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Total Wood Volume Equations for *Tectona Grandis* Linn F. Stands in Gujarat, India

Vindhya Prasad Tewari[1,*] and Bilas Singh[2]
[1]*Himalayan Forest Research Institute, Shimla 171009, India*
[2]*Arid Forest Research Institute, Jodhpur 342005, India*

Abstract

Tectona grandis (teak) is one of the most important timber species worldwide and India is one of the major teak growing countries. Though some volume equations were developed for teak in India but the models developed were neither evaluated using robust statistical criteria nor validated. Hence, the objective of this study was to develop statistically tested appropriate volume equation to predict total wood volume (over- and under-bark) for teak trees in Gujarat. A total of 41 trees with age varying from 15 to 33 years and diameter at breast height (dbh) from 7.3 to 30.8 cm were felled for the purpose. Linear and non-linear equations were used to model the relationship of the total wood volume with respect to dbh and total height. The equations tested mostly fitted well to the data. Model evaluation and validation indicated that models should be calibrated with local data for greater accuracy in the prediction.

Key Words: teak, total wood volume, model fitting, model evaluation, India

Introduction

Teak (*Tectona grandis* L. f.) is one of the most important timber tree species which is generally grown in all the tropical countries. It is naturally distributed in south and south-east Asian countries. The excellent properties and versatile nature of teak timber and its eminent suitability for an array of uses is well documented. Growing market demands have contributed to intensive domestication and cultivation of the species in countries/regions beyond its natural habitat (Hoare and Patanapongsa 1988; Bhat 2000; Perez and Kanninen 2003) and large-scale plantations have been raised in East and West African countries, Caribbean, and south and Central American countries apart from south and south-east Asian countries. In India, the most important natural teak forests are available in Madhya Pradesh, Maharashtra, Karnataka, Tamil Nadu and Kerala besides Uttar Pradesh, Gujarat, Orissa and Rajasthan (Troup 1921). Teak plantations have also been raised in Haryana, West Bengal, Assam, Meghalaya and Dadra and Nagar Haveli (Chakrbarti and Gaharwar 1995).

Volume equations play a very crucial role in forest management. The importance of volume equations is indicated by the existence of numerous such equations and the constant search for their improvement. Equations that provide accurate predictions of volume without local bias over the entire range of diameter are one of the basic building blocks of a forest growth and yield simulation system (Bi and Hamilton 1998). Since growing rates, management regimens, and production objectives are specific to each country or world region, volume equations should not be generalized assuming that trees have similar bole shapes.

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Corresponding author: Vindhya Prasad Tewari

Himalayan Forest Research Institute, Coniferr Campus, Panthaghati, Shimla 171009, India
Tel: 91-177-2626778, Fax: 91-177-2626779, E-mail: vptewari@yahoo.com

For instance, different thinning and pruning regimens alter the stem form significantly and consequently volume predictions may not be accurate if calculated independent of the stand characteristics (Perez and Kanninen 2003).

The literature reveals several studies on teak in which volume equations are reported from various parts of the world like India, Malaysia, Ghana, Sri Lanka, Philippines, Venezuela, Trinidad and Tobago and Costa Rica (Sandrasegaran 1969; Chaturvedi 1973; Singh 1981; Gonzales 1985; Ramnarine 1994; Hamzah and Mohamed 1994; Phillips 1995; Chakrbarti and Gaharwar 1995; Camacho and Madrigal 1997; Moret et al. 1998; Nunifu and Murchinson 1999; Perez and Kanninen 2003; Tewari et al. 2013). These may not be applicable on teak stands in Gujarat since data from this area is not included in these studies.

The role of model evaluation in examining the predictive ability of a model before its application has been stressed by various authors (Goulding 1979; Reynolds et al. 1981; Tewari et al. 2013) and model evaluation is necessary so that the model can be used with some confidence.

Estimating the total volume of trees and stands is extremely important for the valuation of teak plantations. No volume equation is available for teak stand in Gujarat. Hence, the aim of the present study is to develop single and double entry individual-tree total wood volume equations (over- and under-bark) for teak in Gujarat, India.

