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journals.uoz.edu.krd

Science Journal of University of Zakho

Vol. 11, No. 2, pp. 179 –184, April-June, 2023

p-ISSN: 2410-7549
e-ISSN: 2414-6943

EVALUATIONS OF DIFFERENT MODELS FOR PREDICTING MERCHANTABLE VOLUME OF PINUS BRUTIA TEN. IN DUHOK GOVERNORATE

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Received:17 Aug.,2023 /Accepted: 30 Nov.,2023/Published:16 Apr.,2023 *https://doi.org/10.25271/sjuoz.2023.11.2.997*

ABSTRACT:

This study was initiated with the main objective of evaluating the prediction power of previously 24 published models in the literature, developed for estimating the merchantable volume of natural stands of Pinus brutia Ten. The estimation was based on measuring the breast diameter (D), tree height (h), and absolute form quotient (F) of 120 pine trees (Pinus brutia Ten.) from 2 natural stands situated to the east of Duhok governorate. Six indicators of Fit test statistics, namely Adjusted coefficient of determination (R^2- adj.) standard error of estimate (SEE), mean absolute error (MAE), Durbin-Watson statistic (D-W), p-value, and mean biased error (Bias) were used to test the performance of the applied models. The result from the centroid model was considered a reference method for the evaluation during this study. The results indicated that the square root –y logarithmic-x offered the highest performance followed by the double square root model. The square root –y logarithmic-x (equation 11) attributed more than 90% of the variation in merchantable volume to variations in D, h, and F. Furthermore, the mean absolute error of prediction of this model was 0.0434. According to this study, the mean stem form of Pinus brutia trees is (0.64), which signifies quadratic paraboloid.

KEYWORDS: Butt Log Volume, Centroid Method, Tree Form, Volume Estimate, Volume Table.

INTRODUCTION

Since ancient times, merchantable volume equations and merchantable volume tables have been the most prevalent techniques for determining tree stem and wood volume. Merchantable tree volume tables were generated using single, double, and multi-entry tree volume equations (Burkhart & Tomé, 2012). Tree volume prediction is a critical measurement for estimating volume at various merchantable heights estimating woody biomass and carbon stock assessment, forest management and planning, monitoring forest health and productivity, and future projections of the forest. To estimate the single tree and stand, flexible and accurate volume estimation methods that can also be readily integrated into any growth and yield equations are required (Gómez-García et al., 2015).

In general, conventional formulae such as Huber's, Smalian's, Hosfeld's, Simoney's, and Newton Rickey's have been used to estimate log volumes. Because of its simplicity and usefulness, Huber's method is commonly used for log volume estimates. It makes use of an assumed taper function (also known as a "proxy function") (YAVUZ, 1999). The volume estimated by the proxy function is changed by the ratio of the actual cross-sectional area at a randomly chosen point on the log to the anticipated cross-sectional area at that point. VASILESCU et al. (2017), on the other hand, created the Centroid technique (Centroid Sampling), a version of Importance Sampling, for calculating log, merchantable volume, and total tree volumes. Certain studies found that Centroid Sampling yielded more reliable results for several tree species than other common formulae (e.g., Huber, Smalian, and Newton-Riecke).

The main stem volume of a standing tree is obtained by making standard measurements of different segments after the tree is divided into logs. Then the log volume is calculated for each part separately. The total stem volume or actual volume of an individual tree is calculated by adding cumulative volumes. The process of dividing the main stem into pieces and calculating the volume of each portion separately takes a significant amount of time and effort, and hence the cost of computing the volume is expensive (Akpo et al., 2021). Recently, the centroid method was used to estimate the volume of tree trunks instead of the old classical methods (Huber, Smalian, and Newton) and with providing high accuracy. In this method, it is possible to calculate the volume of the trunk with a height of 5-m without affecting the accuracy of the equation.

