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Allometric equations to predict volume of chir pine (*Pinus roxburghii* Sargent) stands based on crown attributes

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ABSTRACT

The study was conducted on chir pine stand *(Pinus roxburghii Sargent)* at Barog forest range (R-31) under Solan Forest Division (Himachal Pradesh), lying at latitude of 30° 51'N and longitude of 77° 04' E to develop volume prediction model based on crown parameters. Various linear and non-linear functions based on stem volume and crown parameter relationships were developed and compared for their performances. Based on adjusted R^2, the log-linear and power function performed better among all the functions and both of them explained 99 per cent variation in stand volume due to crown volume followed by crown area (90 per cent), crown diameter (90 per cent), crown width (88 per cent), and crown length (85 per cent). However, the power function outperformed the log-linear function, when data were subjected to chi-square test of goodness of fit and thereafter using Theil-U test. The predicted volume based on crown volume was cross validated and tested for its accuracy by correlating it with observed volume and volume estimated through volume table. The accuracy was found to be 90 per cent.

Keywords:
Crown, Thiel-U test, Chi-square, Linear, Non-linear.

INTRODUCTION

As the field methods are quite labour intensive, time consuming and difficult, there is need to develop simplified and efficient procedures of volume estimation for forest crops. One simplified approach is through the study of allometry. Regression equations that describe volume increment of trees in response to corresponding changes in more easily measured tree parameters like dbh, height and taper are classified as allometric models and have been put to use extensively to predict stem volume of standing forest crop (Mittal *et al.*, 1991; Negi *et al.*, 1998; Pant, 2001; Forslund, 1982; Pohjonen, 1991 and Sharma and Nanda, 2008)

Recently, crown has been of great interest to foresters, because the three dimensional structure of the canopy determines the distribution of light in a forest ecosystem and is major determinant of stand productivity (Mc Naughton and Jarvis, 1983; Fassnaucht et al, 1994; Gholz, 1982 and Gower et al., 1992). It can be an important variable in evaluating silvicultural operations and ecological conditions of forest stands. The crown characteristics can best be utilized in estimating volume of forest stands with the advancement in aerial photography and satellite remote sensing technique (Hyyppă et al., 2005).

The study is based on the assumption that crown is correlated with tree growth parameters. The present study is therefore, an attempt to compare performance of various linear and non linear relationships between standing stem volume and crown parameters. Consequently, the best fitted function has been validated and tested for its accuracy.

Study Area

The study was conducted on chir pine stand (*Pinus roxburghii* Sargent) in the C-1a and C-2b compartments of Barog range (R-31) under Solan Forest Division (Himachal Pradesh) at elevation range of 1500-1900 m above mean sea level lying at latitude of 30° 51'N and longitude of 77°04' E. It is a transitional zone between sub-tropical and moist temperate region. It has pure chir pine forest of moderate density managed under chil working circle (Solan Forest Division). A few trees of *Quercus leucotrichophora, Pyrus pashia, Prunus padus, Myrica nagi* etc. are present as underwood. *Quercus leucotrichophora* is mainly confined to depressions. Sparse bush growth of *Berberis lycium, Carissa opaca, Rubus ellipticus, Rhus cotinus, Desmodium tilaefolium, Indigofera pulchella and Dabregesia hypoluca* is present.

MATERIALS AND METHODS

After thorough survey of the study area, trees of *Pinus roxburghii* Sargent falling under different dbh classes (10-20 cm to 80-90 cm) were enumerated for crown attributes (crown diameter, crown width, crown length, crown area and crown volume) and volume of each dbh class. In total 210 trees were enumerated with at least 30 trees under each dbh class. Due to inadequate availability of trees at higher diameter classes, a stratified random sampling based on proportional allocation with respect to diameter classes was followed to select sample trees. Stem volume (m^3) was calculated by applying the formula (Chaturvedi and Khanna, 2000) given as under:

$$V = \frac{\pi}{4} d^2 h f$$

Where, V = Stem volume in cubic meters
d = Diameter at breast height in meters
h = Tree height in meters
f = Form factor

Form factor was computed by using the formula derived from the equations given by Pressler (1865) and Bitterlich (1984).

$$f = \frac{2h_1}{3h}$$

h = Tree height in meters

h_1 = Height at which the diameter is half of the dbh

Crown length (m) is the distance from the midpoint of lowest green branches and dead branch adjacent to it to the tip of the tree which was measured with the help of Spiegel Releskop. Crown diameter (m) was measured by projecting the perimeter of the crown vertically to the ground in two opposite directions, at right angle to each other and it was calculated by the formula given by Assamann (1970).