Materials and Methods

Data and field procedure

The data were collected from the eight teak sample plots of different ages (15 to 33 years) and plantation densities (533 to 2171 trees ha^{-1}) laid in Godhara, Baria, Narmada, Vyara and Dang forest divisions representing different geographic and rainfall conditions. All the trees inside the plots were measured for diameter at breast height (dbh) and grouped into diameter classes. Accordingly, 5 trees representing different diameter classes were felled from the surround of each plot representing the range of tree sizes. A total of 41 trees were felled for volume study. The length of the felled tree was measured with a tape and stump height was added to get the total height. For the computation of total volume over-bark, stem and branch wood with a minimum diameter over-bark of 5 cm was considered. The total volume was then calculated by dividing the stem and branches into logs of 3 m length, measuring the mid-diameters and applying Huber's formula to estimate individual log volumes, and summing up the volume of all the individual logs. If the length of the last section was more than 1.5 m, it was considered as separate log. If the length of last log was shorter than 1.5 m, it was added in the previous log length. For estimating under-bark volume, the bark thickness at dbh was measured with a bark gauge on one side which was multiplied by 2 and subtracted from the dbh (outside bark) to arrive at the value of dbh inside the bark. Similarly, bark thickness up the bole and of the branches was also determined with the bark gauge. The summary statistics of the data set, which also includes skewness and kurtosis, is presented in Table 1.

Skewness is usually described as a measure of a dataset's symmetry or lack of symmetry. The normal distribution has a skewness of 0. As a thumb rule, if the skewness is between -0.5 and 0.5, the data are fairly symmetrical. If the skewness is between -1 and -0.5 or between 0.5 and 1, the data are moderately skewed, and if the skewness is less than -1 or greater than 1, the data are highly skewed.

Kurtosis originally was thought to measure the peaked-

Table 1. Summary statistics of the data set used in the study

Variable	Range	Mean	Std. Dev.	Kurtosis	Skewness
dbh (cm)	7.3-30.8	18.07	5.46	-0.18628	0.38643
Total tree height (m)	8.2-22.0	14.27	3.55	-0.45249	0.71753
Age (years)	15-33	22.88	7.20	-1.681	0.40576
Stand Density (Stems ha^{-1})	533-2171	842	552.57	6.67280	2.54035
Volume over-bark (m^3)	0.02927-0.87990	0.21154	0.17865	4.0828	1.84416
Volume under-bark (m^3)	0.02488-0.65894	0.16369	0.13875	3.08330	1.67916

ness (or flatness) of a distribution. However, it is now widely accepted that the kurtosis is a measure of the combined weight of the tails relative to the rest of the distribution (Westfall 2014). It measures the tail-heaviness of the distribution. The value is often compared to the kurtosis of the normal distribution, which is equal to 3. If the kurtosis is close to 3, then a normal distribution is often assumed. These are called mesokurtic distributions. If the kurtosis is greater than 3, then the dataset has heavier tails than a normal distribution (more in the tails) and is called a leptokurtic distribution. If the kurtosis is less than 3, then the dataset has lighter tails than a normal distribution (less in the tails) and is called a platykurtic distribution.

Model fitting

Linear and non-linear equations were used to model the relationship of total volume (V) with dbh (D), and with dbh and total height (H). A total of 8 volume equations (Table 2), which were used for studies on Teak as well as on other species by various workers, were selected from the literature, based on their wide application, to test in this study (Sandrasegaran 1969; Singh 1981; Clutter et al. 1983; Hamzah and Mohamed 1994; Ramnarine 1994; Chakrbarti and Gaharwar 1995; Phillips 1995; Moret et al. 1998; Nunifu and Murchinson 1999; Tewari and Kumar 2003; Perez and Kanninen 2003; Tewari and Singh 2006; Tewari 2007; Tewari et al. 2013).

Each model was applied to the fitting data set. The adjusted coefficient of determination (R^2_{adj}), which shows the proportion of the total variance that is explained by the model adjusted for the number of model parameters, was used to determine the quality of fit. The least square procedure was used to fit linear equations. The non-linear equations were fitted using SPSS* statistical software package through Levenberg-Marquardt minimisation method. The convergence criterion for accepting the values of parameter estimates was taken as 1.00E-08.