Much of the research on predicting tree stem volume has focused on excurrent forms, with D and H serving as predictors (Burkhart & Tomé, 2012). Demaerschalk (1972) demonstrated how a total stem volume equation, combined with taper data, can be used to generate a taper function that is consistent with the volume equation (compatible in the sense that integration of the taper function over the limits zero to total tree height produces the volume equation). Observing that each variable-top merchantable stem volume equation automatically determines an accompanying taper function, reversed the volume-taper compatibility procedure. While the numerical quantities of the coefficients will differ based on which equations are fitted and whose coefficients are generated, the shape of the suggested taper function and the accompanying inverse function are the same whether ratio equations are used. The segmented polynomial taper equation used by (Max & Burkhart, 1976) has been proven to yield reliable results for several species. It is made up of three equations that characterize the lower section's neiloid, the middle section's paraboloid frustum, and the upper bole section's conical form. Using two join points, the three equations are merged into a single equation. The purpose of this study was to see how the centroid method affected the accuracy of merchantable volume estimates obtained for Pinus brutia Ten. The findings are intended to serve as a guide in the selection of appropriate methods for estimating merchantable volume under forest conditions in the Duhok Governorate and elsewhere in the Kurdistan region.

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MATERIALS AND METHODS

Study area

The merchantable volume equations were tested using data from two natural forests of pine trees in the districts of Atrush and Zawita in Duhok, Kurdistan region of Iraq. Duhok Governorate is located north-western part of Iraq, and its geographical coordinates: (37° 6' 15" North, 43° 49' 51" East). It is located at an elevation of 291 to 2574 meters above sea level and encompasses an area of 6,600 km^2. The area of land covered with forest constitutes 28% of the total area of Duhok. The agricultural fields are largely concentrated around communities (FAO, 2003). The climate is comparable to that of the Mediterranean. According to (Vandenplas, 1959), the Mediterranean climate is distinguished by moderate winter rainfall and dry summers. It has a pleasant to chilly rainy winter and a warm to hot dry summer. Field surveys and data collection were performed in the districts of Zawita and Atrush during the autumn of 2021 the first site is about 19 kilometers northeast of Duhok, with geographical coordinates: (36° 54' 23" North, 43° 10' 18" East). While Atrush district is 60 kilometers southeast of Duhok, geographical coordinates: (36° 50' 17" North, 43° 20' 9" East).

Data collection

Before collecting any measurements, the trees were in good health, with no obvious indications of serious injury, and the stand of regular trees was free of disease or insect assault, as well as natural injuries such as broken tops from wind, storm, and fire. Furthermore, trees with many stems, evident cankers, or bent boles were excluded from the study. To create a merchantable volume table, stem volume chart for Pinus brutia Ten. 120 sample trees were chosen from natural forest stands of various ages, diameters, and height classes. Sixty trees were taken from Zawita and 60 from Atrush. The sample trees were collected to assign equal to each diameter and height class. Pinus brutia sample trees ranged in height from 10.5 to 17.5 meters, with the breast height (D) diameter ranging from 19.75 to 51.75 cm. All diameters are measured by calliper via two measures taken of diameter at right angles to one another and calculate the average (West & West, 2009). The sample tree height (h) was measured by the Haga Altimeter tool (Husch, Beers, & Kershaw Jr, 2002).

Method

The butt log volume measurements are performed to evaluate the stump diameter ($d_{0.3}$), and all diameters at 5-m increments above the stump ($d_{0.3}$, $d_{5.3}$), respectively. The mid-log volume measurements are obtained by measuring all diameters for a 5-m interval ($d_{5.3}$, $d_{10.3}$). The Centroid formula will calculate butt log and mid-log volumes for each tree at a 5-m log length above the stump. The centroid formula is the more recent formula used in this research to estimate butt log volume at 5-m length, developed by (West & West, 2009) which is similar to the Newton formula but utilizes cross-sectional area at the mid-volume point rather than at mid-length.

The Centroid technique estimates log volume in three-step. In the first step, the diameter at the big (d_0) and small (d_n) ends of the log, as well as the log length (L), are measured in the first step. The Centroid distance (q) from the big end of the log is computed by Equation (2) in the second step, the Centroid diameter (dc) is measured at this point. And, finally, Equations (4) and (5) are used to estimate the parameters (b1 and b2) of the Centroid Volume Equation (1).

