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# Volume estimation models for Teak *(Tectona grandits)* plantation in Tamil Nadu

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**Introduction:**

Teak (*Tectona grandits, L.f*) is one of the most important tropical timber species and is suitable for multiple end-use. It has excellent vegetation type and teak timber suitability is well documented and teak may grow more than 150 years under plantation conditions. In India, its natural zone of distribution is discontinuous and is mainly confined to the peninsular region south of 24 N latitude. The most important teak forests in India are in Madhya Pradesh, Maharashtra, Karnataka, Tamil Nadu and Kerala. A high quality deciduous timber species are available in India.

Teak resource management is to provide the optimum combination of quantity, quality and product sizes of timber that will maximize financial returns, accurate and flexible models are necessary to provide the information required. The variable used most in decision-making with regard to timber management is some measure of volume. This requires that volume be calculated to various specified limits. Total tree volume is predicted by total volume equations that use dbh (diameter at breast height) and height as predictor variables. To estimate the volume to some specified upper stem diameter or height, in other words the merchantable volume, volume ratio equations are used. An alternative, very useful way to estimate the volume for a variety of products is by using a Simpson 1/3 rule equation (Ravi

Kumar et.al 2020). Because Simpson 1/3 rule models mathematically describe the shape of the tree, they can provide estimates of the diameter at any height along the stem. It is possible to integrate some volume estimation models, which means that the volume can be directly calculated between the base and any other point on the stem, i.e. the merchantable volume.

The objective of this paper is to mathematically review the volume estimation and ecological applications of relative growth in plant science with a view to better understand its current state of the art and to present a holistic picture of previously separated approaches. Finally, we make suggestions for future research directions in this field.

**Models for predicting total and merchantable volume;**

There are two distinct ways to approach indirect volume estimation. Firstly, by directly measuring tree volume, a relationship can be established diameter at breast height (dbh) and total tree height through *total stem volume equation* or a *merchantable volume equation.* The second approach is *taper equation*, this model describes the entire profile of the stem, dbh and tree height.

**1.Total stem volume equations and/or merchantable volume equation**

Most of these volume equations have been developed by combining predictor variables in various ways and then regressing predictors on the dependent variable (volume) to find the best fit using least-squares regression (Sharma and Oderwald, 2001). One of the main factors when developing a volume prediction system is deciding which and how many independent variables will be included in the equation. Two values highly correlated with tree volume that are dbh and tree height (Williams and Schreuder, 2000). The measurement of dbh is an easy and accurately repeatable task, while height can be difficult to measure consistently on standing trees. Height measurement therefore leads to an additional cost and could be subjected to considerable measurement error when sampling for volume estimates. Although height is much more difficult to measure than dbh, its inclusion in a volume equation will nevertheless reduce the variance of the predicted volumes. It is only when the measurement error increases to more than about 40% that the volume estimates become biased.

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### 1.1 Model 1 (Logarithmic)

The first volume tables for teak plantations were developed by Micski and Akchurst (1972). These tables are double entry volume tables, developed from sample trees across the country subjected to different management regimes and climatic conditions. It should not be used to determine the volume of individual trees but only to calculate the per hectare volume of astand from the mean parameters.

The Logarithmic model is

$$V = b_0 D^{b_1} H^{b_2} \qquad (1)$$

where: $V$ = volume per hectare ($m^3$/ha) , $D$ = mean dbh of the stand (cm) , $H$ = mean height of the stand (m).

### 1.2. Model 2 (Generalised Combined variable)

A local volume equation developed for Mtibwa teak plantation which was used by Adegbehin (2002) to describe growth of plantation;

$$V = b_1(D)^2 + b_2(H)^2 + b_3(D)^2 H + b_4(DH^2) \qquad (2)$$

where: $V$ = volume, $D$ = dbh (cm), $H$ = height (m), $b_1 - b_4$ = regression coefficients.

The equations (2) is developed for not only teak plantations rather than to include data from other teak plantation (larger) with relatively mature trees and it was recommended to replace the biased tables by Micski and Akchurst (1972). This model showed that according to their goodness of fit and all single entry volume equations (dbh as the independent variable), double entry (dbh and height) equations are converted as dependent variable to verify the best fit.

