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VOLUME AND BIOMASS FUNCTIONS FOR TREES GROWN UNDER ARID CONDITIONS IN INDIA

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ABSTRACT

Volume equations are critical starting points to make forest management successful and efficient. Allometric equations for predicting total and merchantable volume play a critical and obvious role in the management of any silvicultural system. The importance of volume equations is indicated by the existence of numerous such equations and the constant search for their improvement. The objective of any volume equation is to provide accurate estimates with acceptable levels of local bias over the entire diameter range in the data. 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.

In this article, volume equations for *Eucalyptus camaldulensis*, *Dalbergia sissoo* and *Tecomella undulata* planted in Indira Gandhi Nahar Pariyojana (IGNP) area of Arid Rajasthan and *Acacia nilotica* and *Eucalyptus* hybrid stands in Gujarat state in India are presented. Apart from this, biomass equations for *Azadirechta india* planted in Gujarat are also reported. The biomass equations for each component were derived independently. The component predictions are not additive which implies that the predicted weight of stem plus branches may not be equal to the sum of the predicted values of stem and branch. The volume and biomass equations are extremely useful in estimating above-ground carbon stock in these species and in preparation of carbon tables.

Linear and non-linear equations were used to model the relationship of total volume and/or biomass with dbh, and with dbh and total height of the trees, and were compared on the basis of fit and validation statistics. An equation that fits very well to a data set may not necessarily be the best when applied to another data set collected from the same population. The contrasting results, obtained between model fitting and validation, emphasize the need for model validation as an important step in the model construction process.

Key words: Volume and biomass equation, Linear and non-linear functions, Model evaluation, Rajasthan, Gujarat.

Introduction

Forest mensuration is one of the most fundamental disciplines within forest- and related sciences. It deals with the measurement of trees and stands and the analysis of the resultant information. During the early days of sustained forest management, simple measurement and estimation methods and analysis of inventory and research data were available. The middle of last century, however, witnessed a worldwide increase in the need for more quantitative information about trees and stands. Development of sound management practices is one of the major priorities of the forestry sector. Accurate predictions of stand yield are needed for determining sustainable harvests.

Volume equations play a crucial role in forest management. Accurate estimates of tree volume are fundamental for forest ecosystem modelling and regional carbon accounting. Volume equations are critical starting points if forest management is to be successful and efficient. Allometric equations for predicting wood volume play a critical and obvious role in the management of any silvicultural system, and their absence would represent an impediment to developing and implementing management plans geared towards the harvest and utilization of wood products. The aim of any volume equation is to provide accurate estimates with acceptable levels of local bias over the entire range of tree size in the data. The accurate prediction of intermediate and final harvests in the construction of yield tables depends on the accuracy of individual-tree volume equations (Perez and Kanninen, 2003; Bi and Hamilton, 1998). Although volume is the accepted parameter for measuring forest growth, there are advantages of a weight based approach. The value of wood for fuel-wood, pulp and paper and many other uses is much more closely related to the weight (biomass) rather than the volume (Spurr, 1952). The role of validation in examining the predictive ability of a model before its application has been stressed by various

> Volume equations play an important role in forest Management. Also, volume and biomass equations are extremely useful in estimating above-ground carbon stock and preparation of carbon tables.

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authors (Goulding, 1979; Reynolds *et al.*, 1981).

To improve the agricultural productivity and the living conditions of the people in the arid parts of Rajasthan State in India, the 'Indira Gandhi Canal' was constructed. Large-scale afforestation activities were planned by the state forest department to combat desertification and plantations of various tree species like *Dalbergia sissoo*, *Eucalyptus camaldulensis* and *Tecomella undulata* were established using the water from the canal. Similarly, Gujarat Forest Department took massive plantations of *A. nilotica* and *Eucalyptus.* hybrid in six districts under social forestry scheme. The plantations were of different age groups with varying stand densities. Also, large-scale plantations of *A. indica* were done in Gandhinagar and Palanpur forest divisions of Gujarat.