Centroid: V = SL + (1/2) b1L2+ (1/3) b2L3 (1)

$$q = L - \left(\frac{\left(\frac{d_0}{d_n}\right)^2 - \sqrt{2}}{\sqrt{2}\left(\frac{d_0}{d_n}\right)^2 - \sqrt{2}} \right) L \quad (2)$$

e =L-q (3)

$$b_2 = (B - C\,(L/e) - S\,(1 - L/e))/(L^2 - Le) \quad (4)$$

$$b_1 = (B - S - b_2 L^2)/L \quad (5)$$

Where: B = Cross-sectional area at the large end of butt log outside bark (m^2).

G = Cross-sectional area at 1/3 of butt log length from the large end of the butt log outside bark (m^2).

M = Cross-sectional area at mid-length of butt log outside bark (m^2).

S = Cross-sectional area at the small end of butt log outside bark (m^2).

L = long length (m).

C = Cross-sectional area at the mid-volume of butt log (m^2) measured at a distance q from the large end of butt log outside bark.

d_0, d_n = diameter (cm) at the large and small end of the butt log outside bark, respectively.

The absolute form quotient (F) was extensively used to classify the form of the main stem of an individual tree. It is a summarization of the overall stem form. It is calculated by taking a half-height measurement between breast height and total tree height. This diameter is then divided by the diameter at breast height. It is frequently used to classify trees into form classes, which may be expressed by the equation.

$$F = \frac{d_{0.5}(h-1.3)}{D} \quad (6)$$

Where: d_0.5 (h-1.3) = diameter at half height above breast height measured in cm.

D = diameter at breast height measured in cm.

Absolute form quotients may also be used to predict generic stem shapes: 0.325 – 0.375 neiloid form class (35), 0.475 – 0.525 conoid form quotient (50), 0.675 – 0.725 quadratic paraboloid form quotient (70), and 0.775 – 0.825 cubic paraboloid form quotient 80.

Data analysis

The correctness of the resulting equation is determined by numerous statistical metrics, including the (R^2-adj.), (SEE), (MAE), (D-W), P-Value, and (B). Another critical stage in assessing the equations is to do a graphical analysis of the best-fit equation to evaluate the look of the fitted curves superimposed on the data set. The data will be processed using Statgraphics 19 - X64 and Microsoft Excel 2016. The following statistics equations were used to evaluate the twenty-four merchantable tree volume equations:

The adjusted coefficient of determination:

$$R^2 = 1 - \frac{\sum(Y_i - \hat{Y}_i)}{\sum(Y_i - \bar{Y}i)} * \frac{n-1}{n-p-1} \quad (7)$$

Standard error of estimate: $SEE = \frac{SEE}{\sqrt{n}}\sqrt{1 - \frac{n}{N}}$ (8)

Mean absolute error: $MAE = \frac{\sum_{i=1}^{n}|Yi - Xi|}{n}$ (9)

Durbin-Watson statistic: $DW = \frac{\sum_{i=2}^{n}\left(e_i - e_{i-1}\right)^2}{\sum_{i=1}^{n} e_i^2}$ (10)

Bias $= \sum_{i=1}^{n}\frac{(Y_i - \hat{Y}_i)}{n}$ (11)

Where: Yi, Ŷ, Ȳ, = merchantable volume of observations, estimate, and average values of the dependent variable, respectively.

P = number of equation parameters.

n = number of observations.

RESULTS AND DISCUSSION:

The cubic volume of each part of the sample tree was calculated using the centroid formula (sectional volume of the stem) for both butt log volume, and mid-log volume. The cumulative volumes were then summed to get the merchantable volume for each tree up to an estimated 10cm top diameter outside bark and total volume. The D and h of each sample tree chosen for sectional volume estimates were computed; they are required in regression analysis. The data came from wild Brutia pine forests in Zawita and Atrush. Table 1, shows the dataset distribution statistics by diameter and height classes.