$$D = \frac{D_1 + D_2}{2}$$

Where,

D = Crown diameter in meters

D_1 = Crown diameter in north-south direction

D_2 = Crown diameter in east-west direction

Crown width (m) is the maximum spread of crown along its widest diameter. It was recorded by projecting the perimeters of the crown vertically to the ground. Crown area (m^2) of the tree was calculated by using the formula given by Chaturvedi and Khanna (2000) as:

$$A = \frac{\pi}{4} D^2$$

Where,

A = Crown area in square meters

D = Crown diameter in meters

Inherent shape of tree crowns is modified to some extent by age, site and environmental conditions. In conifers, it is common for crowns to become flat-topped and decurrent with age and again, this is more obvious on poorer sites. The crown volume therefore for the tree falling. under lower diameters class (<40 cm) and trees of higher diameter class (> 40 cm) using conical and parabolic formula respectively, was calculated as described by Chaturvedi and Khanna (2000).

Conical crown

$v = {}^1/_3 AL$

Parabolic crown

$v = {}^1/_2 AL$

Where,

v = Crown volume in cubic meters

L = Crown length in meters

A = Crown area in square meters

The data were subjected to regression analysis by taking crown parameters as independent variable (Diameter, width, length, area and volume) and volume as dependent variable. Thereafter, chi-square test of goodness of fit and Theil-U test was employed (Theil, 1965).

RESULTS AND DISCUSSION

Regression analysis

Various linear and non-linear functions employed to study the relationship between stem volume and crown parameters are significant (Table1). The results revealed that non-linear functions out perform the linear functions when stem volume was regressed with various crown parameters. Among various non-linear functions, both the log-linear and power functions resulted in maximum values of adjusted R^2 with crown volume (0.93) followed by crown area (0.90) crown diameter (0.90), crown width (0.88), and crown length (0.85).

Since the value of adjusted R^2 is the indicator of percentage of variability in the dependent variable caused by the independent variable and is often used to judge the performance of the model, it does not mean that model is a good fit. Therefore, to test the goodness of fit, the chi-square test and Theil-U test was applied. On comparison between log-linear and power function, it was found that power functions were best fit than log-linear function because of non-significant chi-square values and lower values (near to zero) of Theil-U test (Table 2). Thus models based on power function indicated close correspondence

between the observed and estimated values.

The results are in agreement with the findings of Payandeh (1983) who has reported stronger and significant non-linear relationship while estimating biomass of *Betula alleghaniensis* and *Acer sacchrum*. However, Wam- Razali *et al.* (1989), Pant (2001) and Dogra and Sharma (2003) have reported logarithmic functions as the best fit for *Acacia mangium*, *Pinus caribea*, and *Eucalyptus* hybrid, respectively. On the other hand parabolic, polynomial and linear functions have been reported to be best fit for *Tectona grandis* (Chakrabarti and Gaharwar, 1995), *Pinus caribaea* (Allen, 1991) and *Terminalia paniculata* and *Xylia xylocarpa* (Swamy *et al.*, 1999), respectively. On the contrary, Sharma and Nanda (2008) has reported logarithmic and power functions as the best fit for the estimation of volume of *Pinus roxburghii* stand based on dbh and height independently.

Table 1. Stem volume regressed on crown parameters using linear and non-linear functions

	Equation	Adjusted R^2
Simple linear functions		
	V = -1.16 + 0.370* D	0.77*
	V = -1.22 + 0.330* W	0.72*
	V = -1.35 + 0.380* L	0.67 *
	V = 0.05 + 0.030* A	0.75 *
	V = 0.43 + 0.004* v	0.72 *
Log -linear functions		
	LnV = -4.92 + 2.49* ln D	0.90*
	LnV = -5.64 + 2.75* ln W	0.85*
	LnV = -5.48 + 2.58* ln L	0.88*
	LnV = -4.62 + 1.24* ln A	0.90*
	LnV = -3.99 + 0.81* ln v	0.93*
Exponential functions		
	$V= 0.05\ e^{0.36\ D}$	0.81 *
	$V= 0.04\ e^{0.33\ W}$	0.81 *
	$V= 0.04\ e^{0.39\ L}$	0.79 *
	$V= 0.19\ e^{0.03\ A}$	0.67 *
	$V= 0.27\ e^{0.004\ V}$	0.59*
Polynomial functions		
	$V = -0.94 + 0.30\ D + 0.001D^2$	0.77*
	$V = -0.85 + 0.23\ W + 0.001W^2$	0.72*
	$V = -0.96 + 0.26\ L + 0.010\ L^2$	0.67*
	$V = -0.40 + 0.05\ A + 0.001\ A^2$	0.79*
	$V = -0.05 + 0.01\ V + 0.010\ v^2$	0.81*
Power functions		
	$V = 0.007\ D^{2.48}$	0.90*
	$V = 0.004\ W^{2.57}$	0.88*
	$V = 0.004\ L^{2.74}$	0.85*
	$V = 0.010\ A^{1.24}$	0.90*
	$V = 0.020\ v.^{0.81}$	0.93*