In this article, volume equations developed for the pure even-aged stands of *D. sissoo, E. camaldulensis* and *T. undulata* available in IGNP area of Rajasthan and *Acacia nilotica* and *Eucalyptus* hybrid planted in Gujarat have been described. Apart from this, biomass equations for *Azadirechta india* planted in Gujarat are also reported.

Material and Methods

Study area

Rajasthan

The study area is characterized by a large variation in the diurnal and seasonal temperatures. The summer temperature often exceeds 46-48 ^{0}C, especially during May-June. During December-January, the night temperature occasionally reaches 0 ^{0}C owing to cold spells associated with the western disturbance and cause frost conditions. The mean monthly temperature in the area varies between 39.5 and 42.5 ^{0}C while the mean monthly minimum temperature varies between 14 and 16 ^{0}C. The soil temperature often reaches 62 ^{0}C during May and June and often exceeds the air temperature by at least 10 ^{0}C. The mean annual rainfall varies between 150 to 300 mm. The major quantity of rainfall is received during the south-west monsoon (July-September). The mean monthly relative humidity fluctuates greatly during the year between 15 to 80%. The mean evaporation varies from 2.7 to 4.7 mm per day in winter and from 13.2 to 15.3 mm per day in summer. Wind speeds as high as 130 km per hour may be experienced during the summer months. Dust storms are also common in the area. The terrain is very undulating consisting of moving sand dunes, dry undulating plains of hard sand and gravelly soil and rolling plains of loose sand. The soil is rich in potash but poor in nitrogen and low in organic matter. The soils are coarsely textured and the water retention capacity is low.

Gujarat

The temperatures average between 12^{0}C to 27^{0}C during winters while in summers temperature averages between 25^{0}C to 43^{0}C though sometimes it reaches as high as 48^{0}C. The mean annual rainfall varies between 682 to 1006 mm. The soils of the region are gravelly loam to clayey loam in texture.

Data and field procedure

Thirty sample plots of *D. sissoo*, 35 of *Eucalyptus camaldulensis* and 22 of *T. undulata* were laid out in the IGNP area of Rajasthan, and 34 sample plots of *Eucalyptus* hybrid, 22 of *A. nilotica* and 6 of *A. indica* were laid out in Gujarat covering the available age groups and stand densities. The plot size was approx. 0.1 ha and data included a record of the age (A), the dominant stand height (H), the quadratic mean diameter (D_g), the stems/ha (N), the basal area/ha (BA), etc.

All the trees within the sample plots were measured for diameter at breast height (D) and total tree height (H). Then in each plot trees were stratified into different diameter classes. A sub-sample of trees were felled from the surround of each of the plots (to keep the permanent sample plots undisturbed) representing different diameter classes within the particular plot. These were then measured for D, H and wood volumes (over-bark and under-bark). Green weights of stem-wood, branches and leaves and twigs were taken for *A. indica*.

Number of trees necessary for a volume/biomass table for a given species is a critical question. Estimates from many recent studies suggest that 30-100 trees are enough for a regional table using stratified sampling of the population. Sufficient evidence argues that, if sample trees are selected in equal or near equal numbers in each size class, 30 trees for an individual tree volume/biomass table are adequate (MacDicken *et al.*, 1991). A total of 71 sample trees of *D. sissoo*, 91 of *Eucalyptus camaldulensis* and 75 of *T. undulata* were felled from different plantations in IGNP area of Rajasthan. Similarly, 160 trees of *Eucalyptus* hybrid, 80 of *A. nilotica* and 30 of *A. indica* were felled in Gujarat for constructing volume/biomass equations.

The length of the felled tree was measured and stump height was added to get the total height (H). For the computation of total volume (V), stem and branch wood upto a minimum diameter of 5 cm was considered. The volume was then calculated by dividing the stem and branches into logs of 3m length, measuring the mid-diameters and applying Huber's formula ($V=\pi D^2 L/4$; Avery and Burkhart, 1994) to estimate individual log volumes. 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 (over-bark) to arrive at the value of dbh inside the bark (Tewari *et al.,* 2013). Similarly, bark thickness up the bole and of the branches was also determined with the bark gauge; twice the bark thickness on one side at different points along the bole and branches is the total bark thickness at that point.