Table 2. Volume equations compared in the study

Equation	No.
$V=a+b*D^2$	1
$V=a+b*D+c*D^2$	2
$V=a+b*D+c*D^2H$	3
$V=a+b*D^2H$	4
$\sqrt{(V)}=a+b*D$	5
$Ln(V)=a+b*LnD+c*LnH$	6
$V=a*D^b$	7
$V=a*D^bH^c$	8

Model evaluation

The superiority of any model can not be established only on the basis of the fit statistics. Therefore, the comparison of the 8 volume equations fitted and selection of most suitable model was based on qualitative and quantitative evaluation of the models. One of the most common procedures for evaluating a model is to examine the residuals for all possible combination of variables. Residuals over observed values, or observed values over predicted values may be plotted (Gadow and Hui 1999) and examined for bias. The residuals (bias in predictions) were tested for homogenity and normality. Five statistical criteria were used for model performance: *mean residual* (MRES), which describes the directional magnitude, i.e. the size of expected under- or overestimates; *absolute* mean *residual* (AMRES), which measures the average error associated with a single prediction; *root mean squared error* (RMSE), which is based on the residual sum of squares and measures the accuracy of the estimates; *model efficiency* (Mayer and Butler 1993), which is analogous to R^2 and provides a relative measure of performance, and *variance ratio*, which measures the estimated variance as a proportion of the observed one. The mean residual is a measure of average model bias while the others are indices of model precision. The expressions for these criteria are given in Table 3.

Akaike's information criterion differences (AICd), which is a criteria based procedure and is an index to select the best model based on minimizing the Kullback-Liebler distance (Burnham and Andarson 1998), was also used to select the best approximating equation.

$$AICd = n \ln \hat{\sigma}^2 + 2l - \min(n \ln \hat{\sigma}^2 + 2l)$$

$\hat{\sigma}^2$ is the estimator of the error variance of the model, the value of which is obtained as follows:

*SPSS Inc. Headquarters, 233S, Wacker drive, 11th floor, Chicago, Illinois, 60606, USA

Table 3. Criteria for evaluating model performance

Criterion	Formula	Ideal value
Mean residual	$MRES=\frac{\Sigma(y_i-\hat{y}_i)}{n}$	0
Absolute mean residual	$AMRES=\frac{\Sigma\lvert y_i-\hat{y}_i\rvert}{n}$	0
Root mean square error	$RMSE=\sqrt{\frac{\Sigma(y_i-\hat{y}_i)^2}{n-1-p}}$	0
Model efficiency	$MEF=\frac{\Sigma(y_i-\hat{y}_i)^2}{\Sigma(y_i-\bar{y})^2}$	0
Variance ratio	$VR=\frac{\Sigma(\hat{y}_i-\bar{\hat{y}})^2}{\Sigma(y_i-\bar{y})^2}$	1

y, observed values; $\hat{y}$, predicted values; $\bar{y}_i$, mean observed value; $(y-\hat{y})$, residuals; n, total number of observations; p, number of model parameters.

Table 4. Parameter estimates and regression statistics for all the equations tested in this study

Equation no.	a	b	c	Adj. R^2
1	-0.071490	0.000796		0.884
	(0.01878)	(0.000046)		
2	0.164334*	-0.026112	0.001459	0.901
	(0.086545)	(0.009388)	(0.000242)	
3	0.022112*	-0.001954*	0.000040	0.955
	(0.03727)	(0.003034)	(0.000004)	
4	-0.001109*	0.000038		0.955
	(0.009353)	(0.000001)		
5	-0.120831	0.030311		0.912
	(0.011350)	(0.000616)		
6	-9.578514	1.889353	0.891337	0.960
	(0.275848)	(0.126847)	(0.166417)	
7	0.000055	2.775723		0.906
	(0.000029)	(0.159930)		
8	0.000030	2.027827	1.045771	0.957
	(0.000011)	(0.152036)	(0.162323)	

Values in parentheses give the standard error of the parameter estimates, *parameter values not significant.

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

where, y_i and $\hat{y}_i$ are the measured and predicted values of the dependent variable, σ^2 is the variance of y, n the total number of observations used to fit the models, p the number of model parameters, $l=p+1$.

As a thumb rule, models with AICd≤2 have substantial support and should receive consideration in making inferences. Models having AICd of about 4 to 7 have considerably less support, while models with AICd>10 have either essentially no support and might be omitted from further consideration or at least those models fail to explain some substantial explainable variation in the data.