**p value* < 0.05

V = Stem volume, D = Crown diameter, W = crown width, L = Crown length, A = Crown area, v = Crown volume

Table 2. Comparison of linear and non-linear functions for stem volume estimation

Parameters	*Log-linear*			*Power*		
	Adj. R^2	X^2	Theil-U Statistic	Adj. R^2	X^2	Theil-U Statistic
Crown diameter	0.90	2.12*	0.56	0.90	0.14	0.19
Crown width	0.88	2.20*	0.57	0.88	0.17	0.20
Crown length	0.85	2.34*	0.58	0.85	0.22	0.22
Crown area	0.90	2.12*	0.56	0.90	0.14	0.19
Crown volume	0.93	2.07*	0.56	0.93	0.09	0.20

**p value* < 0.05

Cross-validation

The models based on power function were subjected to cross-validation. Out of actual 210 sample trees, 105 were selected at random and the models selected for cross-validation were fitted. The fitted models were used to predict the volume of 105 sample trees (original set) which were used in calibration of model and then the same was used to estimate the expected values of left over 105 sample trees (independent set). Same process was reversed for second half of the observations and the respective values of apparent error, true error, excess error and chi-square values for original, independent and entire data set were computed (Table 3).

The results revealed that apparent error and true error were found negligible, which reflects that the prediction model to be nearly correct. Computed value of the chi-square for original set, independent set and both the sets when taken together were found to be non-significant thereby proving the validity of selected models. The results are in accordance with the findings of Anderson *et al.* (1982), Verbyla and Fisher (1989), Ferreire *et al.* (1991), Chauhan and Sahoo (1997), and Pandey *et al.* (1998). Sharma and Nanda (2008) reported the same results while cross validated the volume prediction model for *Pinus roxburghii* based on dbh and height.

Among all the crown attributes, the crown volume comparatively was the best predictive variable as the apparent error was zero (original as well as independent sets), the true error and excess error were almost negligible and moreover, the chi-square values were also recorded minimum for original, independent and overall set.

Table 3. Cross-validation results of stem volume models

Set	Model	Adjusted R^2	Apparent Error	True Error	Excess Error	X^2 (original)	X^2 (independent)	X^2 (overall)
1	$V=0.0073\ D^{2.462}$	0.89	0.05	0.13	0.07	0.13	0.18	0.31
2	$V=0.0073\ D^{2.489}$	0.90	0.03	0.01	-0.02	0.15	0.18	0.33
1	$V=0.0047\ W^{2.528}$	0.88	0.08	0.09	0.01	0.18	0.22	0.40
2	$V=0.0039\ W^{2.611}$	0.89	0.07	0.05	-0.02	0.17	0.20	0.37
1	$V=0.0043\ L^{2.654}$	0.86	0.15	0.17	0.02	0.20	0.21	0.41
2	$V=0.0039\ L^{2.831}$	0.85	0.08	0.05	-0.03	0.24	0.25	0.49
1	$V=0.013\ A^{1.231}$	0.89	0.04	0.05	0.01	0.13	0.18	0.31
2	$V=0.0098\ A^{1.244}$	0.90	0.04	0.02	-0.02	0.15	0.18	0.33
1	$V=0.0193\ v^{0.803}$	0.93	0.00	0.02	0.02	0.12	0.15	0.27
2	$V=0.0183\ v^{0.812}$	0.93	0.00	0.01	0.01	0.13	0.15	0.28

V = Stem volume, D = Crown diameter, W = Crown width, L = Crown length, A = Crown area, v = Crown volume

Accuracy Assessment

Because of the superiority of crown volume over other crown parameters used in the volume prediction model, it was subjected to accuracy assessment. To check the accuracy of the model, the predicted volume was correlated with observed volume and volume calculated by volume table. A significant correlation (r = 0.90) was noted. The graphical display of relationships (Fig 1) however, showed deviation in predicted volume from the observed volume and volume obtained through volume table at 60-70 cm dbh. This deviation is attributed to the growth behavior of independent crown variables which have shown decreased growth rate with increase in dbh beyond 60-70 cm.

CONCLUSIONS

The study demonstrates that both log-linear and power functions performed better among all functions on the basis of adjusted R^2. However, the power function outperformed the log-linear function as far as chi-square test of goodness of fit and Theil-U test is concerned. Among all crown variables, the crown volume proved to be the best predictive variable and the proposed model seems to meet the standard of accuracy. The exploitable diameter for chir pine however, in this region is 60 cm and therefore application of this model holds appropriate. Further, the testing of this crown based stand volume prediction model at varied sites and inclusion of crown behaviour factor beyond 60 cm dbh crop needs to be investigated.

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