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Tree Taper Model for Selected Tree Species within University of Ibadan, Oyo State

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ABSTRACT

In this study, the performance of different types of taper model for predicting tree diameters of *Terminalia radii* (Tent tree) at Heritage Park and *Tectonia grandis* (Teak) at teak plantation within University of Ibadan was examined. Data from pure (monoculture) stands of *T. radii* (Heritage Park) and *T. grandis* (Teak Plantation) containing a total of 146 tent trees and 131 teak trees respectively. Five taper models developed by various researchers were adopted, fitted and evaluated. The comparison of the model performances was basically on the analysis of three goodness-of-fit statistics and residue analysis found model 5 to be most superior in predicting the stem diameter at any point for the two species in the two study areas. The Model 2 exhibited the worst performance in fitting statistics and residual analysis results. Therefore, the same taper model should be used for prediction of diameter of the two tree species within University of Ibadan.

INTRODUCTION

Tree Taper can be defined as the rate of narrowing in diameter along the tree stem of a given form (Gray 1956). It can be expressed as a function of height above ground level, total tree height, and diameter at breast height (Clutter *et al*., 1983). The term 'taper' function is often used interchangeably with tree form, where 'form' refers to the shape of the tree (Max and Burkart,1976). In 1946, Mesavage and Girard asserted that the tree taper is the degree to which a tree stem or bole decreases in diameter as a function of height above the ground, where tree with a high degree of taper is called a poor taper tree and those with low taper are refer to as good taper tree. Also explained that the form of a tree can be represented by a certain form class called Girard which denoted as the ratio expressed as percentage of butt-log scaling diameter to diameter as the breast height. The traditional geometric shape of tree can be expressed as a mathematical function of height above ground level, total tree height, and diameter at breast height (D) (Sloboda and Saboroske 1981).

Taper equations are very useful as they can provide information about diameter at any height, and height at any diameter based only on commonly taken tree measurements (Byrne and Reed 1986). Furthermore, taper equations can be used to derive volume equations by integration when the equation is rotated around the longitudinal axis of a tree (Bruce *et al.* 1968; Byrne and Reed, 1986).

Many types of taper modeling techniques have been proposed and applied over the years. These mathematical functions are generally described as taper functions tree (Max and Burkart,1976). Its function is essential and play a pivotal role in forest inventory and growth projection, as well as in forest management planning (Rupsy,2018). The function can provide a suitable and relevant information for decision making at an individual tree level, stand level and forest level (Gray,1956).

According to Wang *et al.* (1998), the vulnerability and susceptibility of a tree to wind damage is majorly influenced or determined by the slenderness coefficient or taper of the tree. Whereas, the heritage park and teak plantation are mainly for the recreational and research purpose respectively, their accommodative status are mostly high every time. With this the taper of the selected tree species should be determined, in order to know their susceptibility to wind throw.

Over some decades, tree taper functions have been widely studied all over the world like taper and stem volume equations for the mixed stands developed by Kaya (2016) only for the mixed stands of black pine and scots pine in Devrek Region of Zonguldak but there is little or no documentation on taper model with respect to University of Ibadan. In this recent study, parameters have been estimated for the adopted models developed in other countries.

METHODOLOGY

Study Area

Data used in this study were collected from two (2) study area which are within the University of Ibadan campus. University of Ibadan is located along Oyo Road, Ibadan in Akinyele Local Government Area of Oyo State, Nigeria. It lies between latitude 7º26'35"N to 7º27'33"N and longitude 3º53'57"E to 3º54'06"E. The campus is characterized by dry and rainy season. The relative humidity is very high during the rainy season and low during dry season (Akinyele, 2010). The two locations are Heritage Park and the University Teak Plantation.

University Teak Plantation

University of Ibadan (UI) Tectona grandis plantation lies between latitudes 7°456' N to 7°45.834' N and longitudes 3°90.942' E to 3°90.508' E, within the tropical rainforest in

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the South-western part of Nigeria with mean altitude of 227m above sea level and total land area of approximately 8 ha (Ezenwenyi *et al.*, 2018). The Soils in the University of Ibadan teak plantation is Ferric luvisol but mostly derived from sandstones (Falade, 2017). The average texture in the top 15 cm was 58.8 % sand, 18.4 % silt and 22.8 % clay and thus, the soil textural class is loamy sand (Falade and Oyeleye, 2011). 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. The plantation is managed by Department of Forestry Resource management. (Now; social and environmental Forestry & Forest products and production). It was established mainly for education and research purpose.

