Compatible Taper Equations for *Tectonagrandis*plantation in Aramoko Forest Reserve, Ekiti State, Nigeria

[*1]Faniseyi, A.S., [1]Arowosoge, O.G.E., [2]Ajayi, E.

[1]Department of Forest Resources and Wildlife Management, Ekiti State University, Ado-Ekiti.

[2]Department of Forestry and Wildlife Management,AdekunleAjasin University, Akungba-Akoko, Nigeria

Corresponding Author: asfaniseyi@yahoo.com

Abstract

The study was carried out to generate compatible stem taper equations for the*Tectonagrandis*(Teak) plantation in Aramoko Forest Reserve, Ekiti State, Nigeria. The age series used for the study were 15, 17, 20, 23, 26, and 30 years old, and three plots of 20 x 20m were randomly selected from each age series. The diameter at breast height (dbh) of all trees within each was measured and grouped into 4 classes; 10-20, 20-30, 30-40 and 40-50cm. The tree with the closest dbh to the mean dbh in each diameter class was selected for felling. The diameter at the ground level (D_G), 15 cm (D_{15}), 30 cm (D_{30}) and 45 cm (D_{45}) were measured before felling while, the stump height (SH) and total length were measured after felling.Descriptive statistical analysis was used to summarize the data collected. The taper equations generated for 10-20, 20-30, 30-40 and 40-50 cm; $d^2 = \left(D^2 \quad 1.784\left(\frac{h}{H} - 1\right) - 20.978\left(\frac{h^2}{H^2} - 1\right)\right)$ $\square^2 = \square^2\left(10.264\left(\frac{h}{\square} - 1\right) - 34.239\left(\frac{h^2}{\square^2} - 1\right)\right)$, $\square^2 = \square^2\left(10.916\left(\frac{h}{\square} - 1\right) - 46.935\left(\frac{h^2}{\square^2} - 1\right)\right)$, $\square^2 = \square^2\left(-13.296\left(\frac{h}{\square} - 1\right) - 27.513\left(\frac{h^2}{\square^2} - 1\right)\right)$ respectively were assessed using F-ratio, Root Mean Square of Error (RMSE), Adjusted coefficient of determination (R^2_{adj}). Thetaper equations were satisfactory based on the various criteria used for assessment and validation, and are recommended for estimating the taper of theteak trees in the plantation.

Keywords: Taper equations, Teak, Aramoko Forest Reserve

Introduction

Teak (*Tectoniagrandis*) is a tropical hardwood tree in the family Verbenaceae, native to South and South East Asia and is commonly found as a component of monsoon forest vegetation. It is a large deciduous tree, growing up to 30 – 40 m tall (Robertson, 2002). Teak is one of the important timber tree species in the world with qualities which include: attractiveness in colour and grain, durability, ease of seasoning without splitting and cracking, ease of working and carving, resistance to termite, fungi and weathering as well as suitability for all aspects of household constructions (Kaosa-ard, 1998).

Teak has been widely established in plantations throughout the tropics from the 1850s due to its good timber qualities, market demand, ease of domestication and cultivation.It has gained a worldwide reputation on account of the attractiveness and durability of its wood. Thus, its demands have prompted the establishment of its plantations within and beyond its native countries (Bhat, 2000). As an exotic species, teakhas been established in many countries in Asia (Sri Lanka, Bangladesh, Thailand and China); Africa (Ghana, Nigeria, Ivory Coast, Senegal, Togo, Benin, Sudan and Tanzania); Central America (Puerto Rico and Panama) and South America (Brazil and Ecuador)for the production of high quality poles and timber, with varied degrees of success (Ball *et al.*, 1999).

Nigeria has established several teak plantations, especially in response to the afforestation programme.Kollert and Cherubini (2012) reported that India, Indonesia, Myanmar, Ghana and Nigeria accounted for 87% of the 1.3 million hectares (ha) of teak plantations in the world.Nigeria had about 146,000 ha of teak plantation in 2012 and was second to Ghana with 214,000 ha as the largest in tropical Africa.

Stem taper can be defined as the rate of narrowing of diameter along the stem of a given tree (Muhairwe, 1999). A taper equation describes the entire profile of the stem. Alo*et al.*, (2011) opined that taper is the degree to which trees stem decreases in diameter as a function of increase in tree height. Taper equation is a mathematical function which predicts the diameter of the stem of an individual tree at any distance along its stem. Thus, taper equation can describe changes in diameter along the tree stem and therefore, provide estimates of dimension of logs that can be cut from a stem. Taper equations have been used for more than a century by foresters to express tree form in terms of easily measured characteristics (Perez *et al*., 1990). The importance of taper equations becomes evident from the fact that they are neededto estimate tree growth which is crucial to the sustainable management of forest plantations(Bi, 2000; Lee *etal*., 2003; Shaw *etal*., 2003).

