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Construction of Two-Way Volume Table of *Eucalyptus Tereticornis* for Mid-Himalayan Region of Himachal Pradesh

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Abstract

Eucalyptus is the genus of trees that is most planted around the world because of its large number of species, the ability to adapting in many different sites, and the possibilities of producing wood for many different uses. The present study was conducted to construct the two-way volume table of *Eucalyptus tereticornis* for mid-Himalayan region of Himachal Pradesh. For the purpose, secondary data for diameter and height of *Eucalyptus* trees were collected from four different sites viz. Khaltoo, Ucchagaon, Kharkog and Pandah. From each plantation site,150 trees of *Eucalyptus tereticornis* were selected and the data were subjected to variability analysis in order to test the variability among different sites. Bartlett's chi-square test for testing the homogeneity of variances suggested that there were no variability with respect to DBH, height and volume among different sites. Site wise comparison was also performed to test the equality of means among different sites. Maximum mean diameter (m) was observed at Khaltoo (0.2097) and minimum was observed at Ucchagaon (0.1767). Mean height (m) was observed maximum in Kharkog (10.6374) and minimum in Pandah (9.7873). Maximum mean volume (m^3) was recorded at Khaltoo (0.3955) and Minimum mean volume was recorded at Ucchagaon (0.2105) which was statistically at par with Kharkog (0.2815). Regression analysis was performed to estimate the volume of Eucalyptus trees using ordinary least square estimation method. For the construction of two way volume table, linear model ($V=0.0003+0.7842\ D^2H$) was observed best fit on the basis of highest R^2 value (0.96) and least root mean square error value (0.0282). These models may be used for the construction of volume table.

Keywords: *Eucalyptus tereticornis,* RMSE, volume table

1. Introduction

Sustainable forest management requires estimates of growing stock. Such information guides forest managers in timber valuation as well as in allocation of forest areas for harvest (Akindele and LeMay, 2006). In intensive farm forestry, foresters/farm tree growers should be able to estimate tree volume accurately for such phases of timber management as timber sales, advance planning, growth, yield studies and to estimate increment to assess return on capital, etc. (Dhanda and Verma, 2001). This can be easily done if volume table is available. Volume table is a table showing for a given species the average content of the trees, logs or sawn timber for one or more given dimensions. The given dimensions may be

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DBH (diameter at breast height) alone, DBH and height; DBH, height and some measure of form or taper (Chaturvedi and Khanna, 2011).

Fast growing and short-rotation species, without a doubt, offer significant competitive advntages and versatility. They are the species of choice, especially belonging to the genus *Eucalyptus*, for setting up high yield projects for various reasons *Eucalyptus tereticornis* is one of the most extensively cultivated species in India under major afforestation programmes. This is mainly because of its short rotation period and easy adaptability to a wide variety of soils and climatic conditions (Tiwari, 1991). In India, Eucalyptus was introduced in the regime of Tippu Sultan from 1782 to 1802 at Nandi hills, Bangalore and Sultanpet area in the Deccan. The recorded evidences of introduction from Australia to Nilgiris in the South India had been shown by Captain Dunn and Captain Cotton in 1843 when the species were planted to meet the firewood needs of the locality (Bhatia, 1984). The objective of any volume equation is to provide accurate estimates with acceptable level of local bias over the entire range of tree size in the data (Tewari and Kumar, 2003). Development of sound management practices is one of the major priorities of the forestry sector. As with any branch of research within the natural sciences, simulation modeling and prediction are becoming increasingly important in forestry research (Tewari and Singh, 2006). For the volume estimation of standing trees, models are more suitable as they can provide scientists a tool to make sound recommendations, to aid the conceptualization and sometimes to predict the consequences of an action that would be otherwise expensive, difficult or destructive to do in the real world (Pandey et al., 1998).

Chaturvedi and Venkatraman (1973) prepared volume & weight table for *Eucalyptus* Hybrid. Chaturvedi (1974) prepared tree quality volume tables for *Eucalyptus* hybrid. He used basic data of general volume tables. In his study, heights of trees were plotted against d.b.h. and tree quality curves were drawn. Mishra and Singh (1985) prepared local volume tables of *Acacia catechu* (Khair) and *Lanneagrandis.* Mittal et al. (1991) constructed volume tables for *Acacia auriculiformis.* Standard regression techniques, based on ordinary least square methods were accepted for the construction of volume table. Single tree data of 85 trees was collected by Singh et al. (1995) from Muzaffarnagar road side plantations for preparing volume tables for *Eucalyptus* hybrid. Singh and Upadhyay (2001) prepared volume tables for G48 and D121 clones of *Populusdeltoides* for the tarai and Bhabhar region of Uttaranchal. Dhanda and Verma (2001) prepared timber volume and weight tables for Poplar (*P. deltoids)* which was an important agroforestry tree species in Punjab. Timber volume (both over bark and under bark), fresh timber weight, above ground biomass, and firewood estimate tables were developed based on regression equations.

