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DEVELOPING STEM TAPER EQUATION FOR TECTONA GRANDIS (TEAK) PLANTATION IN AGUDU FOREST RESERVE, NASARAWA STATE, NIGERIA.

SHUAIBU, RABI BINTA

Federal University Dutsin-Ma, Faculty of Agriculture and Agricultural Technology,
Department of Forestry and Wild Life Management, P.M.B 5001, Dutsin-Ma, Katsina State, Nigeria.

E-mail: srabibinta@yahoo.com, rshuaibu@fudutsinma.edu.ng
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ABSTRACT

Stem taper equations were developed for Tectona grandis (teak) plantation in Agudu Forest Reserve, Nasarawa State, Nigeria. Data for fitting and evaluation of the stem taper equations were collected from 100 trees (70 trees for model development and 30 trees for model validation) through purposive selective sampling with the use of meter tape and spiegal relaskop. The trees were purposely selected to ensure coverage of a full range of tree sizes. Four individual stem taper equations were developed and compared for bias and precision using regression techniques. The data consisted of Dst; DBH; diameter at variable distance along the stem; and total height of individual tree. The dbh ranged from 23.0 to 36.0 cm, and the total height ranged from 11.6 to 20.6m. SPSS was used to generate the equations. Various criteria were used to evaluate the ability of each model to predict a specified dependent variable. The four taper equations generated were: $d=0.020+0.869(D)+0.081(h/H)-0.149(h^2/H)$; $d^2=0.162+0.801(D^2)+ 0.069(h/H-1)+0.090(h^2/H^2-1)$; $\ln d=0.156-0.926\ln(D)+0.453-\ln\frac{h}{H}0.231; \ln\frac{h^2}{H^2}$ *and* $\ln d^2=0.296 + 0.928 \ln (D^2)+1.183 \ln(\frac{h}{H}-1)-0.597\ln(\frac{h^2}{H^2}-1)$. *The correlation coefficients of the four models developed were 0.97, 0.95, 0.98 and 0.98 respectively, while the coefficients of determination (R^2) were 94%, 91%, 96% and 96% respectively. The F-ratio was significant ($p<0.05$) with small SEE (0.01, 0.01, 0.02 and 0.05 for the models, respectively). The equation developed was fitted to the data, and the resulting equations possessed desirable statistical properties and model behaviors. Therefore, developing these equations for effective and sustainable management of Teak stands is imperative.*

Keywords: Data, Stem Profile, and Taper Equations.

INTRODUCTION

Foresters have a long history of being aware of the variability in individual tree form and trying to model it so that the overall stem profile can be described more precisely. From the diameter and height growth information, changes in stem form and hence, in volume growth can be determined for a given tree (Khamsene, 2009). Stem taper is defined as the rate of change in diameter with height along the stem, whereas stem profile reflects the shape of the entire stem (Gray, 1956). A taper equation describes the entire profile of the stem mathematically. It is a mathematical description of the relationship between diameter and height. West (2003) defined taper function as a mathematical function, which predicts the diameter of the stem of an individual tree at any distance along its stem. Louis (2005) defined taper equation as a mathematical description of the relationship between diameter and height and allows the estimation of diameter or height at any point along the stem (from stump to tip), thereby permitting the calculation of volume to any merchantability limit. It can be expressed as a function of height above ground level, total tree height, and diameter at breast height (Clutter *et al.* 1983). Taper equations are very useful as they provide information about diameter at any height, and height at any diameter based only on commonly taken tree measurements (Byrne and Reed, 1986). Tree trunk diameter generally decreases from the base to the top. The way this reduction takes place determines the trunk form (Philip, 1994). The major advantage of taper equations is their ability to predict the diameter of a stem at a given height or, following re-arrangement, to predict the height of a stem with a given diameter at a given height (Birger, 2011).

Reliable methods of estimating taper or stem profile of growing forest stock for planning of the uses of forest resources are needed. Accurate, up-to-date information on forest cover and growing stock of forests and trees are basic ingredients for planning and policy development (FAO, 2003). *Tectona grandis* is an exotic species that is important for poles and timber production, the wood produce an attractive veneer, very durable, saws fairly, seasons easily and it has economic value in terms of market price. It is therefore, very important for regional and national development. Teak has been widely established in plantations as an exotic species for producing high quality poles and timber with varied degree of success (Ball *et al.* 1999).