### 1.3.Model 3 (Smalian equation)

Smalian volume equation is commonly used as

$$V_{\log} = \frac{\pi \times I \times (d_1^2 + d_2^2)}{8} \qquad (3)$$

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$V_{\log}$ = volume of the log section (m$^3$), $l$ = log length (m), $d_1$ = diameter at the thick end of the log (m), $d_2$ = diameter at the thin end of the log (m).

### 1.4. Model 4 (Huber equation)

The volume of the tree, the stem diameter between the last diametermeasurement and the tip of the tree, are calculated as the volume of a cone. This concept was suitable in Huber equation which is (Eerikäinen 2003)

$$V_{tip} = I_{tip} \times \frac{S_a}{3} \qquad (4)$$

where $V_{tip}$ = volume of the tip section of the tree (m$^3$), $I_{tip}$ = length of the tip section of the tree (m), $s_a$ = cross sectional area at the base of the conoid (m$^2$).

The total volume of the tree is calculated as

$$V_{tree} = \left( \frac{\sum_i \pi \times I_i (d_{i_1}^2 + d_{i_2}^2)}{8} \right) \times \left( I_{tip} \times \frac{s_a}{3} \right) \qquad (5)$$

where $V_{tree}$ = tree total volume, $I_i$ = log length of the i$^{th}$ section (m), $d_{i_1}$ = diameter at the thick end of the $i^{th}$ log(m), $d_{i_2}$ = diameter at the thin end of the $i^{th}$ log(m).

### 1.5. Model 5 (Simpson's 1/3 rule model)

The modified Simpson1/3 rule model for teak is

$$volume = \frac{h}{3}\int_{h_1}^{h_2} [(r.\log_1 + r.\log_n) + 3(r.\log_2 + r.\log_4 + r.\log_5 + \text{---}) + 2(r.\log_3 + r.\log_6 + \cdots)]dh \qquad (6)$$

where $h$ = dbh value, $h_1 - h_2$ = tree total height, $r.\log_1, r.\log_n$ = first and end log diameter, $r.\log_2, r.\log_4 \cdots$ are even log diameter and $r.\log_3, r.\log_6 \cdots$ odd log diameter. In order to estimate the total volume of a tree an equation using diameter at breast height and total tree height as the input variables is used. These are easily measurable and highly correlated with volume.

**2. Toper equation model**

The total volume mentioned above is often inadequate to satisfy the needs of the forest manager and planner, essentially because utilization standards tend to change over time.

**2.1. Model 1 (Max and Burkhart model)**

The Max and Burkhart model can be written in linear form as:

$$Y = b_1(z-1) + b_2(z^2-1) + b_3(\alpha_1 - z)^2 I_1 + b_4(\alpha_2 - z)^2 I_2 \quad (7)$$

where $Y = \frac{d_i^2}{D}$, $d_i =$ upper stem diameter underbark(cm) at height $h_i$, $D =$ diameter at breast height (cm), $\alpha_1 =$ upper join point, $\alpha_2 =$ lower join point and $Z = \frac{h_i}{H}$, $h_i$ = height at diameter $d_i$ (m), $H$ = total tree height (m), $b_1$ … $b_4$ = parameters to be estimated by regression,

$I_i = 1$, if $Z \le \alpha_i$ (or) $I_i = 0$ if $Z > \alpha_i, i = 1,2$.

In order to reduce the number of parameters that need to be estimated by regression, as well as alternative variable-form taper models and compared with best fit of "refitting" the model with different dbh values

**Conclusion**

In this study, the volume and shape of teak trees have been adequately described by a number of models that can be applied with relative ease. One, totally unmeasured aspect that may influence the results produced by these models is fluting. For this reason, a specific study is required to determine the amount and effect of fluting on volume estimates and to develop some measure whereby the predictions made by the models developed in this study can be appropriately adjusted. Since fluting is highly controlled by provenance and most of the teak plantations in Tamil Nadu have been established by the same provenance, it is possible to determine the amount of fluting that recently planted trees, showing little or no signs of fluting, will exhibit in the future. This result showed that as based on 15-16yrs old tree data, the multiple linear regression model $V = 0.223495 - 0.025470\ x_1 + 1.0346562\ x_2$, where

$x_1 = dbh$ and $x_2 = height$ is more optimal to estimate volume of Tamil Nadu teak, as well as predication of yield, which is confirmed by $R^2$ (0.95).

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