For biomass, the leaves and twigs were also separated. The green weights of each component were then measured in the field itself. Small representative samples of wood from both the ends of each log and leaves and twigs were collected and their green weights were recorded (Kumar and Tewari, 1999). Oven dry weights were determined for these samples in the laboratory. Based on these two (green and dry) sample weights, dry weights for each tree were calculated (Kumar and Tewari, 1999).

Volume equations

The data were divided into two sets by random sampling. The first data set contained 70% of the observations and was used for fitting the volume equations while the latter contained the remaining data and was used for validation. These data sets will henceforth be referred to as the fitting and validating data sets, respectively (Kumar and Tewari, 1999).

Model fitting and validation

Linear and non-linear equations were used to model the relationship of total volume with dbh, and with dbh and total height. A total of 10 volume equations (Table 1) were selected from the literature based on their wide application (Spurr, 1952; Loetsch *et al.,* 1973; Clutter *et al.,* 1983; Ramnaraine, 1994; Chakrabarti and Gaharwar, 1995; Moret *et al.*, 1998; Perez and Kanninen, 2003). Each model was applied to the fitting data set. The SPSS★ statistical software package was used for the linear and non-linear regression.

To reduce heteroscedasticity in the error structure of volume estimation and to avoid the consequences of violating the distributional assumptions, weighted least squares regression was applied for fitting the multiple linear equations. The non-linear equations were fitted through Levenberg-Marquardt minimisation method of SPSS. The convergence criterion for accepting the values of parameter estimates was taken as 1.00E-08. Furnival's (Furnival, 1961) index of fit was used to select the best weight function value of k ranging from 0 to 3 with an even interval of 0.05. This index is based on transformed maximum likelihood values and takes the following form:

$$I = [\text{antilog}\{\Sigma(\log\surd(X_i)^{-k})/n\}]^{-1}S$$

where, X_i is $D_i^2H_i$ or D_i^2 as the case may be and S is the least squares estimate of the standard error of the weighted error term. It provides a relative measure of the departures from linearity, normality and homoscedasticity of residuals.

The bias (B), which tests the systematic deviation of the model from the observations, root mean squared error (RMSE), which measures the accuracy of the estimates, 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 and the number of observations were used to determine the quality of fit (Cao *et al.*, 1980; Biging, 1984; Fowler and Rennie, 1988). The expressions for these criteria are as below:

Bias:

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

Root mean squared error:

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

Adjusted coefficient of determination:

$$R^2_{adj} = 1 - \frac{n-1}{n-p} \sum_{i=1}^{n} \frac{(y_i - \hat{y}_i)^2}{(y_i - \bar{y}_i)^2}$$

One of the most common procedures for evaluating a model is to examine the residuals for all possible combination of varables. Residuals over predicted 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.

For validation purpose, models can be tested in various ways. Firstly, the re-sampling approach (Bi and

Table 1: Equations for the total volume tested in the study

Equation type	Model No.
$V = a+bD^2H$	1
$V = a+bD^2$	2
$V = a+bD+cD^2$	3
$V = a+bD+cD^2+dD^2H$	4
$\surd V = a+bD$	5
Log (V) = a+b Log (D)	6
Log (V) = a+b Log (D)+c Log (H)	7
$\text{Log}(V) = a+bDH+cD^2H$	8
$V = aD^b$	9
$V = aD^bH^c$	10

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

Hamilton, 1998; Bi, 1999; 2000) may be adopted. Secondly, iterative validation procedure (Williams, 1997) may be considered. Thirdly, if the dataset is small, PRESS statistics (Greeen, 1983) may be used. Fourthly, if one has two independent data sets from the same area or population, one set can be used for fitting and the other for validation or alternatively if one has only one data set, it can be divided into two through random procedure for the purpose. Here the last approach has been adopted. Wilcoxon's sign and rank test was used to test the significance of any bias. The root mean squared error (RMSE) and the average bias (B) were used as evaluation criteria for model validation (Cao *et al*., 1980; Gordon, 1983; Biging, 1984; Fowler and Rennie, 1988; Trincado *et al*., 1996).