Before computing the above statistics for equations 5 and 6, the right hand side of these equations [√V and Ln(V)] was transformed to 'V' to make the statistics for these equations comparable with the statistics of remaining equations.

A rank was assigned to each equation based on each criterion (Cao et al. 1980). The smaller the rank the better the performance of the model. The ranks were then summed up to arrive at final fit rank for each model which is indicative of its performance with respect to all the criteria considered.

Results

The skewness values given in Table 1 showed that the data is fairly symmetrical for dbh and age. For height, it is moderately skewed while for density and volume, it is highly skewed. The values for kurtosis indicated that the distribution is platykurtic for dbh, height and age while for density and volume, it is leptokurtic.

A total of 41 trees were felled from eight sites covering diameter range of 7.3-30.8 cm and tree height range of 8.2-22.0 m. A total of 8 models were tested in this study; 4 representing total volume over-bark (V_{ob}) from dbh and 4 predicting the V_{ob} from dbh (D) and total tree height (H). The values of model coefficients obtained by applying various equations to the fitting data set are given in Table 4.

The standard errors given in Table 4 show that all the tested models produced significant parameter estimates ($p<0.05$) except for D in equation 3 and intercept in equations 2-4. For the total wood volume estimation from dbh and total tree height, all the equations gave satisfactory re-

Table 5. The estimated values for the statistical criteria considered to test the predictive abilities of the models tested in the study

Model no.	MRES	AMRES	RMSE	MEF	VR	AICd	∑Rank	Overall Rank
1	-0.000150 (4)	0.043211 (8)	0.061678 (8)	0.119200 (8)	0.934413 (6)	39.217240 (8)	42	7
2	-0.000129 (3)	0.037773 (5)	0.056975 (6)	0.101716 (6)	0.978517 (3)	32.620490 (6)	29	4
3	-2.3E-06 (2)	0.023440 (1)	0.038535 (2)	0.046530 (2)	1.034574 (4)	0.554981 (2)	13	2
4	7.3E-08 (1)	0.023826 (3)	0.038230 (1)	0.045800 (1)	1.006832 (1)	0.000000 (1)	8	1
5	0.002486 (7)	0.039266 (7)	0.060724 (7)	0.115542 (7)	0.792977 (8)	37.939420 (7)	43	8
6	0.006034 (8)	0.025635 (4)	0.044606 (4)	0.062345 (4)	0.829885 (7)	12.550910 (4)	31	6
7	0.002007 (6)	0.038121 (6)	0.055997 (5)	0.098255 (5)	0.982927 (2)	31.29474 (5)	29	4
8	0.001559 (5)	0.023880 (2)	0.038566 (3)	0.046606 (3)	1.057322 (5)	0.621636 (3)	20	3

Values given in the parentheses are ranks assigned based on the values.