Heritage Park

This park was situated in the campus opposite Queen Elizabeth Hall after the university's main gate (First gate). The park was comprised of *Terminalia radii* (Tent tree). It serves as a recreation, relaxation and reading center for students and staffs, beautification purpose and habitat for birds 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. The park is approximately 1.34ha in size.

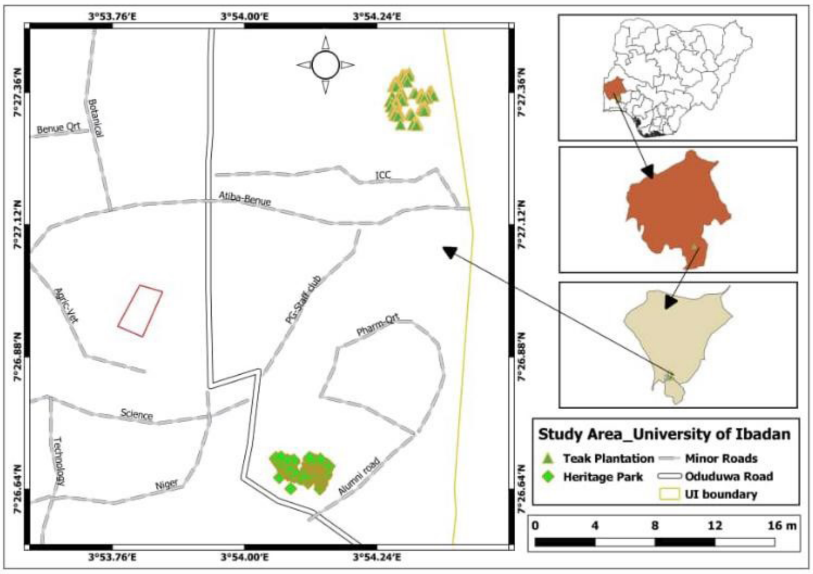

Figure 1: Map showing Study Locations (Heritage park and Teak plantation) in University of Ibadan Sampling Procedure

Sample Techniques

Systematics technique was used to select 2(two) Trancept alternately in the 8ha UI teak plantation with distance of 70meters from one another, 5 plots were laid from each making 10plots in total with mechanical spacing of 10meters. All living trees within each plot were enumerated and measured which makes 131trees in total. For Heritage Park, all the tree were also enumerated and measured (total enumeration) with the total number of 146trees. UI teak plantation and heritage park mainly comprised of exotic trees which are *Tectonia grandis* (Teak) and *Terminalia radii* (Tent tree) respectively.

Tree Taper models

The tree taper (d) usually expressed as a function of Diameter at breast height (D), total height (H) and upper(top) stem/bole height (h). The most common expression or illustration for functional form of a taper equations is:

d = f (D, H, h).

Taper equations can be represented in many forms: example in a; single simple quadratic form or complex form describing sections of trees.

According to James and Kozak (1984), the standing tree taper equations for several species produce more reliable estimates than the inside bark equations. In respect to this observation, the Diameter over bark was used in this study.

Kozak *et al.* (1969) asserted that the real advantage of complex taper models were little, therefore Single taper functions were adopted for the study

Adopted Tree Taper Models

Kozak *et al.* (1969) Model: This model was developed mainly on the basic relationship of a single parabolic function. It was conditioned by $(h/_H-1)$ and $(h^2/_{H2}-1)$ as predictor variables, when h equals to H, estimated diameter gives exactly zero.

$$d^2 = D^2\left(\beta_1\left(\frac{h}{H}-1\right)+\beta_2\left(\frac{h^2}{H^2}-1\right)\right)\ldots \quad 1$$

Sharma and Oderwald (2001) Model: this function implies a certain condition; when h = H, d= 0, and when h = BH (BH is breast height equal to 1.3 m), d = D

$$d^2 = D^2\left(\frac{h}{BH}\right)^{2-\beta_1}\left(\frac{H-h}{H-BH}\right) \quad \ldots\ldots\ldots 2$$

Ormerod (1973) Model: Sharma and Oderwald (2001) Model condition also applies to this Ormerod. Another condition is that if β =1, the resulting tree profile is conic and when β is one-half the resulting tree form or shape is parabolic (Reed and Byrne 1985) and when β > 1 but less than one-half i.e., three-fourths (3/4), the tree shape is between a cone and a parabola which usually called "paracone".

