)	3.40	26.60	13.7879	6.1267	0.5690	20.229
MHT (m)	1.60	23.00	8.2259	4.6559	0.4320	37.537
BA	0.72	161.10	12.3820	24.6825	2.2900	21.678

n = 116, DBH; Diameter at breast height, THT; Tree Total Height, MTH; Merchantable Height, BA; Basal Area.

Table 3: Frequency distribution of the species.

S/N	Species	Family	Frequency
1	*Afzeliabella*	Leguminosae	3
2	*Anogeissiusleiocarpa*	Combretaceae	1
3	*Azadirachtaindica*	Meliaceae	1
4	*Camelia sinensis*	Theaceae	1
5	*Cedrelaodorata*	Meliaceae	2
6	*Delonix regia*	Fabaceae	2
7	*Eucalyptus camaldulensis*	Myrtaceae	24
8	*Eucalyptus Tereticornis*	Myrtaceae	16
9	*Khaya ivorensis*	Meliaceae	2
10	*Khaya senegalensis*	Meliaceae	2
11	*Mansoniaaltisima*	Sterculiaceae	1
12	*Miliciaexcelsa*	Poaceae	1
13	*Naucleadiderrichii*	Rubiaceae	17
14	*Pentaclethra macrophylla*	Leguminosae	1
15	*Pinus caribaea*	Pinaceae	3
16	*Raphia palm*	Arecaceae	1
17	*Roystonea regia*	Arecaceae	2
18	*Senna fistula*	Fabaceae	1
19	*Stereospermumtetragonum*	Bignoniaceae	1
20	*Tectoniagrandis*	Lamiaceae	2
21	*Terminalia randii*	Combretaceae	8
22	*Terminalia superba*	Combretaceae	20
23	*Treculiaafricana*	Moraceae	1
24	*Triplochitonscleroxylon*	Malvaceae	2