Biomass functions

The data from the destructive sampling of *A. indica* trees were used to find allometric relationship for biomass as a function of D and H. Step-wise regression using SPSS package was fitted on the data to select independent variables on the basis of increasing values of F. Best models were selected on the basis of significance of partial regression coefficients at the P-0.05 level, highest F-value, high R^2 and low standard error of estimate (SEE).

Results and Discussion

Total wood volume equations

All the tested models produced significant parameter estimates ($P<0.05$), a high coefficient of determination ($R^2>0.95$), and low root mean squared error. However, the standard errors for parameter estimates are not exact due to heteroscedasticity of the error terms and multicollinearity among variables in equations 3, 4, 7 and 8. Also, the standard errors for the parameter estimates for the equations 9 and 10 are asymptotic as these functions were fitted through non-linear technique.

The predictive ability of the different equations was assessed using an independent data set (validating data set) for model validation. The volume equations obtained from the fitting data set were applied to the validating data set. The bias gives the accuracy of prediction while the variance provides information regarding precision of the prediction. The root mean square error provides a composite measure (combining bias and precision) of the overall accuracy of prediction. The smaller these values the better the prediction. The validation process is necessary so that the model can be used with some confidence (Goulding, 1979; Reynolds and Chung, 1986).

The equation which performed best in the fitting phase did not perform well during model validation. This emphasises the importance and need of validating a model prior to its use. Hence, based on high R^2 value and low RMSE, a ranking was assigned to all the equations during fitting as well as validation phase. The ranks were then combined and best ranked equation was selected for estimating volume of the particular species. Height is often difficult to measure accurately and may not always be available. In such cases, volume-diameter equations may be the best alternative. Thus, the finally selected single- and double entry volume equations for different species are given below (Tewari and Kumar, 2001, 2003; Tewari and Singh, 2006 a, b; Tewari, 2007).

E. camaldulensis

$V = 0.000169*D^{2.41298}$ Adj. $R^2 = 0.995$; RMSE = 0.02922

$V = -0.00226 + 0.0000333\ D^2H$ Adj. $R^2 = 0.990$; RMSE = 0.00001

D. sissoo

$V = 0.01328 – 0.00538\ D + 0.000760\ D^2$ Adj. $R^2 = 0.961$; RMSE = 0.00005

$V = -0.0023 + 0.0000364\ D^2H$ Adj. $R^2 = 0.992$; RMSE = 0.00006

T. undulata

$V = 0.000088\ D^{2.381398}$ Adj. $R^2 = 0.918$; RMSE = 0.00803

$V = 0.000066\ D^{2.100121}H^{0.553696}$ Adj. $R^2 = 0.924$; RMSE = 0.00772

E. hybrid

$V = 0.000076*D^{2.761477}$ Adj. $R^2 = 0.978$, RMSE = 0.02844

$V = 0.000014*D^{2.141947}H^{1.168588}$ Adj. $R^2 = 0.989$, RMSE = 0.02054

A. nilotica

$V = 0.000071*D^{2.735778}$ Adj. $R^2 = 0.975$, RMSE = 0.03015

$V = 0.000018*D^{2.363677}H^{0.938962}$ Adj. $R^2 = 0.983$, RMSE = 0.02512 where, V is the total wood volumes (m^3) over-bark, D is the dbh (cm) and H is the total tree height (m).

Useful models must be based on easily and cheaply measured tree parameters (Philips, 1995). In the present study, simple linear models as well as non-linear models were tested. For the estimation of total wood volume from tree size variables, simple linear and lograthmic models gave satisfactory results but non-linear models showed more precision in the estimate and less bias in the pattern of residuals and hence were considered the better choice for predicting tree volume. 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). Though, the non-linear equations have more biological logic as volume would be zero when D=0 and H=0.

The models were fitted using the method of least squares. Logarithmic volume equations have the advantage of more nearly satisfying the homogeneity of variance assumption of ordinary regression but suffer from the disadvantage that a transformation bias is introduced (Avery and Burkhart, 1994). Although the error term of model 10 is of multiplicative form, no heteroscedasticity was found.