The present study was undertaken to provide the handy tool for foresters/scientists to know rough estimate of wood volume of Eucalyptus at any farm without using any destructive method. Some statistical models were used on the basis of basic field data regarding the present research problem with the objective to construct the two way volume table for Eucalyptus *tereticornis*.

2. Materials and Methods

The present study was conducted on the secondary data of high density plantation of Eucalyptus in 2015. tereticornis raised by the Department of Silviculture and Agroforestry, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni-Solan (HP). The University is situated at an elevation of 1255 m above mean sea level and lies at 30.86° N latitude and 77.16° E longitude. The plantation was established by transplanting five months old polybag seedling on 12.07.1986 to four sites viz. Khaltoo, Ucchagaon, Kharkog and Pandah in the University area. The data on DBH and height of Eucalyptus trees were collected by the Department of Forest Products, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni-Solan (HP) India.

Volume of tree on DBH and height basis was calculated by using following formula:

Where, $V=\{(\pi d^2)/4\}\times h$

V = Volume of tree
d = Diameter at breast height
h = Height of the tree

Bartlett's chi-square test was applied to check whether two or more independent samples are drawn from same population or from different population.

Suppose there are k-independent samples of sizes n1, n2, ...,nk with sample variance $s^1_2, s^2_2,\ldots, s_k^2$ respectively,

Where,

$$s_2^i=\frac{1}{n_i-1}\sum_{j=1}^{ni}(X_{ij}-X_i)^2,\ (i=1,2,\ldots,k)$$

be the unbiased estimate of the population variance, obtained from the ith sample Xij, (j=1, 2,...,ni) and based on vi = (ni - 1) d.f., all the k samples being independent.

Under the null hypothesis that the samples were collected from the same population with variance σ^2, i.e., the independent estimates s^2_i, (i=1,2,...,k) of σ^2 are homogeneous, Bartlett proved that the statistic

$$\chi^2=\sum_{i=1}^{k}(v_i\log_e\frac{S^2}{S_i^2})\div[1+\frac{1}{3(k-1)}\{\sum_i(\frac{1}{V_i})-\frac{1}{V}\}]$$

Where,

$$S^2=\frac{\sum V_iS_i^2}{\sum V_i}=\frac{\sum V_iS_i^2}{\sum V}$$

$$\sum_{i=1}^{k}V_i=V$$

follows chi-square distribution with (k-1) degrees of freedom.

If calculated value of χ^2 is more than the tabulated value of χ^2 at specified level of significance and at an appropriate degree of freedom (i.e. χ^2 is significant), the null hypothesis is rejected

and it is concluded that the samples are having significantly different variances and thus further analysis is to be done independently for each site.

If calculated value of χ^2 is less than the tabulated value of χ^2 at specified level of significance and at an appropriate degree of freedom (i.e. χ^2 is non-significant), the null hypothesis is accepted and it is concluded that the sample variance do not differ significantly and thus further analysis is to be done with pooled data.

Regression analysis is a mathematical measure of the average relationship between two or more variables in terms of original unit of data. In regression analysis, there are two types of variables. The variable whose value is to be predicted is called dependent variable and the variable which influences the values or is used for prediction is called independent variable. Dependent variable is also known as regressed or explained variable and independent variable is also known as regressor or predictor or explanatory variable

If the variables in a bivariate distribution are related, we will find that the points in the scatter diagram will cluster round some curve called the "curve of regression". If the curve is a straight line, it is called the line of regression and there is said to be linear regression between the variables, otherwise regression is said to be curvilinear. The line of regression is obtained by the principle of least squares. A relation between two variables may be approximately linear when studied over a limited range but markedly curvilinear when a broader range is considered. The selection of the form of the regression equation which bests express a curvilinear relation is not always a simple problem. There is practically no limit to the number of kind of curves that can be expressed by mathematical equation. Models which are non-linear in the parameters are intrinsically linear if a transformation will make them linear, typical examples are logarithmic and exponential curves.