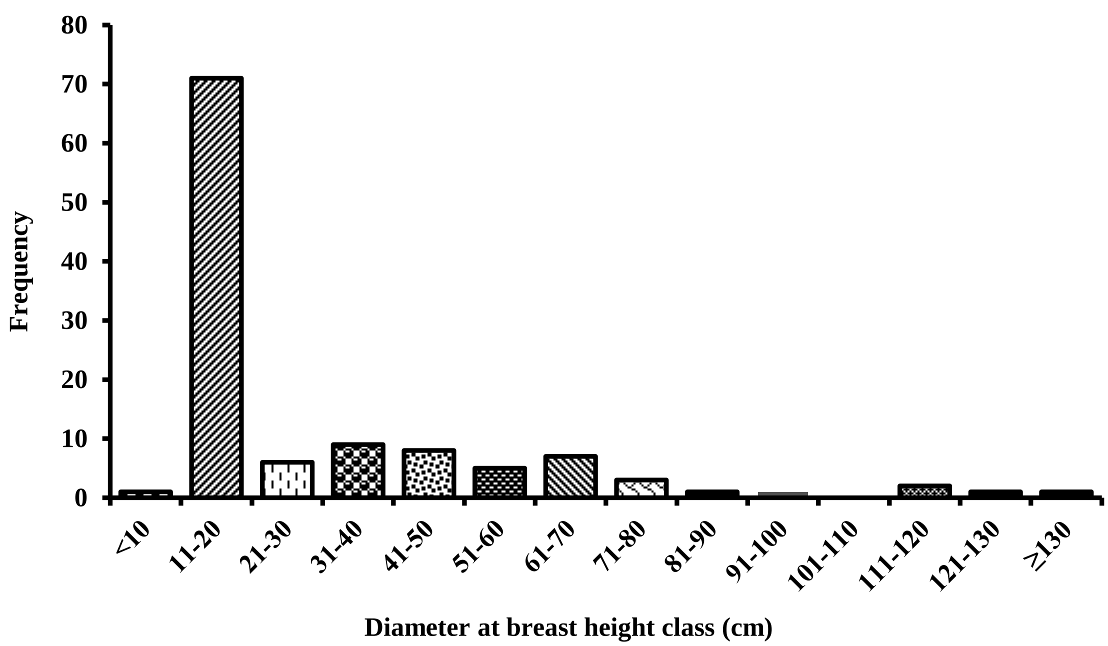

Figure 2: Diameter distribution for the trees in the study area

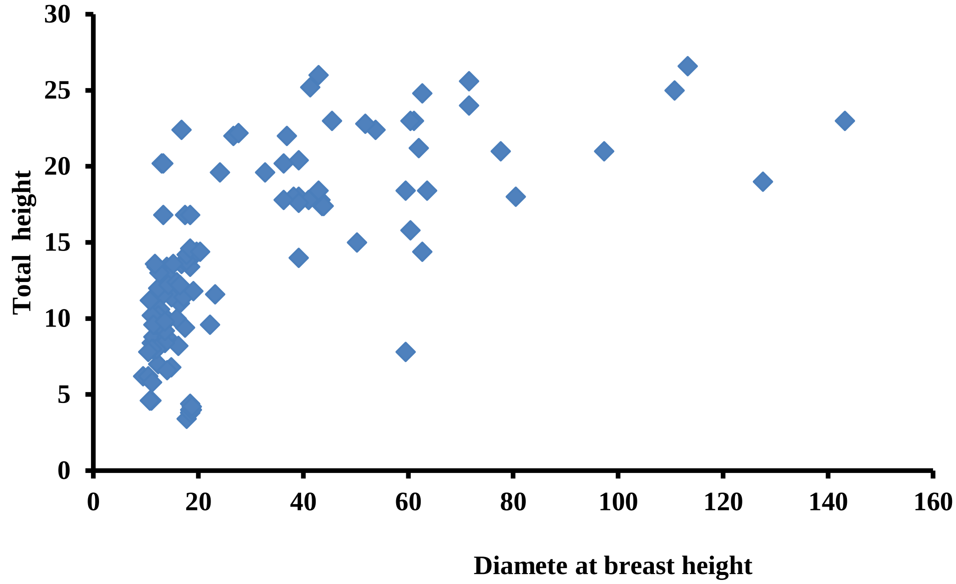

Figure 3: Relationship between Total height and diameter at breast height

Table 4: Model parameter estimates and fit statistics

		Parameter estimates		**Fit Statistics**			
No.	**Models**	**a**	**b**	**AIC**	**RMSE**	**SEE**	**R^2**
1	$HT = 1.3 + aD^b$	3.06276	0.4353	122.8979	4.256	4.295	0.920
2	$HT = 1.3 + e^{a+b/(D+1)}$	3.18705	14.6735	122.4568	4.083	4.122	0.927
3	$HT = 1.3 + aD/(b + D)$	27.7796	27.8888	172.8217	4.096	4.135	0.926
4	$HT = 1.3 + D^2 + (a + bD^2)$	10.8761	-0.9990	123.2952	5.194	5.239	0.881
5	$HT = 1.3 + ae^{b/D}$	23.7865	-13.4495	122.8179	4.088	4.127	0.926

n=116, HT: Height, a,b: Regression parameters, AIC: Akaike Information Criterion, RMSE: Root Mean Square Error, SEE: Standard Error of Estimate, R^2: Coefficient of Determination.