The model for general volume estimation for *A. nilotica* presented in this study showed an estimated error of 1.27% between predicted and measured volume for the fitting data set. When this data was divided in two stocking levels of < 1000 trees ha^{-1} and > 1000 trees ha^{-1}, the error varied from 0.28% to 11.76%, respectively. When divided by height classes, trees with height > 8m showed a smaller error (1.10%) between measured and predicted volume compared to the trees < 8m of height (5.90%). Similarly, when divided by dbh classes, trees with a dbh > 10cm showed less error (1.23%) between measured and predicted volume than the trees with a dbh of < 10cm of dbh (2.70%). This suggests that the volume equations for *A. nilotica* are more accurate on trees with dbh greater than 10 cm and total heights greater than 8 m, on plantations with less than 1000 trees ha^{-1} (Tewari and Singh, 2006 a).

Similarly, the model for general volume estimation for *E. hybrid* showed estimated error of 0.15% between predicted and measured volume for the fitting data set. When the data was divided in two stocking levels of < 1000 trees ha^{-1} and > 1000 trees ha^{-1}, the mean error varied from -3.77% to 3.73%, respectively. When divided by height classes, trees with height > 10m showed less error (-0.43%) between measured and predicted volume compared to the trees < 10m of height (8.94%). Similarly, when divided by dbh classes, trees with dbh > 15cm showed less error (-2.74%) between measured and predicted volume than trees with < 15cm of dbh (7.11%). This suggests that the volume equations of this study are more accurate on trees with dbh greater than 15 cm and total heights greater than 10 m (Tewari and Singh, 2006 b).

Volume equations will gain importance for projection of total and commercial volume at different stages (thinnings and final harvest) as the plantations mature (Perez and Kanninen, 2003). It will be necessary to calibrate the predictive equations if differences in form and taper are found due to site variations and stand characteristics. The validation process is necessary so that the model can be used with some confidence (Goulding, 1979; Reynolds and Chung, 1986).

Biomass equations

The green and dry weights of total biomass (stem+branches+leaves+twigs), total wood (stem+branches), stem wood, branch wood, bark and leaves and twigs were regressed on D and H to give the biomass equations for *A. indica* (Kumar and Tewari, 1999). The equations obtained for various parts of the trees are as follows:

Equations	Parts
Weight = a + b*D^2H	Stem green and dry weight (both over-bark and under-bark)
	Total wood green weight (over-bark)
	Total wood dry weight (under-bark)
	Total dry biomass
	Bark (both green and dry weights)
Weight = a + b*D^2 + c*DH	Branch green and dry weight (over-bark)
	Total green biomass
Weight = a + b*D^2	Branch green and dry weight (under-bark)
	Leaves and twigs (both green and dry weights)
Weight = a + b*D + c*D^2	Total wood green weight (under-bark)
Weight = a + b*D^2H + c*H^2	Total wood dry weight (over-bark)

The values of various coefficients and summary statistics are given in Tables 2 and 3 for green and dry weights (over-bark), respectively.

Similar equations have been derived for under-bark wood biomass also. The parameters of these equations are given in Tables 4 and 5.

Since the bark is used for various medicinal purposes, it was deemed proper to derive equations for bark biomass too. It was found that the combined variable equation performed better in this case. The values of regression coefficients and summary statistics for the same are given in Table 6.

The F-values in the above tables show high significant levels of results for all the regressions. The values of standard errors show that all the partial regression coefficients are significant.

The values of D and H in the sample plots ranged from 5.4 cm to 35.8 cm and 4.5 m to 16.2 m, respectively

Table 2: Coefficients and summary statistics for green weight equations (over-bark)

Biomass	Intercept	D^2	D^2H	DH	Mean (kg/tree)	Bias (10^{-14})	R^2 (%)	SEE	F-ratio**
Stem	9.610 (4.217)	-	0.024 (0.001)	-	93.49	0.95	97.8	14.06	839.82
Branch	-0.744 (18.028)	0.692 (0.100)	-	-0.930 (0.255)	68.07	4.52	97.0	18.48	179.02
Total wood	-20.687 (5.666)	-	0.047 (0.001)	-	138.87	1.09	98.9	18.89	1683.34
Leaves & twigs	-5.371 (9.692)	0.233 (0.025)	-	-	63.52	0.26	82.4	29.23	89.14
Total Biomass	1.409 (14.573)	1.382 (0.103)	-	-1.219 (0.249)	202.39	-2.40	99.2	22.78	1073.42