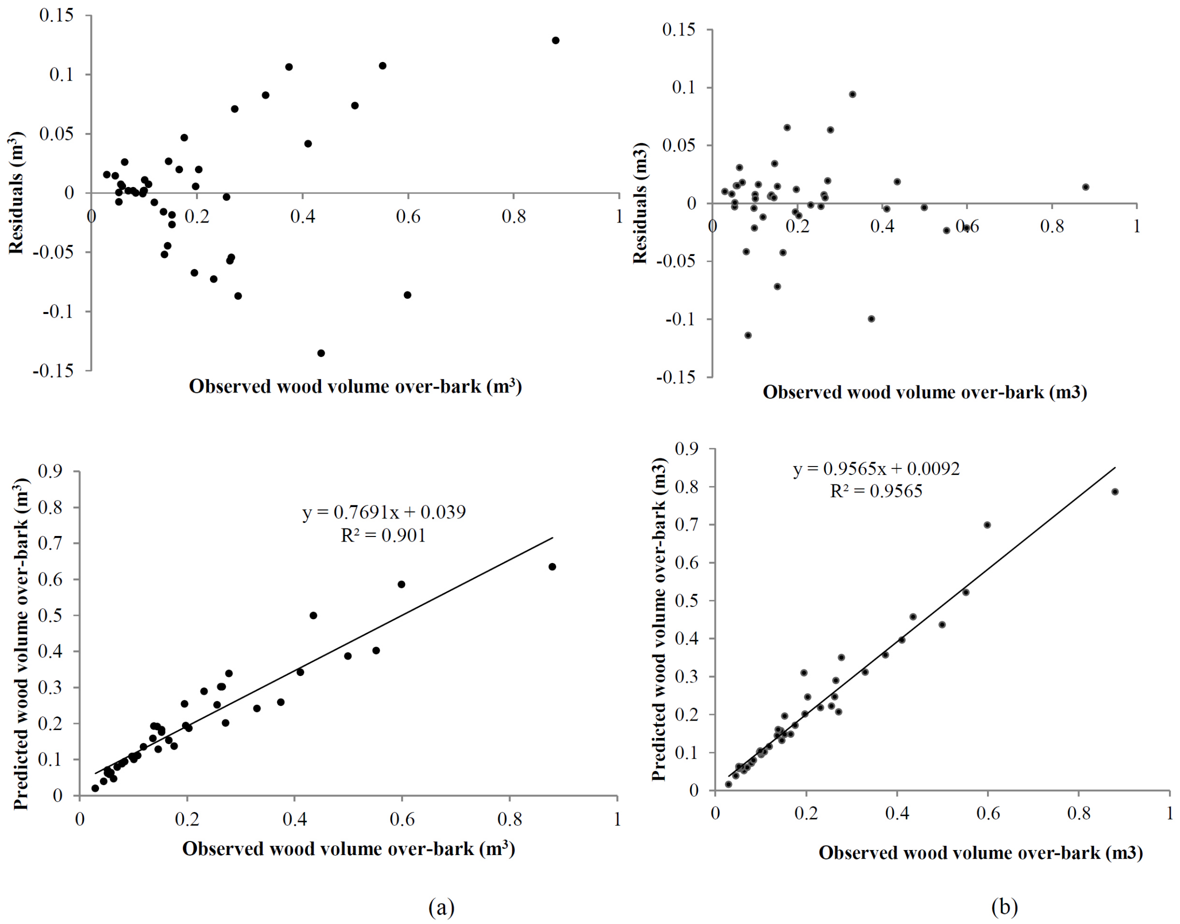

Fig. 1. The residuals and predicted vs. measured volume for (a) equation 7 and (b) equation 4 selected to predict total wood volume over-bark.

sults with high Adj. R^2 value (Table 4).

All the models were quantitatively evaluated based on Akaike information Criterion differences (AICd) and the statistical criteria given in Table 3 to test their predictive abilities. The values of these criteria obtained for different equations are presented in Table 5 and finally a rank was as-

Table 6. Parameter values and regression statistics for the best models tested in the study to estimate total wood volume for *T. grandis* in Gujarat

Model no.	a	b	c	Adj. R^2	RMSE
			Outside Bark volume (V_{ob})		
4	-0.001109	0.000038		0.955	0.038230
	(0.009353)	(0.000001)			
7	0.000055	2.775723		0.906	0.055997
	(0.000029)	(0.159030)			
			Inside Bark volume (V_{ub})		
4	-0.001760	0.000029		0.957	0.028518
	(0.006976)	(0.000001)			
7	0.000045	2.759404		0.912	0.041487
	(0.000023)	(0.154208)			

In brackets, standard errors are given.

signed to each equation.

Values of the Akaike's information criterion differences (AICd) (Table 5) suggest that double-entry equations 1, 3 and 8 have substantial support in the model selection and, hence, any of these equations can be used for volume estimation while the equation 6 failed badly in explaining some substantial explainable variation in the data and hence must not be given any consideration during model selection.

The overall rank given in Table 5 indicates that for single-entry volume equations, equation 2 and equation 7 performed equally good and, hence, any of these equations can be used for the purpose. However, based on the significance of parameter coefficients and Akaike information criterion difference, equation 7 is preferred. Also, this equation has more biological logic as volume would be zero when D=0. Thus, based on the ranks given in Table 5, equations 7 and 4 are recommended for use as single- and double-entry volume equations. Equation 7 may be preferred by the field foresters because of its simplicity and ease of use in the field.

Fig. 1 presents the predicteded vs. measured volume and the distribution of residuals for (a) equation 7, and (b) equation 4. The equation 7 over-estimated the volume with an average difference of 0.95%. For equation 4, this difference was negligible (0.000035%).