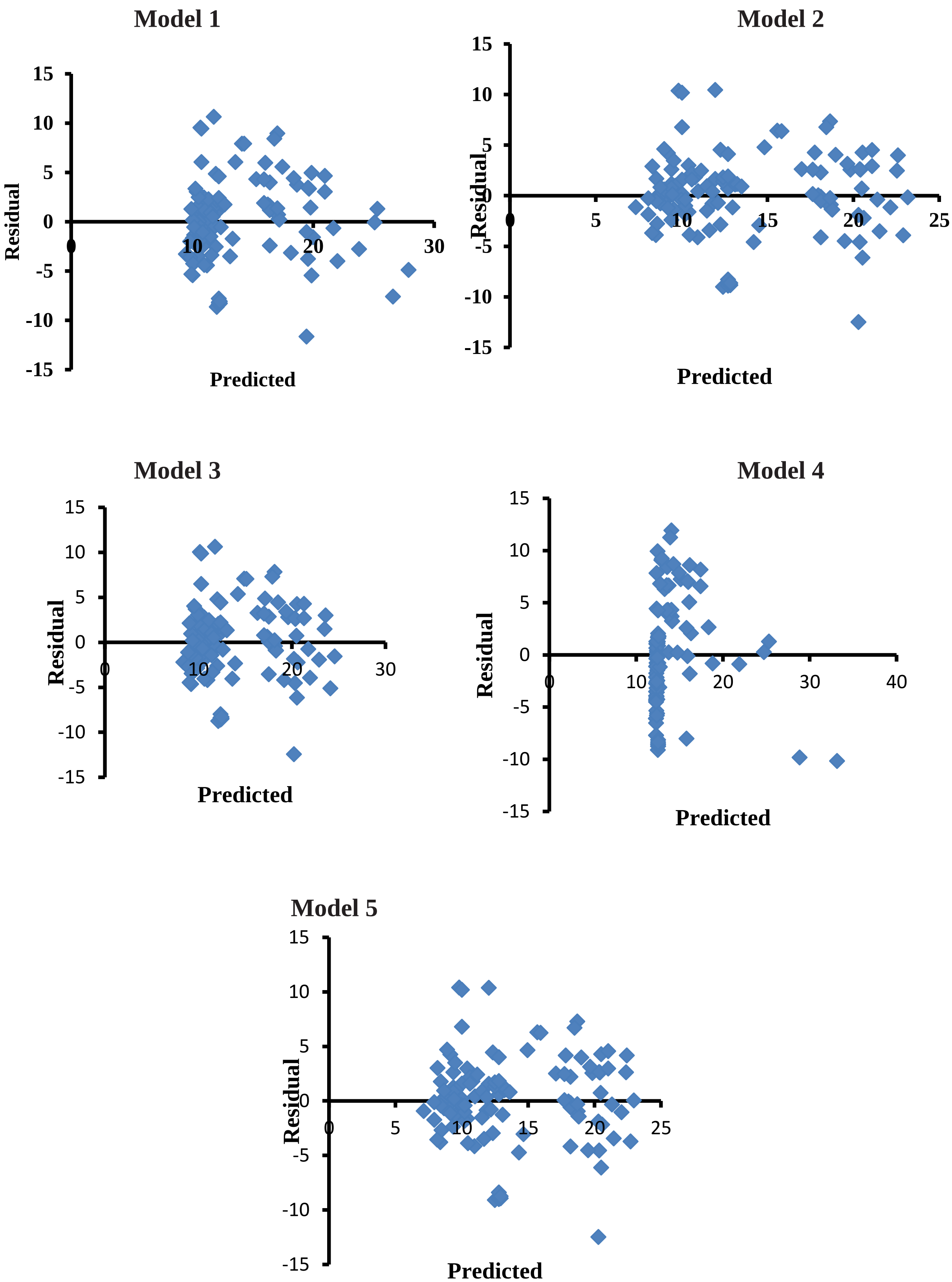

Figure 4: Residual Graph Plots

DISCUSSION

Since the study area comprises of mixed tree species, determination of the height-dhb relationship was carried out for the different tree species. Using the least square method, the strong correlated relationship between height and diameter at breast height was limited to a non-linear equation as shown in Table 1. This was done by determining the unknown parameters (i.e. regression constant and regression slope) chosen to minimize the sum of squares error over the whole observation. All the models used to depict the functional relationship between total height and diameter at breast height shows high value for coefficient of determination (R^2). But, model 2 shows the highest R^2 value and lowest SEE, and RMSE value as seen in Table 4. This high value means that the proportion of the variation present in the total height (the dependent variable) is as a result of the changes in the high values of diameter at breast height. In other words, the diameter at breast height (independent variable) explains about 92.0%, 92.7%, 92.6, 88.1% and 92,6% of the variation in the total height (dependent variable) of model 1,2,3,4 and 5 respectively. The remaining percent can be explained by unknown, lurking variables or inherent variability. The high R^2 values indicates that the regression line fits the data set, though not perfectly but highly. This affirms that the diameter at breast height of a tree species can well be made a function of its total height (Opii, 1985; peng *et al.,* 2001; Colbert, 2002; Oner *et al.,* 2006). From the characteristics of the models as in Table 5; model 2 with the lowest SEE and RMSE and high R^2 value, is a good model for height prediction (Avery and Burkhart, 2001).

However, from the residual plot as shown in Figure 4, it was shown that model 4 has a more dispersed residuals and outliers along the horizontal axis which makes it not a very good representative of the data set. The diameter distribution irrespective of species class shows a negative exponential or inverse J pattern, which is typical of an uneven aged forest stand. Also, the relationship between total height and diameter at breast height is a nonlinear relationship as shown in Figure 3, hence the use of the nonlinear models to predict height from diameter at breast height.

CONCLUSION

Tree height-diameter relationship will be useful to forest managers in predicting tree's height. Tree height is an important variable which is used for estimating stand volume and site quality and for describing stand vertical structure. Measuring tree heights is costly however, and foresters usually welcome an opportunity to estimate this variable with an acceptable accuracy. Missing heights may be estimated using a suitable height–diameter function. Based on a comprehensive data set which includes very small diameters, such height–diameter functions were fitted for 115 trees of varying specie found around and within the department of Forest Resources Management and the department of wildlife and Ecotourism, University of Ibadan.The height-diameter model used in this study gave reasonably precise estimates of tree heights and could be used to predict the height of the tree species under consideration.Among the Five models, Shreuder model (M2) demonstrated the best fit and accounted for the greatest proportion of total height variations (R^2 = 92.7%). The model was mathematically flexible and biologically robust. Based on the results of this study it can be recommended that the shreuder model (M2) be used for predicting height of the tree species under consideration in the study area.

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