The assessment of *Tectona grandis* in order to develop taper equations needed to estimate the variables, and identifying the kind of management practices necessary for its growth is therefore crucial to the sustainable management of the resources. From the diameter and height growth information, changes in stem form can be determined for a given tree through taper equations. *Tectona grandis* has been one of the most preferred species for investment opportunities, due to its high wood quality and excellent growth performance. Information on wood management options and stem profile are urgently needed to derive the real stock and estimated value of *T. grandis* available in the country.

The difficulty of having an appropriate taper equations developed for *Tectona grandis* has resulted in the use of models generated for other tropical tree species. These models are not consistent with the morphology of Tectona grandis. Taper equations are generally species specific, for each species a separate set of parameters for a fixed taper equation that identifies the unique bole shape is needed. Also, effective management of teak plantation requires information on the stem taper, especially if poles are needed. Therefore, developing taper profile models for the Tectona grandis in Agudu Forest Reserve of Nasarawa State, Nigeria is very important. The objective of this study is to develop taper equations that will estimate the stem profile of *Tectona grandis* trees and stands in Agudu Forest Reserve, Nasarawa State and in other regions with similar vegetation and environmental factors.

MATERIALS AND METHODS

The Study Area

This study was carried out in *Tectona grandis* (Teak) plantation established in Agudu Forest Reserve situated at Obi Local Government Area of Nasarawa State, Nigeria. It is located between latitude 08º 32" N and Longitude 08º 18" E (Collins maps.com). Obi Local Government have an area of 967 km² and a total population of 148,874 at the 2006 census. Farming is a common feature within the communities in the area. Obi Local Government Area shares boundary to the North with Lafia Local Government Area, to the West with Doma L.G.A, to the South with Keana L.G.A, and to the East with Awe L.G.A.

The *Tectona grandis* plantattion was established in 1982-1984 and managed previously by forestry section under the Plateau State Ministry of Agriculture Lafia, and handed over the management to Nasarawa State Ministry of Agriculture Lafia after the creation of Nasarawa State. It was latter handed over to Forestry and WildLife Department, Faculty of Agriculture Nasarawa State University, Keffi. The size of the plantation is 161.28ha.

Data Collection

The data for this study were collected in April, 2013 through nondestructive sampling method with the use of Spiegel Relascope and metre tape to measure the diameter and height of Teak stand. Selective sampling design was adopted; the data were collected from four sample plots which include 2 Permanent Sample Plots (PSP) and 2 Temporary Sample Plot (TSP) that was established in February, 2008. Each sample plot contained an average of 72 trees. A total of 100 trees with desirable characteristics were purposively selected for enumeration, 70 trees were measure for calibration (model generation) while 30 trees were measure for model validation. Healthy trees with more typical growth form and trees that would allow a clear view along most of the stem were selected, dead trees and trees with abnormalities such as limb, bulge, leaning trees, trees that are forked were avoided. This was because the taper equations developed in this research are for the growing stands known as living trees of commercial value classified as poles and timber which must meet the requirements for commercial poles and logs. From the forest reserve, the following measurements were taken;

1. Diameter at 30cm above the ground level with the use of metre tape
2. Diameter at 80cm above the ground level with the use of metre tape
3. Diameter at 1.3m with the use of metre tape
4. Diameter at variable distance along the stem; 1.7m, 2m, 2.5m, and 2.8m intervals above the breast height diameter with the use of Spiegel Relascope
5. The base height and the top height was taken with Spiegel Relascope
6. The total height was obtained by adding the base height and the top height, and multiplies it by 10% which was the horizontal distance.

Data Analysis

The data collected was arranged in excel and the statistical analysis which include determination of total height, changing of diametr in cm to metre, estimation of basal area, volume, and form factor of the collected dataset was performed using Microsoft Excel. While the Statistical Package for Social Scientists (SPSS) was used to develop four regression equations relating tree diameter at any height and tree height at any diameter. The residual plots of the observed value versus the predicted value of the four equations developed were analyzed using regression analysis.

Models

A tree's taper was expressed as a function of diameter at any height (d), diameter at breast height (D), total height (H) and upper stem height (h). In this study, the taper of the stem of a tree is considered as a function of the independent variables, diameter at breast height; total height, and height of interest which is expressed as follows:

$$d = f(D, H, h) \quad \text{-- 1}$$

$$\frac{d}{D} = Y \quad \text{-- 2}$$

If $\frac{d}{D} = Y$, and

$$Y = ß_0 + ß_1(X) + ß_2\,(X^2) \quad \text{-------------------- 3}$$

Where; Y = dependent variable,
$ß_0$ = intercept,
X, X² = Independent Variables,
$ß_1$, and $ß_2$ are regression parameters,
D = tree diameter at breast height,
H = tree total height, h = height of interest (h ≤ H).