In present investigation, volume estimation of Eucalyptus trees was done by taking volume as dependent variable and diameter at breast height (DBH) and height of trees as independent variables.

The term validation refers to the process of assessing in some sense the degree of agreement between the model and real system being modeled. Once a model which gives an adequate fit to the data has been found, the next step in the process is to use the model for prediction purposes. Before a model is to be used or recommended, it is advised to check its validity. In the present study, different techniques used for validation purpose were coefficient of determination and root mean square error.

2.1. Coefficient of determination

An important measure of amount of the variation about the mean explained by the model is defined as coefficient of determination i.e. R^2, which is the square of correlation between response values and the predicted response and is called the square of multiple correlation coefficients or the coefficient of multiple determination. R^2 is defined as the ratio of sum of squares of deviation and the total sum of squares.

R^2=SSR(Sum of squares due to regression)÷TSS(Total sum of square)

R^2 can take any value between 0 to 1. The closer the value of R^2 to 1, smaller is the scatter of the points about the regression plane and better is the fit.

2.2. Root mean square error (RMSE)

The root mean square deviation (RMSD) or root mean square error (RMSE) is a frequently used measure of the differences between values (sample and population values) predicted by a model and the values actually observed. The RMSD represents the sample standard deviation of the differences between predicted values and observed values which is given by

RMSE=√MSE

Where,

MSE=SSE/df

A value closer to 0 indicates the best fit of the model and can be used for prediction.

Volume table is a table showing for a given species the average content of the trees for one or more given dimension. These tables were based on the actual measurement of sufficiently large number of trees and have been prepared on the assumption that the same species with the same dimension will have the same volume. For the construction of volume table, some regression equations or models were first prepared from the basic field data and out of these models, the model which gave results of desired accuracy was selected for preparation of volume table. The volume of a tree mainly depends upon three variables *viz*. diameter at breast height (DBH), height and tree form. Out of which, diameter at breast height is most important, than height and last of all tree form. The choice of variable depends upon the extent of their application.

In the present study, two volume tables were constructed *i.e.*one-way volume table and two-way volume table. For the construction of one-way volume table, volume of tree and only one variable *i.e.,* diameter at breast height was required in which volume was taken as dependent variable and diameter at breast height as independent variable. For the construction of two way volume table, diameter at breast height and height were combined together to form a variable D^2H. This combined variable (D^2H) was taken as independent variable and volume as a dependent variable. These variables were subjected to regression analysis using ordinary least square method and various models were fitted. Models obtained from regression analysis were than tested for their goodness of fit and the best fitted model was used for the preparation of volume tables.

3. Results and Discussion

Four sites viz. Khaltoo, Ucchagaon, Kharkog and Pandah were selected for the present study and 150 trees of *Eucalyptus tereticornis*from each plantation site were selected for

variability analysis for diameter, height and volume, respectively

Bartlett's chi-square calculated values for diameter, height and volume are 3.8353, 4.8128 and 5.5118, respectively which were less than chi-square table value (7.8147) at 5% level of significance and 3 degree of freedom, and hence the results were non-significant. This showed that there is no significant difference for variances among four sites with respect to diameter, height and volume.

Various linear and non-linear (straight line, logarithmic, quadratic, inverse, cubic, compound, power, S, growth and exponential) functions were tried for the estimation of volume and best fitted function was used for the construction of one way and two way volume table.

The pooled data were used to fit different models. These models and respective values of coefficient of determination (R^2) and root mean square error values are presented in Table 1. The data revealed that linear model was best fit for the estimation of volume with highest R^2 value of 0.96 and least RMSE value of 0.0282 followed by quadratic model with R^2 and RMSE values being 0.93 and 0.0547, respectively. Thus, volume of Eucalyptus can be estimated by using linear model ($V= 0.0003+0.7842\ D^2H$).