Reliable methods for estimating taper profile of growing stock are always needed for sustainable management of forest plantations. Hence research has continued in the development of taper equations. This study was, therefore, carried out to develop taper equations for different diameter classes of *Tectonagrandis* Plantation in Aramoko Forest Reserve, Ekiti State, Nigeria.

Materials and Method

Study area

The study was carried out in the Teak (*Tectonagrandis*) Plantations at Aramoko Forest Reserve in Ekiti West Local Government Area (LGA) of Ekiti State, Nigeria. Aramoko Forest Reserve is located between latitude 7.73622°N and 7.76710°N and between longitude 5.04523°E and 5.05729°E in South-western Nigeria.

Method of data collection

A reconnaissance survey of Teak Plantations in Aramoko Forest Reserve was carried out with a view to determining the suitability of the stands for subsequent sampling operations. Six age classes: 15, 17, 20, 23, 26, 30 years old trees in Aramoko Forest Reserve were selected for the study. Three sample plots of 20× 20m were randomly selected from each age class. The height (Ht) and the diameter at breast height (dbh) of all the trees in the sample plots were measured using Spigel Relaskop and girth tape respectively. The diameters at the top (D_t) and at the middle (D_m) were measured using Spigel Relaskop while the diameter at the base (D_b) was measured using girth tape. The trees in each sample plot were divided into four dbh classes: of 10–20, 20–30, 30–40 and 40–50 and the tree with the dbh closest to the mean dbh of each class was selected for felling. The diameter of the tree at ground level (D_G) and at 15 cm (D_{15}), 30 cm (D_{30}) and 45 cm (D_{45}) above ground was measured using girth tape. After felling, the stump height, total length of the tree and the diameter along the stem was measured at intervals of 5cm.

Data analysis

The relationship between diameter at individual relative height and explanatory variable for this study followed the equation developed by Jaroslaw (2002) which is expressed as;

$$d_h = b_0 + b_1 X_1 + b_2 X_2 \text{ ....1}$$

where; d_h = relative diameter at height (h_j)
b_0 = equation constant
b_1-b_n = equation parameters of estimation of diameter at relative height(h_j)
X_1-X_n = independent variable correlated with estimated diameter.
If d_h is Y, then $Y = \beta_1 X_1 + \beta_2 X_2$

If $Y = \frac{d^2}{D^2}, X_1 = (\frac{h}{H} - 1) \quad X_2 = \frac{h^2}{H^2} - 1)$

If $\frac{d^2}{D^2} = b_1(\frac{h}{H} - 1) + b_2(\frac{h^2}{H^2} - 1)$
..........................2

$d^2 = D^2 b_1(\frac{h}{H} - 1) + b_2(\frac{h^2}{H^2} - 1)$
......................3

where D = diameter at breast height of the tree (dbh)
H = total height of the tree
d = diameter at height (h) of the tree
h = height at diameter (d) of the tree
β_1, β_2 = Regression parameters

All regression models were generated using Microsoft excel and Statistical package for social sciences (SPSS21.0 for windows) and were assessed using significance of regression equation (F-ratio), Adjusted coefficient of determination (Adjusted R^2), Root Mean Square Error (RMSE).

Results

The summary of the taper equation data for *Tectonagrandis* plantations in Aramoko Forest Reserve is presented in Table 1. The total height (TH) of the trees ranged from 8.3 to 16.3 m; diameter at breast height of the trees ranged from 15.5 to 41.1 cm while the total length (TL) rangedfrom 7.6 to 15.5 m. The stump height (H_{st}) ranged from 0.5 to 1.25m, diameter at the ground level (D_G) ranged from 20.3 to 52.5 cm while diameter at 15 cm (D_{15}), 30 cm (D_{30}) and 45 cm (D_{45}) above the ground level ranged from 18.8 to 50.0 cm; 17.3 to 47. 5 cm; and 16.1 to 42.2cm respectively