Where $Y = \frac{d}{D}$, then:

$$\frac{d}{D} = ß_0 + ß_1(X) + (X^2) \quad \text{------------------------ 4}$$

Where X = $[\frac{h}{H}]$, then:

$$\frac{d}{D} = ß_0 + ß_1\,[\frac{h}{H}] + ß_2\,[\frac{h^2}{H^2}] \quad \text{-------------------------- 5}$$

Where d = diameter at height h, h = height of interest, H = total height, and D = dbh. Cross multiplying equation 5 will give equation 6

$d = ß_0 + ß_1(D) + ß_2(\frac{h}{H}) + ß_3(\frac{h^2}{H^2})$------------- 6

If $Y^2 = ß_0 + ß_1(X-1) + ß_2(X^2-1)$.

Where $Y^2 = \frac{d^2}{D^2}$ and $X - 1 = \frac{h}{H} - 1$ then,

$d^2 = ß_0 + ß_1(D^2) + ß_2(\frac{h}{H} - 1) + ß_3(\frac{h^2}{H^2} - 1)$ ---7

The Logarithmic transformations of equation 6 and 7 resulted in equation 8 and 9.

$\ln d = ß_0 + ß_1 \ln(D) + ß_2 \ln\left(\frac{h}{H}\right) + ß_3 \ln\left(\frac{h^2}{H^2}\right)$ -- 8

$ln d^2 = ß_0 + ß_1 \ln(D^2) + ß_2 \ln\left(\frac{h}{H} - 1\right) + ß_3 \ln$ --- 9

Evaluation of the Models

The models were evaluated in order to test their plausibility and recommend them for application using the following statistical methods:

i. Significance of Regression

This was used in testing the overall significance of the regression equation. The critical value of F (that is, F-tabulated) at $p < 0.05$ level of significance was compared with the F-ratio (F-calculated). Where the variance ratio (F-calculated) is greater than the critical values (F-tabulated) such equation is considered significant and can be accepted for prediction.

ii. Multiple Correlation Co-efficient

The (R) measures the degree of association between two variables (Y-Dependent variable and X-Independent variable). The R- value must be high (> 0.50) for the model to be considered good fit (Mead *et al.* 1994).

iii. Coefficient of Determination (R^2)

The (R^2) measures the proportion of variation in the dependent variable that is explained by the behavior of the independent variable. In order for the model to be accepted, the R^2 value must be high i.e >50% (Thomas, 1977).

iv. Standard Error of Estimate (SEE)

The value must be relatively small for the model to be considered valid.

$$\sigma_{est} = \sqrt{\frac{\sum(Y - \bar{Y})^2}{N}} \quad \text{--------------------10}$$

Where $(Y-Y')^2$ = the squared errors of prediction,
N = observation

A paired student T-tests, and simple linear regression analysis were also applied to test the adequacy of the models and determine the significance of differences between measured values and the values they predicted. All the predicted values were compared to observed values, using student t-test; simple linear regression equation; and graphical analyses of residuals. The observed values were used as the dependent variable while the predicted values were used as independent variables.

Models Validation: According to Ajit, (2010), validation is a statistical test procedure that can ensure to a certain extent, the safe use of models. This was achieved by comparing the models' output (i.e. predicted diameter) with field results (i.e. observed diameter). The calibrating set comprised tree variables from seventy (70) trees (70%) which were used for generating the taper models. The validating set comprised growth variables from thirty (30) trees (30%). The validation process according to Marshall and Northway (1993), examines the usefulness of the models or validity. Marshal and Northway, (1993) maintained that for models with good fit, there should be no significant difference (p>0.05 or t-statistic < t-tabulated/critical) between the mean of the observed and predicted values with the result of the student t-test.