Equations 7 and 4, considered as the best equations to predict volume over-bark from dbh (D), and dbh (D) & total height (H) respectively, were also used to estimate the total volume inside-bark (V_{ub}). Table 6 presents the regression coefficients and the statistics for these finally selected equations.

Discussion

In the present study, simple linear as well as non-linear equations were tested. The use of volume equations to estimate yield in future studies may offer better estimates whilst avoiding destructive sampling (Nunifu and Murchinson 1999). Useful models must be based on easily and cheaply measured tree parameters (Phillips 1995) and ease of operation is an important considerstion in the use of volume tables (Perez and Kanninen 2003).

The combined variable equation (equation 4) showed more precision in the estimate as eveinced by the values of absolute mean residual, root mean squared error, model efficiency and variance ratio (Table 5) and, hence, was considered the better option for volume prediction. The equation 4 showed negligible error between measured and predicted volume (Fig. 1). Needless to mention that the combined variable equation, has been well recognised in volume predictions of many tree species with R^2 usually above 95% (Avery and Burkhart 1994).

The models were fitted using the method of least squares. Logarithmic volume equations have the advantage of more nearly satisfying the homogeneity of varience assumption of ordinary regression but suffer from the disadvantage that a transformation bias is introduced (Avery and Burkhart 1994).

Guidelines have been framed for documenting and reporting allometric equations (Jara et al. 2014). Of the two equations selected in the present study for total wood volume estimation, equation 7 is more simple and practical since it requires only one predictor variable (dbh) to be measuired and avoids the height measurements which is more expensive and time-consuming. It also avoids the inaccuracies inherent in height measurements of standing trees. The larger trees of dbh>30 cm and height >22 m were not available. This in one of the limitation and hence larger trees would be needed in future.

Volume equations are an important tool for projection of total and commercial volume at different stages (thinnings and final harvest) as the plantations mature (Perez and Kanninen 2003) and these should be calibrated with local data the predictive equations if differences in form and taper are found due to site variations and stand charecteristics.

Conclusion

The equations tested in the study fitted the observed data well. Most of the equations produced almost comparable results. The final total wood volume equations selected based on the model evaluation criteria are given below:

Total Wood volume equations:

$V_{ob}=0.000055*D^{2.775723}$ $R^2=0.906$, RMSE=0.055997

$V_{ub}=0.000045*D^{2.759404}$ $R^2=0.912$, RMSE=0.041487

$V_{ob} = -0.001109+0.000038*D^2H$

$R^2=0.955$, RMSE=0.038230

$V_{ub}=0.001760+0.000029*D^2H$

$R^2=0.957$, RMSE=0.028518

Any volume equation must be able to provide accurate estimates with acceptable levels of local bias over the entire diameter range in the data. The models developed must be evaluated so as to produce desired results if applied on any other independent population grown in the area. The model evaluation is an important step in the model construction process. One of the limitations of this study is that the data set was small and trees of larger size were not available. For greater applicability, data set should be sufficiently large.

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References

Avery TE, Burkhart HE. 1994. Forest Measurements. 4th ed. McGraw-Hill, New York.

Bhat KM. 2000. Timber quality of teak from managed tropical plantations with special reference to Indian plantations. Bois et Forêts des Tropiques 263(1): 6-15.

Bi H, Hamilton F. 1998. Stem volume equations for native tree species in southern New South Wales and Victoria. Australian Forestry 61(4): 275-286.

Burnham KP, Andarson DR. 1998. Model Selection and Inference: A Practical Information-Theoretical Approach. NY Springer New York, New York.

Camacho P, Madrigal T. 1997. Ecuaciones de volumen preliminares para *Tectona grandis*. III Congreso Forestal nacional. 12-29 de Agosto. San José, Costa Rica, pp 131-133.

Cao QV, Burkhart HE, Max TA. 1980. Evaluation of two methods for cubic-volume prediction of loblolly pine to any merchantable limit. Forest Science 26: 71-80.

Chakrbarti SK, Gaharwar KS. 1995. A study on volume estimation for Indian teak. Indian Forester 121(6): 503-509.

Chaturvedi AN. 1973. General standard volume tables and height-diameter relationship for teak. Indian Forest Record 12(8): 1-8.