Table 1: The summary of the taper equation data for *Tectonagrandis* plantation

Age (Yrs)	dbh Class	dbh (cm)	TH (m)	H_{st} (m)	TL (m)	D_G (cm)	D_{15} (cm)	D_{30} (cm)	D_{45} (cm)
15	10-20	15.5	8.3	0.75	7.6	23.5	21.8	20.6	18.8
15	20-30	23.0	12.7	0.84	11.8	30.0	28.6	26.3	24.2
17	10-20	17.4	9.0	0.9	8.1	26.0	25.2	24.6	24.0
17	20-30	22.3	9.2	1.25	8.0	27.8	26.0	25.6	24.2
20	10-20	18.2	13.9	0.5	13.1	29.0	26.3	23.0	21.9
20	20-30	25.4	15.9	0.55	15.3	33.0	31.3	28.9	27.0
20	30-40	33.9	14.05	0.55	13.5	47.7	44.5	41.7	37.5
23	10-20	15.9	10.7	0.6	10.1	20.3	18.8	17.3	16.1
23	20-30	26.3	13.0	0.7	12.3	36.0	34.4	32.4	31.4
23	30-40	32.7	14.9	0.8	14.1	45.3	43.0	40.5	38.0
26	10-20	17.8	10.9	0.5	10.4	22.5	21.0	20.3	18.4
26	20-30	26.5	13.4	0.62	12.8	36.5	34.9	31.0	29.5
26	30-40	33.4	13.6	0.7	12.9	42.5	40.0	38.3	35.0
30	10-20	19.0	13.7	0.5	13.2	26.5	24.3	23.0	21.4
30	20-30	25.8	14.7	0.7	14.0	34.3	31.8	29.0	27.5
30	30-40	35.2	14.2	0.7	13.5	47.0	44.5	40.7	38.3
30	40-50	41.1	16.3	0.8	15.5	52.5	50.0	47.5	44.2

Where dbh = Diameter at the Breast Height, TH = Total Height, H_{st} = Stump Height, TL = Total Length
D_G = Diameter at the ground level, D_{15} = Diameter at the 15 cm above the ground level
D_{30} = Diameter at the 30 cm above the ground level, D_{45} = Diameter at the 45 cm above the ground level.

The regression models generated for the diameter classes presented in Table 2 were significant ($p<0.05$) and found appropriate using the criteria for model appropriateness (Adjusted R^2, F-ratio, RMSE). The form of each taper equation for each diameter class in the study area is presented in Table 3.

Table 2: Taper Equations developed for *Tectonagrandis based on diameter class* in Aramoko Forest Reserve, Ekiti State, Nigeria.

Diameter Class (cm)	Regression Parameters		Std Error	Criteria for model Assessment		
	β_1	β_2		R^2_{Adj}	F –ratio	RMSE
10-20	1.784	-20.978	0.304	0.989	1234.175*	1.48
20-30	10.264	-34.239	0.279	0.984	5256.778*	2.45
30-40	10.916	-46.935	0.273	0.980	663.770*	3.73
40-50	-13.296	-27.513	0.277	0.983	879.475*	3.71

** All regression parameters are significant at 5% (p <0.05)*

Table 3: Taper Equation for each diameter class in Aramoko Forest Reserve, Ekiti State, Nigeria

Diameter Class (cm)	Taper Equation
10-20	$d^2 = D^2\left(1.784\left(\frac{h}{H}-1\right) - 20.978\left(\frac{h^2}{H^2}-1\right)\right)$
20-30	$d^2 = D^2\left(10.264\left(\frac{h}{H}-1\right) - 34.239\left(\frac{h^2}{H^2}-1\right)\right)$
30-40	$d^2 = D^2\left(10.916\left(\frac{h}{H}-1\right) - 46.935\left(\frac{h^2}{H^2}-1\right)\right)$
40-50	$d^2 = D^2\left(-13.296\left(\frac{h}{H}-1\right) - 27.513\left(\frac{h^2}{H^2}-1\right)\right)$

Discussion

The development of stem taper equations for the different diameter classes of *Tectonagrandis* in Aramoko Forest Reserve of Ekiti State was based on the equation form used to estimate the relative diameter at individual height whose explanatory variable is expressed by the relationship between relative diameter height (d_h) at relative height ($\frac{h}{H}$)(Sharma and Oderwald, 2001). The taper equations developed in this study used all the measured tree diameters in the existing plantation thereby enabling the whole diameter range and by extension taper variations, in the plantations to be captured.

The analysis of variance for the taper equations for the four diameter classes showed that the adjusted R^2 values were high for all the diameter class which ranges from 0.980 to 0.989. The highest adjusted R^2 (0.989) was obtained for 10-20 cm diameter class while the lowest (0.980) was obtained for 30-40cm diameter class. All the variables used for fitting taper functions were significant. It was observed that height-diameter relationship varied from stand to stand. Dorado *et al.,* (2010) had observed that height and diameter varies from stand to stand and even within the same stand and the relationship is not constant over time. Thus, a single equation may not capture all the possible taper variations that exist within a forest stand. This was the view of Brooks *et al.,* (2005) that most taper equations do not adequately cater for variability found in any population. This informed the fitting of five taper equations for teak plantations in the study area.

All the taper equations generated for the diameter classes were significant suggesting that irrespective of the diameter class, the diameter at the base of the tree (D_t) differed significantly from the middle (D_m) and the top (D_t) of the tree which indicated the tapering nature of *Tectonagrandis*. The results are similar to taper equations obtained for *Eucalyptus pilulairis* and *Eucalyptus grandis* in New South Wales, Australia (Muhairwe, 1999).