Statistical Indices

The following statistics were used to assess the goodness of fit for the models: Absolute Bias (AB), percentage Absolute Bias (AB %), Root Mean Square Error (RMSE), were calculated as follows:

$RMSE = \sqrt{\frac{1}{n}\sum_{i-1}^{n}(y_i - \hat{y}_i)^2}$ --------------------- 11

$Bias = \frac{1}{n}\sum_{i-1}^{n}(y_i - \hat{y}_I)^2$ --------------------------- 12

$\%Bias = 100 = \frac{\sum_i^n = 1(y_i - \hat{y}_I)/n}{\sum_i^n = 1\hat{y}_I/n}$ -------------------- 13

Where y_i = observed value and $\hat{y}_I$ = predicted value. The Root Mean Square Error (RMSE) must be relatively small for the model to be acceptable for management purposes (Adekunle *et al.*, 2013). Also, the value of Bias and %Bias must be relatively small for the model to be precise and accurate and suitable for use in practical surveys.

RESULTS

Four (4) forms of taper models (Two single functions and the logarithmic transformation of the single function regression models) were developed for tree estimation at any height along the stem. Table 1 and Table 5 show the summary of tree variables measured for calibration sample and validation sample respectively. Based on the fit statistics and residual plots, the four taper equations provided a strong fit to the data, the models are presented in Table 2. The correlation coefficients of the four (4) models generated were 0.97, 0.95, 0.98 and 0.98, respectively. The coefficients of determination are 94%, 91%, 96% and 96% respectively. The F-ratio was significant (p<0.05) with small standard error of estimate (0.01, 0.01, 0.02 and 0.05, respectively)

Table 1: Summary of Tree Variables Measured for Model Generation

Tree variables	Number	Minimum	Maximum	Mean	STDV	Range
Total Height (m)	70	11.6	20.2	15.86	2.17	8.6
DBH (m)	70	0.23	0.36	0.29	0.03	0.13
Volume (m^3)	70	0.51	1.47	0.89	0.198	0.96
Form Factor	70	0.75	0.98	0.85	0.05	0.24

STDV = Standard Deviation

Table 2: Taper models Developed for *Tectona grandis* in Agudu Forest Reserve

No.	Fitted Models	R	R^2%	SEE	RMSE	F-ratio	Bias	% Bias
1	$d = 0.020 + 0.869\ (D) + 0.081\ (\frac{h}{H}) - 0.149\ (\frac{h^2}{H^2})$	0.97	94	0.01	2E-04	333	0.00	0.00
2	$d^2 = 0.162 + 0.801\ (D^2) + 0.069\ (\frac{h}{H} - 1) + 0.090\ (\frac{h^2}{H^2} - 1)$	0.95	91	0.01	4E-04	211	1E-05	0.01
3	$\ln d = -0.156 + 0.926\ \ln(D) + 0.453\ \ln\frac{h}{H} - 0.231\ \ln\frac{h^2}{H^2}$	0.98	96	0.02	1E-03	471	6E-05	-0.001
4	$\ln d^2 = 0.296 + 0.928\ \ln(D^2) + 1.183\ \ln(\frac{h}{H} - 1) - 0.597\ \ln(\frac{h^2}{H^2} - 1)$	0.98	96	0.05	2E-03	471	2E-04	0.001

SEE = Standard Error Estimate, RMSE = Root Mean Square Error

Observed Measured Diameter versus Predicted Diameter Results

A paired Student‘s t-test applied on the measured and predicted diameters showed that models (1) to (4) have p-values > 0.05 indicating that the difference between observed and predicted diameters is not significant. The results in table 3 also shows that the t-test statistics for the models (1) to (4) is less than t-critical (t-stat < t-critical), the models therefore, has good fit. The result of simple linear regression in Table 4 shows that all the four taper equations yielded high correlation coefficient, coefficient of determination (R^2), and F-value between predicted and measured diameters. The SEE and RMSE were very low for all the four models, indicating that all the models have good ability to predict stem taper. There were no significant differences in the observed versus predicted models for all the models. Simple linear regression confirmed that the models had adequate fit. Graphic presentation of residual plots against four (4) predicted values shown in Figures 1-4 indicated homogenous variance. There was no identifiable trend of scatter-plots. This showed that the models did not violate any assumptions and there were no heteroscedasticity problems. The adopted statistical methods revealed the plausibility of these models and that the models are more adequate for tree diameter prediction at any point along the stem.