Clutter JL, Fortson JC, Pienaar LV, Brister GH, Bailey RL. 1983. Timber Management: A Quantitative Approach. Wiley, New York.

Gadow KV, Hui GY. 1999. Modelling Forest Development. Kluwer, Dordrecht.

Gonzales LL. 1985. Growth and yield prediction model for teak (*Tectona grandis* Linn.) plantations in the Magat experimental forest Part I. Tree volume equations and tables. Sylvatrop: The Philippine Forest Research Journal 10(4): 231-241.

Goulding CJ. 1979. Validation of growth models used in forest management. New Zealand Journal of Forestry 24: 108-124.

Hamzah KA, Mohamed AH. 1994. Volume equations and tables for teak (*Tectona grandis* Linn) in Mata Ayer, Perlis, Malaysia. FRIM Reports 65: 18-33.

Hoare P, Patanapongsa N. 1988. Long-rotation, high value trees: an alternative strategy for private forestry. Commonwealth Forestry Review 67: 351-61.

Jara MC, Henry M, Réjou-Méchain M, Wayson C, Zapata-Cuartas M, Piotto D, Guier FA, Lombis HC, López EC, Lara RC, Rojas KC, Pasquel JDÁ, Montoya ÁD, Vega JF, Galo AJ, López OR, Marklund LG, Fuentes JMM, Milla F, Chaidez J de JN, Malavassi EO, Pérez J, Zea CR, García LR, Pons RR, Saint-André L, Sanquetta C, Scot, C, Westfal, J. 2014. Guidelines for documenting and reporting tree allometric equations. Ann Forest Sci 72: 763-768.

Mayer DG, Butler DG. 1993. Statistical validation. Ecological Modelling 68: 21-32.

Moret AY, Jerez M, Mora A. 1998. Determinación de ecuaciones de volumen para plantaciones de teca (*Tectona grandis* L.) en la Unidad Experimental de la Reserva Forestal Caparo, Estado Barinas - Venezuela. Revista Forestal Venezolana 42(1): 41-50.

Nunifu TK, Murchinson HG. 1999. Provisional yield models of teak (*Tectona grandis* Linn F.) plantations in northern Ghana. Forest Ecol Manag 120: 171-178.

Perez CLD, Kanninen M. 2003. Provisional equations for estimating total and merchantable volume for Tectona grandis trees in Costa Rica. Forests, Trees and Livelihoods 13: 345-359.

Phillips GB. 1995. Growth functions for teak (Tectona grandis Linn. F.) plantations in Sri Lanka. Commonwealth Forestry Review 74: 361-375.

Ramnarine S. 1994. Growth and yield of teak plantations in Trinidad and Tobago. MS Thesis, University of New Brunswick, Canada.

Reynolds MR, Burkhart HE, Daniels RF. 1981. Procedures for statistical validation of stochastic simulation models. Forest Sci 27: 349-364.

Sandrasegaran K. 1969. A general volume table for *Tectona grandis* Linn f. (teak) grown in North-West Malaya. Malayan Forester 32(2): 187-200.

Singh SP. 1981. Total tree volume table for *Tectona grandis* (teak). Indian Forester 107(10): 621-623.

Tewari VP. 2007. Total wood volume equations and their validation for *Tecomella undulata* plantations in hot arid region of India. Indian Forester 133(12): 1648-1658.

Tewari VP, Kumar, VSK. 2003. Volume equations and their validation for irrigated plantations of *Eucalyptus camaldulensis* in the hot desert of India. J Trop Forest Sci 15(1): 136-146.

Tewari VP, Mariswamy KM, ArunKumar AN. 2013. Total and merchantable volume equations for *Tectona grandis* Linn F. Plantations in Karnataka, India. J Sustain Forestry 32(3): 213-229.

Tewari VP, Singh B. 2006. Total and merchantable wood volume equations for *Eucalyptus hybrid* trees in Gujarat State, India. Arid Land Research and Management 20(2): 147-159.

Troup RS. 1921. *The silviculture of Indian trees*. Vol. II, Clarendon Press, Oxford.

Westfall PH. 2014. Kurtosis as Peakedness, 1905-2014. R.I.P.. The American Statistician 68: 191-5.