Table (1): Distribution of Diameter and Height of Pinus brutia Ten.

Diameter	Mid	Height classes (m)								
Classes (cm)	Point	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	Total
19.5 - 21.4	20.5	3								3
21.5 - 23.4	22.5	1	1		2					4
23.5 - 25.4	24.5	3	1	4	1					9
25.5 – 27.4	26.5	2	2		1					5
27.5 - 29.4	28.5	1	1	1	1					4
29.5 - 31.4	30.5	2	6	1	4	2				15
31.5 – 33.4	32.5	1	5	1	1	3	1			12
33.5 – 35.4	34.5	3	4	1	4					12
35.5 – 37.4	36.5	2	2	3	1	3	3			14
37.5 – 39.4	38.5		2	1	3	1	3			10
39.5 – 41.4	40.5	1	5			4		1	1	12
41.5 – 43.4	42.5	1		3	1	2				7
43.5 – 45.4	44.5		2		2		1	2		7
45.5 – 47.4	46.5					2				2
47.5 – 49.4	48.5			1				1		2
49.5 – 51.4	50.5							1		1
51.5 – 53.4	51.5								1	1
Total		20	31	16	21	17	8	5	2	120

Several merchantable volume equations are employed in various ways to build tree volume equations. Many of these merchantable volume equations were developed using a single variable, D, or two variables, (D and h). Because the goal of this study was to create a merchantable form class volume table, merchantable volume equations based on three variables (D), (h), and, (F). The functional form of these equations was V = f. (D, h, F). Twenty-four different merchantable volume equations have been obtained displaying a list of possible volume equations in Table 2.

Table (2): List of developed merchantable volume equation

No.	Name of Equation	Equation
1	Linear model	$MV = -0.151786 + 0.00238085 * D * h * F$
2	Square root-Y model	$MV = (0.245084 + 0.00161642 * D * h * F)^2$
3	Exponential model	$MV = \exp(-2.06763 + 0.00459523 * D * h * F)$
4	Squared-Y model	$MV = \sqrt{(-0.492726 + 0.00290926 * D * h * F)}$
5	Square root-X model	$MV = -0.849222 + 0.0826521 * \sqrt{(D * h * F)}$
6	Double square root model	$MV = \left(-0.2408 + 0.0568432 * \sqrt{(D * h * F)}\right)^2$
7	Logarithmic-Y square root-X model	$MV = \exp(-3.48659 + 0.163815 * \sqrt{(D * h * F)})$
8	Reciprocal-Y square root-X	$MV = 1/(9.03877 - 0.396013 * \sqrt{(D * h * F)})$
9	Squared-Y square root-X	$MV = \sqrt{(-1.30607 + 0.0987069 * sqrt(D * h *}$
10	Logarithmic-X model	$MV = -3.2952 + 0.68311 * \ln(D * h * F)$
11	Square root-Y logarithmic-X model	$MV = \left(-1.95829 + 0.476065 * \ln(D * h * F)\right)^2$
12	Multiplicative model	$MV = \exp(-8.54511 + 1.39129 * \ln(D * h * F))$

13	Reciprocal-Y logarithmic-X model	$MV = 1/(21.821 - 3.46158 * \ln(D * h * F))$
14	Squared-Y logarithmic-X model	$MV = \sqrt{(-4.12051 + 0.796876 * ln(D * h * F))}$
15	Reciprocal-X model	$MV = 1.16071 - 159.979/(D * h * F)$
16	Square root-Y reciprocal-X model	$MV = (1.1586 - 114.536/(D * h * F)^2$
17	S-curve model	$MV = \exp(0.600547 - 344.397/(D * h * F))$
18	Double reciprocal model	$MV = 1/(-1.12916 + 908.448/(D * h * F))$
19	Squared-Y reciprocal-X model	$MV = \sqrt{(1.04461 - 177.945/(D * h * F)}$
20	Squared-X model	$MV = 0.216144 + 0.00000345639 * D^2 * h^2 * F^2$
21	Square root-Y squared-X model	$MV = (0.500417 + 0.0000022901 * D^2 * h^2 * F^2)^2$
22	Logarithmic-Y squared-X	$MV = \exp(-1.32556 + 0.0000063451 * D^2 * h^2 * F^2)$
23	Reciprocal-Y squared-X	$MV = 1/(3.69785 - 0.0000141468 * D^2 * h^2 * F^2)$
24	Double-squared	$MV \sqrt{(-0.0615268 + 0.00000441127 * D^2 *}$