$$d = D\left(\frac{H-h}{H-BH}\right)^{\beta_1} \quad \ldots\ldots\ldots3$$

Polynomial Series Model: This model represents the general and common form of polynomial. Figueired-Filho *et al.* (1996) noted that high degree polynomials have been used in some studies but the most common ones are around fifth degree polynomial

$$d = D\left(\beta_0 + \beta_1\left(\frac{h}{H}\right) + \beta_2\left(\frac{h}{H}\right)^2 + \cdots \beta_n\left(\frac{h}{H}\right)^n\right) \quad \ldots\ldots\ldots4$$

Byrne and Reed (1986): this is the transformation form of Ormerod (1973) Model

$$d = \beta_1 D\left(\frac{H-h}{H-BH}\right)^{\beta_2} \quad \ldots\ldots\ldots5$$

Where: D=Diameter at Breast Height, H= Total height, d= diameter over bark at height h (m), BH = breast height equal to 1.3 m h= height of ith point from ground (m), β1- βn= coefficient

Evaluation for the judgement of model performance

All the fits and tests were carried out on R Program. The 4 (four) goodness of fit were used to evaluate the adequacy of the models. Fit statistics of residual analyses were also employed alongside with the graphical methods of residual plotting. Goodness of Fit statistics used were among the most common ones. they included: RMSE (Root Mean Square Error), Ecrit (Critical Error), AIC (Akaike information criterion) and BIC (Bayesian information criterion). The smaller the statistics are, the better the model.

Statistical Test (indices):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{n}} \ldots\ldots\ldots6$$

$$Ecrit = \sqrt{\frac{\gamma^2 \sum(h_i - \hat{h}_i)^2 / x^2 crit}{H_i}} \ldots\ldots\ldots7$$

$$AIC = n \times \ln\left(\frac{RSS}{n}\right) + 2P \ldots\ldots\ldots8$$

$$BIC = n \times \ln\left(\frac{RSS}{n}\right) + p \ln n \ldots\ldots\ldots9$$

where Y_i and hi is observation, $\hat{Y}_i$ and $\hat{h}_i$ is prediction, n is number of observations, P is the numbers of estimated parameters, x^2 is critical value obtained at α =0.05, H is average height, ϒ is standard normal deviate, RSS is sum of square regression.

Graphs of residuals were plotted against predicted values and independent variables, and these were examined for evidence of bias. In addition, frequency distributions of residuals were examined whether data deviate from normality or not.

Ranking of Models

The traditional standard or ordinal ranks for model performance was used. It shows the order of the models adopted. The models were compared using four fitting statistics, the method of relative ranking was not used because the same model superior others in all the indices and the exact position of each model was easy to allocate.

RESULTS AND DISCUSSION

Results

The descriptive statistic summary of the raw data is presented in table 1. It shows the mean(average), standard error of mean, standard deviation, minimum and maximum statistical value for the *Terminalia radii* and *Tectonia grandis.*

Table 1: Descriptive statistics for the individual tree variables for the two (2) study sites

Study site	Species	Variable	Mean	Std Error	Std D	Min	Max
HP	*Terminalia radii*	d (cm)	15.602	0.456	5.506	3.930	12.630
		Dbh (cm)	32.524	0.642	7.761	10.600	58.400
		h(m)	6.949	0.171	2.069	2.000	13.000
		H(m)	15.404	0.251	3.029	6.000	21.000
		d/D	0.478	0.010	0.126	0.250	0.750
		h/H	0.458	0.011	0.133	0.147	0.880
		G(m^2)	0.088	0.003	0.039	0.009	0.268
		G/ha (m^2/ha)	0.066	0.002	0.030	0.007	0.201
		V(m^3/)	1.981	1.101	13.306	0.089	161.565
		V/ha(m^3/ha)	1.486	0.826	9.980	0.067	121.174
TP	*Tectonia grandis*	d(cm)	54.855	35.210	4.570	6.750	33.430
		Dbh(cm)	38.835	0.797	9.125	13.500	65.800
		H (m)	17.265	0.369	4.225	3.250	28.000
		H(m)	30.395	0.592	6.777	12.500	50.000
		d/D	0.463	0.007	0.082	0.285	0.714
		h/H	0.570	0.008	0.088	0.260	0.880

		G(m^2)	0.125	0.005	0.059	0.014	0.340
		G/ha (m^2/ha)	0.312	0.013	0.148	0.036	0.850
		V (m^3/)	1.587	0.079	0.899	0.094	4.836
		V/ha (m^3/ha)	3.967	0.196	2.247	0.230	12.090