Residual Plots for Observed versus Predicted Values of Taper Model Generated

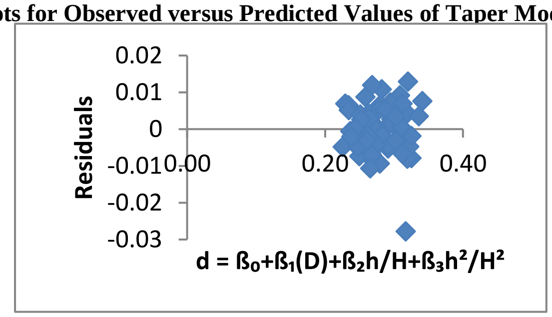

Figure 1: Residual plot for Model 1 Observed Value versus Predicted Values

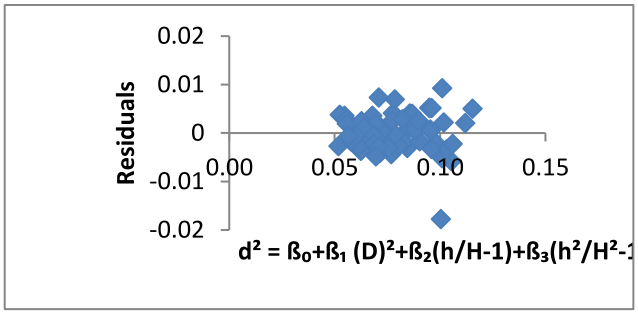

Figure 2: Residual plot for Model 2 Observed Values versus Predicted Values

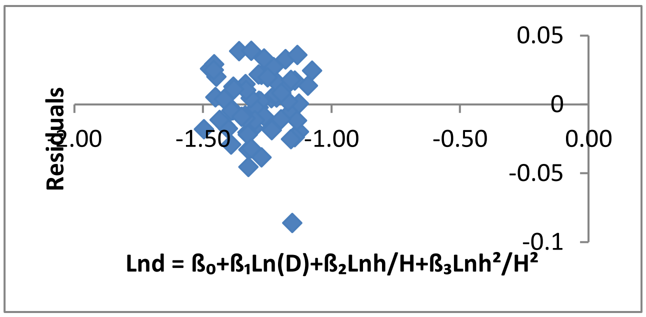

Figure 3: Residual plot for Model 3 Observed Values versus Predicted Values

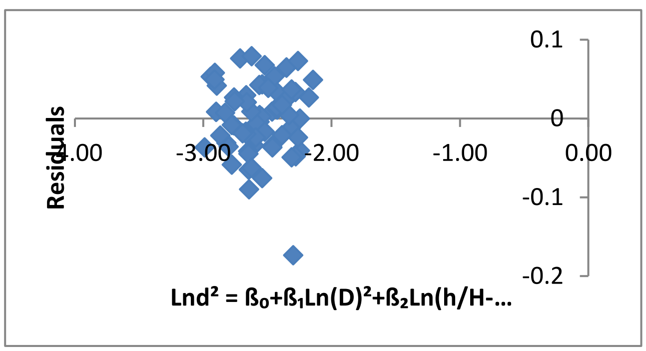

Figure 4: Residual plot for Model 4 Observed Values versus Predicted Values

Table 3: Student T-test for the Models

Model No.	Pearson correlation	t-Stat	t-critical	P-value	Df
1	0.98	0.031	1.99	0.98	69
2	0.97	0.9	1.99	0.37	69
3	0.98	0.33	1.99	0.74	69
4	0.98	-0.34	1.99	0.73	69

Table 4: Linear Regression Analysis for the Observed versus Predicted Diameters

Model No.	R	R^2 (%)	SEE	RMSE	F-value	t-Stat	p-value	Sig. F	Df
1	0.98	95	0.01	4E-05	1402	-0.63	0.53	4E-47	69
2	0.97	95	4E-03	2E-05	1221	-1.31	0.2	4E-45	69
3	0.98	96	0.02	0.001	1486	0.07	0.95	6E-48	69
4	0.98	96	0.04	0.002	1487	-0.11	0.91	6E-48	69

Table 5: Summary of Tree Variables Measured for the Validation

Tree variables	Number	Minimum	Maximum	Mean	StDv	Range
Total Height (m)	30	12.6	20.6	16.713	2.398	8
Dbh (m)	30	0.2176	0.3468	0.291	0.029	0.129
Volume (m^3)	30	0.4982	1.4819	0.941	0.201	0.984
Form Factor	30	0.7005	0.9241	0.847	0.046	0.224