The accuracy of merchantable volume predictions for each equation was assessed numerically and graphically using residuals. This statistical build-up can strongly influence the selection of the correct equation. It is indicated from the table above that the dependent variable in the equations was in its original form, so it can be compared to the equations directly.

To compare Among equations and select the best equation for calculating the volume of wood, 24 different forms of regression equations were used. From 24 equations, the best 8 equations were selected to estimate the merchantable volume. Table 3 shows the equations that were chosen based on the criteria mentioned above.

Table (3): List of selected equations for merchantable volume based on their criteria

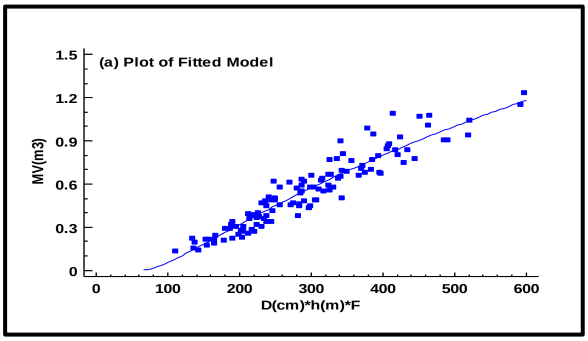
NO.	Equation	R^2-adj.	SEE	MAE	Bias
6	$MV = \left(-0.2408 + 0.0568432\sqrt{(D * h * F)}\right)^2$	90.0182	0.0544	0.044	0.003129
7	$MV = exp(-3.48659 + 0.163815\sqrt{(D * h * F)}$	87.6251	0.177	0.1425	0.001337
11	$MV = \left(-1.95829 + 0.476065 * ln(D * h * F)\right)^2$	90.1723	0.0540	0.0434	0.003069
12	$MV = exp(-8.54511 + 1.39129 * ln(D * h * F))$	90.2904	0.1568	0.1276	0.003399
13	$MV = 1/(21.821 - 3.46158 * ln(D * h * F))$	80.4747	0.5858	0.4416	-0.030829
17	$MV = exp(0.600547 - 344.397/(D * h * F))$	88.5557	0.1702	0.1319	0.011239
18	$MV = 1/(-1.12916 + 908.448/(D * h * F))$	88.8189	0.4433	0.3363	-0.034151
22	$MV = exp(-1.32556 + 0.000006345 * D^2 * h^2 * F^2)$	70.096	0.2752	0.2153	0.002916

All of the above equations were evaluated, and the best match equations to the merchantable volumes were chosen. Table 3 shows that the value of R^2-adj is greater than 0.87 in all equations except (13 and 22), which had values of (70,096 - 80.4747) and were thus eliminated from the competition. The higher the value of (R^2-adj.) the stronger the relationship between the two variables.

Another criterion for evaluating the models is SEE, if the value of SEE is equal to zero, then there is no variation corresponding to the computed line and the correlation will be perfect. It is indicated that the lowest value of SEE is located in equation 11 (0.0540), whereas the highest value was located in equation 18 (0.4433). As a result, equations (7, 17, and 18) were excluded from the competition because the values of their standard errors were greater than the remaining equations (0.177, 0.1702, and 0.4433) respectively.

The remaining competing equations include (6, 11, and 12) where the criteria values were very close to each other in terms of MAE, and Bias, with preference given to equation 11 where the MAE values were (0.044, 0.0434, and 0.1276) respectively, while the bias values were (0.003129, 0.003069, and 0.003399) correspondingly. As a result, model (11) was the most successful equation among the 24 developed equations examined in this study.