The taper equations developed for different diameter classes would minimize the level of variance and error that can arise from the change between the classes and within each class. Bi and Long (2001) had concluded that the evaluation of prediction accuracy over 10 diameter classes showed that the local bias of relative prediction is mostly ±0.015 within any stem section. Alsosince the taper equations provide accurate estimates of diameter along a tree stem (Li and Weiskettel, 2010), the taper equations developed in this study would predict the diameter of individual *Tectonagrandis* tree at a given height.

Conclusion

The taper equations generated in this study have been tested with the various assessments for model formulation and found to exhibit good fit. The evaluation based on different criteria such as significance of regression equation (F-ratio), adjusted coefficient of determination (Adjusted R^2), Root Mean Square Error (RMSE) showed that the taper equations met the requirements and can be suitable for sites with similar ecosystems.

References

Alo, A. A., Onyekwelu, J.C. and Akindele, S.O. (2011). Taper equations for *Gmelinaarborea* in Omo Forest Reserve, southwestern Nigeria. *Applied Tropical Agriculture 16 (1 and 2): 120 - 127.*

Ball, J.B., Pandey, D. and Hirai, S. (1999). Global overview of teak plantations. In: Regional Seminar on Site, Technology and Productivity of Teak Plantations. Chiang Mai, Thailand, 26–29 January 1999:11–34.

Bhat K. M. (2000). Timber quality of teak from managed tropical plantations with special reference to Indian plantations. *Bios etForets des Tropiques* 263(1):5-29.

Bi, H. (2000). Trigonometric variable-form taper equations for Australian Eucalyptus. *Forest Science* 46 (3): 369-409.

Bi, H. and Long, Y. (2001). Flexible taper equation for site-specific management of *Pinusradiata* in New South Wales, Australia. *Journal of Forest Ecology and Management 148:79-91.*

Brooks, J. R., Lichun, J. and Jingxin, W. (2005). Compatible taper and volume equations for yellow-poplar in West Virginia. *Forest Ecology and Management* 213:399-409.

Dorado, F.C., Diéguez-Aranda, U., Anta, M.B., Rodríguez,M.S and von Gadow, K. (2010). A generalized height-diameter model including random components for radiata pine plantations in northwestern Spain. *Forest Ecology and Management* 229: 202-213.

Fang, Z. and Bailey, R.L. (1999). Compatible volume and taper models with coefficients for tropical species on Hainan Island in southern China. *Forest Science* 45: 85-100.

Fang, Z. B. Borders, E. and Bailey, R.L. (2000). Compatible volume-taper models for loblolly and slash pine based on a system with segmented-stem factors. *Forest Science* 46: 1-12

Jaroslaw, S (2002). A taper model for Norway spruce (*Piceaabies* L. Karst). *Electronic Journal of Polish Agricultural University, Forestry Series*, 5(2): 1-14.

Kaosa-ard, A. (1998). Overview of problems in teak plantation establishment. In: Kashio, M. and White, K. (ed.)Second Regional Seminar on Teak Series; RAP Publication-1998/05, 249pp.

Kollert, W. and Cherubini, L. (2012). Teak Resources and Market Assessment 2010. FAO Planted Forests and Trees Working Paper FP/47/E, Rome, 42pp. Available at http://www.fao.org/forestry/plantedforests/67508@170537/en/25th

Lee, W., Seo, J., Son, Y., Lee, K. and Von Gadow, K. (2003). Modelling stem profiles for *Pinusdeniflora* in Korea. *Forest Science and Management* 172:69-77.

Li, R. and Weiskittel, A.R. (2010). Comparison of Stem Taper Equations for Predicting Diameter and volume of Balsam Fir, Red Spruce and White Pine in the Acadian Region. CFRU Technical Report 18 pp.

Muhairwe, C.K. (1999). Taper equations for *Eucalyptus pilulairis*and *Eucalyptus grandis*for the north coast in New South Wales, Australia. *Forest Ecology and Management,* 113: 251-269.

Perez, D.N., Burkhart, H.E. and Stiff, C.T. (1990). A variable-form taper function for *Pinusoocarpa* Schiede in Central Honduras. *Forest Science* 36: 186–191.

Perex, D. (2008): Growth and volume equations developed from stem analysis for *Tectonagrandis* in Costa Rica *Journal of Forest Science* 20(1):66-75.

Sharma, M. and Oderwald, R.G. (2001). Dimensionally compatible volume and taper equations. *Canadian Journal of Forest Resources. 31:797-803.*

Shaw,D.J., Meldahl,R.S., Kush, J S. and Somers, G L. (2003). A Tree Taper Model based on Similar Triangles and Use of Crown Ratio as a Measure of Form in Taper Equations for Long Leaf Pines. USDA, Southern Research Station: General Technical Report, SRS-66. 8pp.