Table 3: Coefficients and summary statistics for dry weight equations (over-bark)

Biomass	Intercept	D^2	D^2H	DH	H^2	Mean (kg/tree)	Bias (10^{-14})	R^2 (%)	SEE	F-ratio**
Stem	5.923 (3.186)	-	0.017 (0.001)	-	-	63.59	1.86	97.3	10.62	695.56
Branch	-1.394 (11.633)	0.477 (0.065)	-	-0.638 (0.164)	-	46.83	5.99	97.4	11.92	206.81
Total wood	8.690 (5.675)	-	0.036 (0.001)	-	-0.360 (0.077)	94.81	-3.52	99.6	07.89	2307.38
Leaves & twigs	-3.744 (4.649)	0.106 (0.012)	-	-	-	27.56	0.25	80.8	14.02	80.01
Total Biomass	-13.410 (5.636)	-	0.040 (0.001)	-	-	122.37	-1.10	98.5	18.78	1232.25

Table 4: Coefficients and summary statistics for green weight equations (under-bark)

Biomass	Intercept	D	D^2	D^2H	Mean (kg/tree)	Bias (10^{-14})	R^2 (%)	SEE	F-ratio**
Stem	4.818 (3.420)	-	-	0.021 (0.001)	76.73	-0.90	98.0	11.40	938.65
Branch	-43.027 (10.367)	-	0.247 (0.022)	-	51.37	1.20	91.3	22.71	126.16
Total wood	44.789 (13.831)	-10.749 (1.629)	0.798 (0.042)	-	110.98	1.09	99.6	09.22	2292.89

Table 5: Coefficients and summary statistics for dry weight equations (under-bark)

Biomass	Intercept	D^2H	D^2	Mean (kg/tree)	Bias (10^{-14})	R^2 (%)	SEE	F-ratio**
Stem	3.348 (2.581)	0.015 (0.001)	-	53.62	-0.68	97.7	08.60	805.88
Branch	-31.354 (7.245)	-	0.178 (0.015)	36.74	1.70	91.8	15.87	134.40
Total wood	-12.651 (3.128)	0.026 (0.001)	-	78.12	2.54	98.9	10.42	1787.99

The standard errors of regression coefficients are given in the parentheses. ** Pr ≤ 0.0001

while the range of these values for felled trees were from 7 cm to 35.6 cm and 6 m to 15.4 m, respectively indicating that the trees felled for destructive sampling were good representative of the population (Kumar and Tewari, 1999).

In Tables 2-6, the means of the data are given to see the relative size of the SEE. The average bias detected from the plots of the residuals against the measured data have also been presented as bias is just as important as the high R^2 and low SEE. The bias detected is almost negligible (of the order of 10^{-14}).

Table 6: Coefficients and summary statistics for bark biomass equations

Bark	Intercept	D^2H	Mean (kg/tree)	Bias (10^{-14})	R^2 (%)	SEE	F-ratio**
Green	-3.601 (1.241)	0.009 (0.000)	27.89	0.06	98.6	4.14	1365.68
Dry	-2.719 (0.860)	0.006 (0.000)	16.69	-0.67	98.3	2.87	1081.75

The standard errors of regression coefficients are given in the parantheses. ** Pr≤0.0001

The biomass equations for each component were derived independently. The component predictions are not additive (Kozak, 1970) which implies that the predicted weight of stem and branches may not be equal to the sum of the predicted values of stem and branch.

Conclusions

The equations tested in the study fitted the observed data well. Single-entry and double-entry total wood volume equations have been constructed and validated for *D. sissoo, E. camaldulensis, T. undulata*, *A. nilotica* and *Eucalyptus* Hybrid. These assume importance in projecting the total volume at different stages (thinnings and final harvest) as the plantations mature. Volume equations proposed may be applied on any population of these species available in the study area or in the areas having similar growing conditions. Also, total and component-wise biomass equations are presented for *A. indica*. The volume and biomass equations are extremely useful in estimating above-ground carbon stock and in preparation of carbon tables.