The plot of the fitted values predicted by the model versus the observed values, and residuals versus predicted values from equation 11 revealed that model 11 is adequate for stand volume. Figure (1) shows the plot of fitting for model (11). It describes the relationship between a response variable defined by D (cm)*h (m)*F and predictor variables represented by MV (m^3). There is a statistically significant association between the dependent and independent variables at a 95% confidence level and P-value of less than 0.05. After changing to an inverse normal scale to linearize the model, the R^2-adj. the statistic reveals that the model as fitted explains 90.1723 percent of the variability in MV (m^3). The correlation value is 0.950, showing that the variables have a very strong association. The value of SEE indicates that the residuals' standard deviation is 0.0540. Figure (1. b) shows the distribution of the observed merchantable volume values against the estimated merchantable volume values. The observed and estimated merchantable volume were randomly clustered around the regression line. A simple linear model was fitted to the data. If there are considerable estimating errors, the model intercept will not be zero ($a \neq 0$), and the slope will not be one ($b \neq 1$). To investigate potential prediction errors in the model, estimated values were regressed against observed values. The model intercept and slope were given confidence ranges. The best equation 11 did not exhibit any bias in the diameter estimate. Using Model 11, the confidence intervals varied from (0.0781 to 1.1777) and the model intercept and slope from (0.1376 to 1.2335), respectively. The intercept was not substantially different from zero, and the slope was not significantly different from one, according to these findings.



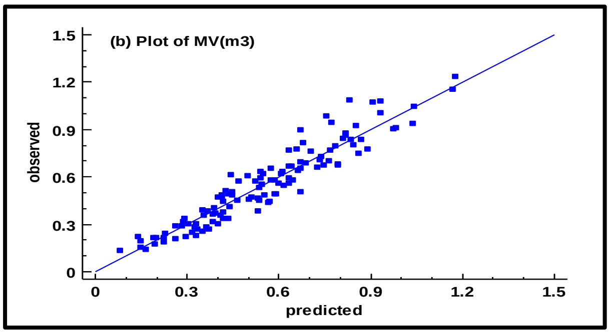


Figure (1): (a) Distribution of the measured merchantable volume values, (b) The relationship between the field observations and the estimated merchantable volumes of the pinus brutia pine trees

Figure (2) shows that the plot for equation 11 is more uniform on either side of the X - axis. A residual plot is a scatterplot that shows the residuals on the vertical axis and the independent variable on the horizontal axis. Residual plots assist us in determining whether equation 11 is appropriate for modeling the given data. Furthermore, the scatter diagram shows that the residuals have not had any pattern and the data points are randomly distributed around the zero-line.

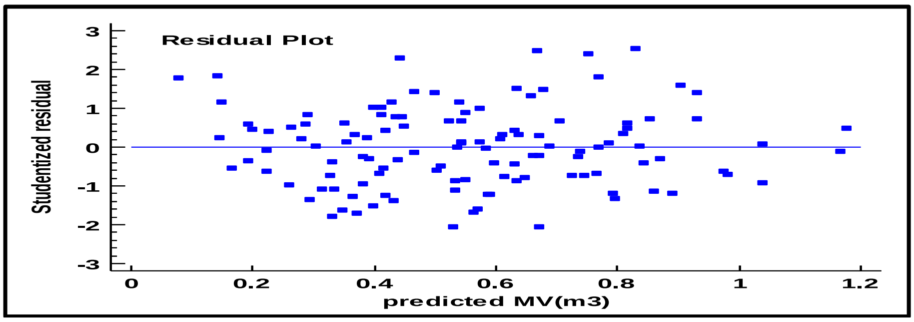


Figure (2): Residual plot scatters of the residuals on the vertical axis and the independent variable on the horizontal axis

A form factor is a description of the overall shape of the stem. It is one of the three main factors that define a tree. When mature, a tree species is a perennial species with secondary thickening (i.e., true wood) that typically attain tree shape and size. A tree's stem volume can be calculated by multiplying its height and basal area by the form factor for a given age, species, and location. The form class volume table for equation 11 is demonstrated in Table 4. According to this study, the mean stem shape of Pinus brutia trees is (0.64) which means quadratic paraboloid. Table 4 shows the value of merchantable volume for each tree. Once the variables of an individual tree are known, such as diameter, height limit at 10.3 m, and stem shape, the merchantable volume of each pine tree can be determined. Where the values of these variables are entered into the selected merchantable volume equation represented by equation 11 (Square Root-Y Logarithmic-X model). As a result, the merchantable volume of each tree can be obtained.