STDV = Standard Deviation

Table 6: Validation Results for the models

No.	Fitted Models	R	R^2 (%)	SEE	RMSE	F-ratio	Biases	% Bias
1	$d = 0.012 + 0.884\,(D) + 0.157\,(\frac{h}{H}) - 0.654\,(\frac{h^2}{H^2})$	0.94	88	0.01	0.003	64.4	1E-05	0.01
2	$d^2 = -0.175 + 0.837\,(D^2) + 0.102\,(\frac{h}{H} - 1) - 0.277\,(\frac{h^2}{H^2} - 1)$	0.94	87.5	0.01	0.001	60.7	4E-07	0.01
3	$\ln d = -0.052 + 0.937\,\ln(D) + 2.603\,ln\,(\frac{h}{H}) - 1.287\,ln(\frac{h^2}{H^2})$	0.95	90	0.1	0.01	77.6	1E-04	-0.01
4	$\ln d^2 = 2.526 + 0.937\,\ln(D^2) + 5.205\,ln(\frac{h}{H} - 1) - 2.575\,ln(\frac{h^2}{H^2} - 1)$	0.95	90	0.1	0.02	77.6	3E-04	0.004

Validation Result for the Models

Although there are no set of specific standards or tests that can be easily applied to determine the "appropriateness" of a model, we need to establish a minimum validation procedure to ensure reliability and reasonable performance of a new model (Huang *et al.,* 2003). One approach to validate a statistical fitted model is to apply the fitted results to an independent data set (Li *et al.,* 2012). The validation results for the four models generated are presented in Table 6 below.

The statistics describing the fit of the models to diameters at the relative heights in the calibrated dataset showed the same trend for the validation data as for the fitting data. The validated results shows that the models generated provide the best overall results, they predicts diameter very well over the entire stem with only a slight increase in variance below breast height.

DISCUSSION

In this study, the observed values of the diameters for the sample trees were obtained by taking the measurements of individual trees directly. Four (4) taper models in table 2 which include two simple and two logarithmic transformations of taper models that could be used for estimating diameter and height at any point were developed and tested. Based on the fit statistics and residual plots, taper equation developed provided a strong fit to the data. The models explained more than 97 percent of the total variation of diameter for the teak specie, indicating a good agreement between observed and predicted diameter. Most residuals clustered around 0 (Figure 1-4), indicating that the model was not biased. The simple single taper models generated and tested in this study were precise in their predictions of over bark diameters of *Tectona grandis*. The data were fitted into four published taper functions from available literatures which include single simple model by Kozak *et al.* (1969) which assumed a constant influence of section height on taper regardless of tree height. It slightly underestimated bigger diameters and slightly over estimated the smaller diameters. This study contradicts the study of Khamsene, (2009) which stated that model by Kozak, 1969 underestimated small diameters but overestimated the bigger diameters. Model by Ormerod (1973), slightly underestimated the diameters of all stem sizes. On the whole, the taper equations developed in this study represent a modest improvement to the Kozak (1969) taper equation, and Sharma and Orderwald, (2001).

The use of these equations is recommended based in part on the results of the student t-test in table 3; and Simple linear regression equation of the observed and predicted volumes in table 4. There were no significant differences between observed and predicted values, the t statistics was less than the t-critical (t-statistic < t-tabulated/critical) between the mean of the observed and predicted values with the result of the student t-test and $p>0.05$. This is in line with the study of Birger, (2011) who stated that A paired Student's t-test applied on the measured and predicted diameters showed that equations (1) to (4) have p-values > 0.05 indicating that the difference between observed and predicted diameters is not significant. The validated results shows that the models generated provide the best overall results, they predicts diameter very well over the entire stem with only a slight increase in variance below breast height. The equations were evaluated to see how well the taper models developed would work on independent sets and also to see if any of the models were significantly better than the other. These measures of accuracy and precision showed that the four models did quite well in predicting diameters. Results from the T-test, simple linear regression, SEE, RMSE, Absolute Bias and percentage Bias on the validation data showed that the t-statistics were less than the t-critical and the p-values were greater than the significant level; R, R^2, and F-values were very high; SEE, RMSE, and Absolute Biases were lower for all the equations. According to Parresol *et al.* (1987), AB values provide a clear distinction between examined equations and are important statistics for drawing conclusions and making recommendations regarding the suitability of equations for use in practical surveys.

CONCLUSION

The taper models developed in this study predicted teak diameter very well; it yielded better estimates of teak diameters than existing equations, and is therefore an improvement over previously published equations.

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