The contrasting results obtained during model fitting and validation process of volume equations emphasize the need for model validation as an important step in the model construction process in order to get the best choices. The resulting equations should apply only to the region where sample plots were laid out for data collection. The equations could be used more widely, though with caution.

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ou ic/ e vk;ru lehdj.k ,d vge Hkfedk vnk djr gA vk;ru lehdj.k ØkfUrd 'k: okrh fcUn g] ;fn ou ic/ dk liQy vkj l{ke gkuk gA dy vkj foØ; vk;ru dh Hkfo";ok.kh fy, lki{kferh; lehdj.k fdlh Hkh ou lo/fud i.kkyh d ic/ e ,d ØkfUrd vkj iR;{k Hkfedk vnk djr g vkj budh vuifLFkfr dk"B mRiknk dh mit vkj mi;kx dh fn'kk e lftr ic/ ;ktukvk d fodkl vkj dk;kUo;u e ,d ck/k dk ifrfuf/Ro djxhA vk;ru lehdj.kk dk egRo bl idkj d vl[; lehdj.kk dh mifLFkfr vkj bud l/kj d fy, lrr [kkt }kjk inf'kr gkrh gA fdlh Hkh vk;ru lehdj.k dk mnn'; vkdMk e lEi.k O;kl jt e LFkkuh; >dko d Lohdk; Lrjk d LkkFk ifj'k¼ vkdyuk dk miyC/ djkuk gA O;kl dh lEi.k jt e LFkkuh; >dko d fcuk vk;ru dh ifj'k¼ Hkfo";ok.kh miyC/ djku oky lehdj.k ,d ou of¼ ,o mit mRij.k i.kkyh d vk/kjHkr fuek.k Cykdk e l ,d gA bl 'kk/i=k e Hkkjr e 'k"d jktLFkku d bfUnjk xk/h ugj ifj;ktuk {k=k e jkfir यूकेलिप्टस कमल्डूलिनसिस, डैल्बर्जिया सिस्सू vkj टेकोमेला अण्डुलाटा vkj xtjkr e ऐकेशिया निलोटिका vkj ;dfylVl gkbfcM LV.Mk d vk;ru lehdj.k iLrr fd, x,A bld vykok] xtjkr e jkfir ऐजेडिरैक्टा इंडिका d fy, toek=kk lehdj.kk dk Hkh lfpr fd;k x;kA iR;d l?kVd d fy, toek=kk lehdj.kk dk Lor=k : i l O;RiUu fd;k x;kA og l?kVd Hkfo";okf.k;k ;kT; ugh g] ftue ifjyf{kr g fd ruk /u 'kk[kkvk d io dfFkr Hkkj ruk vkj 'kk[kk d iodfFkr ekuk d ;kx d cjkcj ugh gk ldr gA dkcu lkjf.k;k dk r;kj dju e vkj bu itkfr;k e HkE; ifjd dkcu LVkd dk vkdyu dju e vk;ru vkj toek=kk lehdj.k vR;f/d mi;kxh gA

o{kk dh o{kPprk O;kl ,o dy Åpkb d lkFk vkj o{kPprk O;kl d lkFk dy vk;ru vkj@vFkok toek=kk d lc/ d ekMy d fy, jf[kr vkj xj&jf[kd lehdj.kk dk mi;kx fd;k x;k vkj iQhV rFkk ekU;dj.k lkf[;dh d vk/kj ij ryuk dh xbA fdlh fu/kfjr vkdM d fy, cgr vPNh rjg iQhV gku okyk lehdj.k vfuok;r% rc Hkh t:jh ugh g fd lokRre gk tc ml mlh vkcknh l ,df=kr fu/kfjr nlj vkdM i;Dr fd;k tk,A ekMy fiQfVx vkj ekU;dj.k d chp ikIr fojk/kHkk"kh ifj.kke ekMy fuek.k ifØ;k e ,d egRoi.k dne d : i e ekMy ekU;dj.k dh vko';drk ij tkj nrk gA

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