Table (4): Merchantable form class volume table for natural pine trees in cubic meters at absolute form quotients (0.64)

Diameter Classes (cm)	Mid-Point	Merchantable Height Classes (m)							
		10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5
19.5 - 21.4	20.5	0.149440	0.184799	0.220503	0.256255	0.291854	0.327167	0.362101	0.396598
21.5 - 23.4	22.5	0.185667	0.224866	0.264088	0.303087	0.341702	0.379828	0.417401	0.454381
23.5 - 25.4	24.5	0.222248	0.264958	0.307399	0.349369	0.390742	0.431442	0.471428	0.510679

25.5 – 27.4	26.5	0.258867	0.304812	0.350219	0.394926	0.438841	0.481914	0.524124	0.565468
27.5 - 29.4	28.5	0.295314	0.344260	0.392416	0.439662	0.485933	0.531205	0.575477	0.618762
29.5 - 31.4	30.5	0.331449	0.383191	0.433911	0.483523	0.531991	0.579313	0.625507	0.670601
31.5 – 33.4	32.5	0.367178	0.421540	0.474660	0.526487	0.577013	0.626255	0.674249	0.721036
33.5 – 35.4	34.5	0.402441	0.459265	0.514643	0.568553	0.621013	0.672061	0.721747	0.770127
35.5 – 37.4	36.5	0.437199	0.496347	0.553854	0.609730	0.664015	0.716767	0.768050	0.817933
37.5 – 39.4	38.5	0.471428	0.532776	0.592299	0.650037	0.706050	0.760414	0.813208	0.864514
39.5 – 41.4	40.5	0.505117	0.568553	0.629991	0.689495	0.747148	0.803043	0.857273	0.909930
41.5 – 43.4	42.5	0.538262	0.603685	0.666945	0.728130	0.787345	0.844697	0.900293	0.954235
43.5 – 45.4	44.5	0.570864	0.638183	0.703181	0.765970	0.826675	0.885417	0.942316	0.997485
45.5 – 47.4	46.5	0.602928	0.672061	0.738720	0.803043	0.865171	0.925242	0.983387	1.039729
47.5 – 49.4	48.5	0.634464	0.705333	0.773584	0.839376	0.902868	0.964212	1.023551	1.081015
49.5 – 51.4	50.5	0.665481	0.738016	0.807794	0.874996	0.939797	1.002363	1.062846	1.121388
51.5 – 53.4	52.5	0.695990	0.770127	0.841373	0.909930	0.975989	1.039729	1.101313	1.160891

$MV = (-1.95829 + 0.476065*\ln(D*h*F))^2$

R^2-adj. = 90.1723 SEE = 0.0540

MAE = 0.0434

Bias = 0.003069 No. of trees = 12

CONCLUSION

The Square Root-Y Logarithmic-X model is the best equation for predicting merchantable volume for natural Pinus brutia based on statistical assessments and graphical analysis. However, as long as the alternatives are supplied and a significant number of sample trees are measured, developing distinct volume equations for each location and tree species will be more effective in explaining variability in tree shape and making more accurate volume estimations.

The created merchantable volume table may be used to measure the economic potential of trees in the research region to achieve the management's economic aim. Furthermore, this volume table plays an important role in long-term management since the volume table generated anticipates growth and productivity.

As a final point, based on ranking, the following model is recommended to be preferred over other equations:

$MV = (-1.95829 + 0.476065*\ln (D\ h\ F))^2$

it is possible to apply this equation to determine the above-ground biomass and carbon content for Pinus brutia Ten.

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