Where Dbh=Diameter at Breast Height, THT= Total height, d= diameter over bark at height h (m); h= height of ith point from ground (m), HP=Heritage Park, TP= Teak Plantation,G= Basal area, V= Volume

Table 2: Tree Taper Model Estimation for two Species

Study site	Species	Model	Parameters	Estimate	Standard Error	P-value
HP	*Terminalia radii*	1	β_1	-0.284	0.2168	0.192
			β_2	-0.104	0.154	0.5
		2	β_1	2.606	0.0313	<2e-16
		3	β_1	1.396	0.060	<2e-16
		4	β_0	-2.123	2.074	0.308
			β_1	11.353	26.485	0.669
			β_2	-52.409	124.703	0.675
			β_3	121.806	274.648	0.658
			β_4	-140.843	285.453	0.623
			β_5	63.068	112.744	0.577
		5	β_1	0.557	0.025	<2e-16
			β_2	0.275	0.077	0.000497
TP	*Tectonia grandis*	1	β_1	0.529	0.280	0.060779
			β_2	-0.643	0.180	0.000511
		2	β_1	2.305	0.014	<2e-16
		3	β_1	0.965	0.025	<2e-16
		4	β_0	-103.13	21.84	6.16E-06
			β_1	988.28	210.33	6.79E-06
			β_2	-3719.94	789.66	6.48E-06
			β_3	6808.25	1445.35	6.47E-06
			β_4	-6057.94	1289.99	6.86E-06
			β_5	2095.87	449.04	7.73E-06
		5	β_1	0.525	0.037	<2e-16
			β_2	0.179	0.085	0.0361

Where H P= Heritage park, TP= Teak plantation, β (1, 2, 3….) is coefficient

Residual Analysis

Graphical representation of residuals was plotted for each tree taper model and they are presented in Figure 2 and 3. Visualizations of the residuals plotted against the predicted showed that only model 4 of both study sites produced more homogeneous residual variance than other models. It was obviously that precisions in residual analysis predictions for both study sites were not similar. The ranges of Errors in the predictions of all models were not distributed uniformly, some distributed between +100 to -100 while some -10 to +10.

Also, some models were more biased than others. The model 5 of Heritage Park is less biased in the distribution while model 5 of Teak plantation is moderately biased and the alternative models from the both study sites.

There were more differences in the trend residual distributions for the five models for two study sites. Also, the models are dependently distributed except the model 5 (Byrne and Reed 1986) of both study site that are independently distributed. Further evaluation of the models used in the study were shown in the results of fit statistics.

The statistical analysis for the normality distribution of residual used to indicate whether the residual of each model violated the assumption of normality or not.

The Shapiro-wilk test from table 3 reveal that model 3 and 1 statistical values were greater than p-level for *Terminalia radii* and only model 3 statistic greater than p-value for *Tectonia grandis*. And the yardstick for shapiro -wilk is that statistic value greater than the level of hypothesis (0.05) indicated the acceptance of null hypothesis and this implies that the data are normally distributed while the smaller statistical implies that the normality assumption are violated. Model 5 (Byrne and Reed 1986) of the studies gave the lesser value and this inferred that their residual was not normally distributed but the Model 3(Ormerod,1973) of the both selected study sites were normally distributed.