Table 1: Linear and non-linear functions for volume using D^2H as independent variable

Models	Equations	R^2 value	RMSE
(1) Linear	$V= 0.0003+0.7842\ D^2H$	0.96	0.0282
(2) Logarithmic	$V= 0.6341 + 0.2912\ \ln (D^2H)$	0.90	0.0707
(3) Quadratic	$V= -0.0008+0.7895\ (D^2H) + 0.0051\ (D^2H)^2$	0.93	0.0547
(4) Inverse	$V= 0.5553+0.0660/(D^2H)$	0.65	0.1640
(5) Cubic	$V= 0.0088+0.7767\ (D^2H)-0.0204\ (D^2H)^2+0.014\ (D^2H)^3$	0.90	0.0632
(6) Compound	$V = 0.0993\times11.2777(D^2H)$	0.89	0.1974
(7) Power	$V= 0.7847\times(D^2H)^{0.9998}$	0.88	0.0500
(8) S	$V= \exp (-0.4207-0.2525/(D^2H))$	0.89	0.2000
(9) Growth	$V = \exp (-2.3099+2.4265\ (D^2H))$	0.88	0.1974
(10) Exponential	$V = 0.0993\ e^{2.4228(D2H)}$	0.89	0.1949

RMSE= Root mean square error

Tewariet al. (2001) and Dogra and Sharma (2003) suggested the use of combined variable (D^2H) for the construction of volume tables which are in line with the present investigation.

After applying various statistical checks (*i.e.*, highest R^2 and least RMSE value), linear straight line model was established to be the best fit for the construction of two way volume table of *Eucalyptus tereticornis*. Using linear ($V= 0.0003+0.7842\ D^2H$) model, a two way volume table was constructed in which volume was taken as dependent variable and D^2H was taken as an independent variable. Table 2 presents the volume over bark of Eucalyptus trees for different diameters ranges from

Table 2: Two-way volume table (Overbark) for *Eucalyptus tereticornis*

D	Height (m)													
	7	8	9	10	11	12	13	14	15	16	17	18	19	20
10	0.0579	0.0657	0.0736	0.0814	0.0892	0.0971	0.1049	0.1128	0.1206	0.1284	0.1363	0.1441	0.1520	0.1598
15	0.1265	0.1441	0.1618	0.1794	0.1970	0.2147	0.2323	0.2500	0.2676	0.2852	0.3029	0.3205	0.3382	0.3558
20	0.2225	0.2539	0.2852	0.3166	0.3480	0.3793	0.4107	0.4420	0.4734	0.5048	0.5361	0.5675	0.5988	0.6302
25	0.3460	0.3950	0.4440	0.4930	0.5420	0.5910	0.6400	0.6890	0.7380	0.7870	0.8360	0.8850	0.9340	0.9830
30	0.4969	0.5675	0.6380	0.7086	0.7792	0.8497	0.9203	0.9908	1.0614	1.1320	1.2025	1.2731	1.3436	1.4142
35	0.6753	0.7713	0.8674	0.9634	1.0594	1.1555	1.2515	1.3476	1.4436	1.5396	1.6357	1.7317	1.8278	1.9238
40	0.8811	1.0065	1.1320	1.2574	1.3828	1.5083	1.6337	1.7592	1.8846	2.0100	2.1355	2.2609	2.3864	2.5118
45	1.1143	1.2731	1.4318	1.5906	1.7494	1.9081	2.0669	2.2256	2.3844	2.5432	2.7019	2.8607	3.0194	3.1782
50	1.3750	1.5710	1.7670	1.9630	2.1590	2.3550	2.5510	2.7470	2.9430	3.1390	3.3350	3.5310	3.7270	3.9230
55	1.6631	1.9003	2.1374	2.3746	2.6118	2.8489	3.0861	3.3232	3.5604	3.7976	4.0347	4.2719	4.5090	4.7462
60	1.9787	2.2609	2.5432	2.8254	3.1076	3.3899	3.6721	3.9544	4.2366	4.5188	4.8011	5.0833	5.3656	5.6478

D: Diameter (cm); cm: centimeters; m: meters; m^3= Cubic meters

10 to 60 cm and height ranges from 7 to 20 m, which was calculated by using proposed linear equation.

These findings are in close conformity with the earlier findings of Dhanda and Verma (2001), Singh et al. (2001) who also used combined variable (D^2H) and linear model for the construction of two way volume tables .

4. Conclusion

Bartlett's chi-square calculated values for diameter, height and volume are 3.8353, 4.8128 and 5.5118, respectively which were less than chi-square table value (7.8147) at 5% level of significance and 3 degree of freedom, and hence the results were non-significant. This showed that there is no significant difference for variances among four sites with respect to diameter, height and volume. Among all the models linear was found to be fitted best.

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