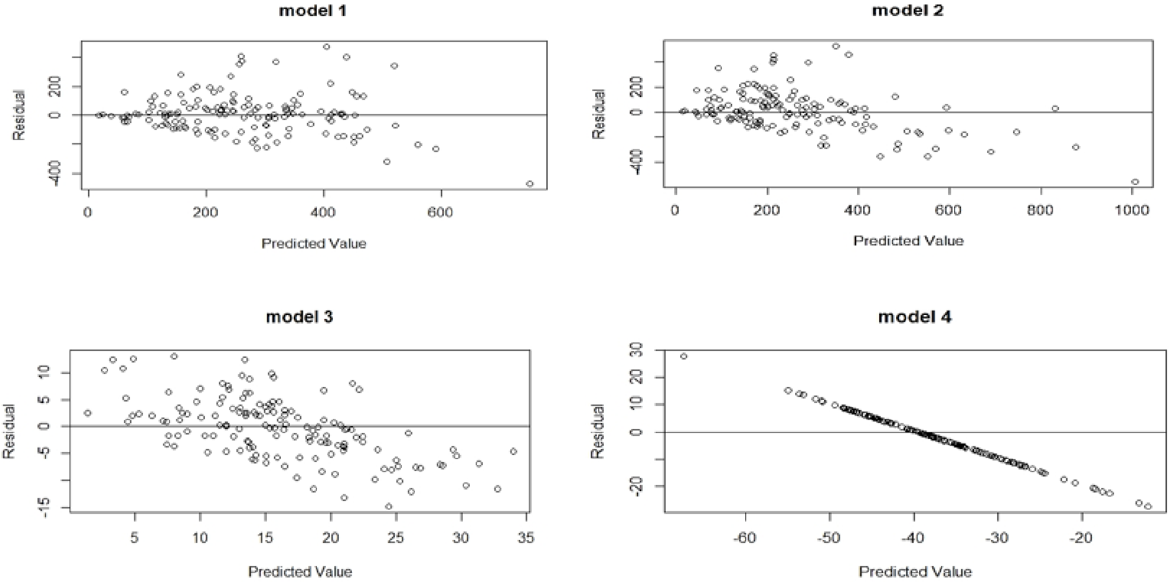

Figure 2: Graphical representation of Residual analysis for the Heritage Park (*Terminalia radii*)

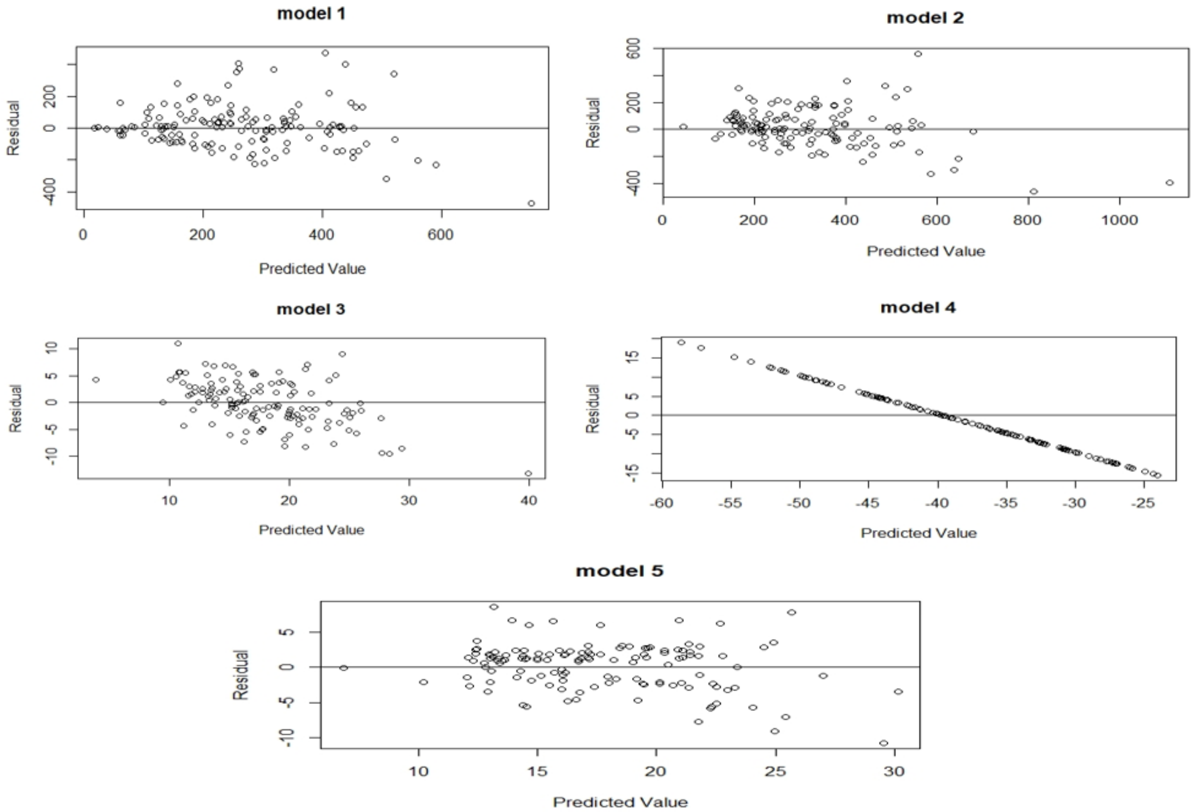

Figure 3: Graphical representation of Residual analysis for the Teak plantation (*Tectonia grandis*)

Evaluation statistics

Table 3 showed Goodness of fit used to examine the five tree taper models adopted for the two study sites. Those statistics were RMSE (Root Mean Square Error,) Ecrit (Critical Error), AIC (Akaike information criterion) and BIC (Bayesian information criterion). The smaller the statistics are, the better the model. The assessment showed that Model 5 gave the superior performance while Model 2 (Sharma and Oderwald, 2001) gave worst performance which inferred from the fact that Byrne and Reed 1986 model (Model 5) gave lowest value of AIC, RMSE, Ecrit and BIC statistics (goodness of fit)

Moreover, Ormerod,1973 model (model 3) follows Byrne and Reed 1986 (Model 5) in terms of statistics evaluation, standard Error and significant level (0.05).

Table 3: The Evaluation statistics for the two species

Study site	Species	Model	RMSE	AIC	BIC	Ecrit	Shapiro
HP	*Terminalia radii*	1	139.9	1860.966	1869.917	100.338	3.435^05
		2	164.1	1906.754	1912.721	118.179	0.0014
		3	5.659	923.418	929.385	2.000	13.000
		4	9.223	1070.926	1096.81	6.524	0.107
		5	3.917	816.97	825.92	2.810	0.012
TP	*Tectonia grandis*	1	132.1	1655.285	1663.91	89.720	8.759^-05
		2	143.9	1676.743	1682.493	98.123	0.008
		3	4.233	752.803	758.554	2.886	0.799
		4	8.305	934.229	954.355	5.551	0.015
		5	3.281	687.005	695.631	2.228	3.55^-04

DISCUSSION

Five taper models were adopted for study. Most models are bias only model 5 are not biased. The remain models (taper functions) used in this study performed poorly. The screening test were carried out on all models examining residual plots because they were obvious biased. Only one model was relatively unbiased (Model 5), and it was chosen as the best. The model 2 point is only estimated parameter that is very sensitive it was the least among others function. According to Sharma and Oderwald, 2001; it takes a purely parabolic form to depict a tree shape if it is greater than 2, the function predicts the diameter at the butt much larger than diameter at breast height 'D'; and if it is smaller than 2, the function predicts the diameter at the butt smaller than diameter at breast height 'D'. the both study site model 2 estimated values were greater than 2. So, this finding is accordance with Sharma and Oderwald, 2001.

Model 3 by Ormerod (1973) was biased. it may be the outcome of estimated diameters (overestimate) of all stem sizes.

The result of study by Reed and Byrne (1985), in which the same taper function was applied to jack pine, contradicts the findings. In Reed and Byrne (1985) finding, it was observed that the values of estimated parameter (β1) less than 0.5 while this study estimated it as 1.396 for *Terminalia Radii* (Heritage Park) and 0.965 for Teak Plantation.

According to the Reed and Byrne (1985) report when β1 estimated value less than 0.5 this implies tree stems are cylindrical and when β =1, the resulting tree profile is conic and when β is one-half the resulting tree form or shape is parabolic and when β > 1 but less than one-half; three-fourths (3/4), the tree shape is between a cone and a parabola which usually called "paracone". With this observation, the two species could be categories to different form, this finding inferred the *Terminalia radii* and *Tectonia grandis* in the two study sites are "Paraconic" and "Conic" respectively.

The Model 5 (Byrne and Reed,1986) was best model due to the superior performance towards the goodness of fit and residual analysis. This may be the result of transformation process occur from model 3 (Ormerod 1973) to Model 5. Since both models' findings closely with one another for the two species, two models can work interchangeably for predicting of the tree diameters.

CONCLUSIONS

All taper functions adopted in this study are simple to use (single function) and provide a more accurate diameter prediction at a specified height.

The results of the statistical analyses indicated that Model 5 (Byrne and Reed, 1986) gave the overall best performance in predicting tree diameter at a specified height.

Moreso, the study concluded that both *Tectonia grandis* in Teak Plantation and *Terminalia radii* in Heritage Park are not cylindrical in shape(form). So, the two species were not susceptible (prone) to windbreak, there should be no wind damage record for the two species in the two study sites. Ormerod (1973) model could be used for the estimation of tree form (shape) for the two species.

The observed result for this study is significant for prediction of stem diameter at any point (stem taper) for *T. radii* stand as well as *T. grandis* stand depending on various ecological factors, stand size and silvicultural management of the certain forest.

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