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STAND VOLUME EQUATION FOR *Pinus brutia* Ten. NATURAL GROWING IN ZAWITA AREA, KURDISTAN REGION OF IRAQ

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ABSTRACT

Calabrian pine (*Pinus brutia* Ten.) is grown naturally in Zawita area, Kurdistan Region of Iraq. It is preferable to have stand volume equation specifically for natural stand of this species due to its importance in decision making regarding many forest management problems. In this work, a reliable stand volume equation was developed for this species to fill this gap. The developed equation was found to be in accord with the least square assumptions. As was the case with many stand volume models that have been developed for different species, stand basal area and stand height were the best in explaining the variation in stand volume. A stand volume table was presented to instantly estimate stand volume from combinations of stand basal area and stand height.

KEYWORDS: Calabrian Pine, Kurdistan Region of Iraq, Stand volume, Zawita Area

INTRODUCTION

Stand volume is essential information every forest manager needs for decision-making. It is needed for timber appraisal, quantity and value of carbon stored in stand biomass, impact of silvicultural treatment on stand volume and stand management plan (Brack and Wood, 1998). Therefore, forest managers need a mean to rapidly and efficiently estimate stand volume with minimum time and cost (Cole, 1971). Simplicity characterize developing static stand volume equations and implementing them because the explanatory variables used in these equations such as basal area, stand height, mean diameter and number of trees are easily obtained (Tang et al., 2019). This is contrary to forest inventory which involves tedious measurements. Stand volume equations are also been found unbiased (Ung and Ouellet, 1991) which means it gives reliable estimates to stand volume. Model complexity, indeed, does not necessarily increase the accuracy of the prediction (Hevia, 2013). Gadow (1996) and Garcia (2003) believe that stand models are preferable because they compromise between generality and accuracy of estimate. In addition, stand volume equations can be used for estimating both total and merchantable volume to minimum stamp height and upper stem diameter (Shepperd and Mowere, 1984).

As a result of its simplicity and accuracy, many stand volume equations have been developed to cover different forest types. After extensive work, Spurr (1952) found that the product of stand height and stand basal area was the best in explaining the variation in stand volume. Since then, many authors have used it in developing stand volume equation among them are Brinkman (1967), Shepperd and Mowere (1984), and Tang et al. (2017). hetroscedasticity in the residuals about the regression line is associated with stand volume equations when stand volume in the original form is used in developing the model, therefore, many authors resorted to weighted and logarithmic equations. Passesol (1999) used weighted equations by 1/(BH)2 to compensate for nonhomogeneity of the error term, where B is stand basal area and H is a measure of stand height.

Stand volume equations have been given this name because of the similarity of the functional form to tree volume equation when product of stand's basal area and height are used as independent variables (Clutter et al, 1983). When such a stand volume equation has no y-intercept, then the stand is assumed to have a constant form factor (The slop of the regression equation). This type of equations greatly simplifies the stand volume estimation, however, many stand and site factors affect stand form factor, therefore, they are never fixed constant

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(Kong et al. 2012). Its value is also affected by whether stand height was represented by average dominant trees or mean of all the trees, whether total volume or merchantable volume was intended to be measured, and whether branch volume is included or excluded from volume measurement.

Calabrian pine (Pinus brutia Ten.) is grown naturally in Zawita area, Kurdistan Region of Iraq. It is naturally distributed over a vast area of Zaita-Atroosh district. It has also been one of the main species used in reforestation. To develop stand volume equation for calabrian pine, Ghaueeh (2009) employed 30 plots taken from three locations, Akre, Atroosh, and Zawita. The plots were taken from both natural and planted stands. He obtained the following equations that predict the volume of main stem, branches and total volumes respectively;

$$V = 0.21 + 0.00004\ dq^{2.89}\ N^{1.077}$$

$$V = 0.4 + 0.000051\ dq^{1.959}\ N^{1.17}$$

$$V = 0.74 + 0.00002\ dq^{2.552}\ N^{1.125}$$

Where V is stand volume, dq is quadratic mean diameter and N is number of trees per plot area. This work aims at developing a stand volume equation specifically for natural grown calabrian pine (*Pinus brutia* Ten.) in Zawita area, Kurdistan Region of Iraq as natural stands of this species differ in many aspects than those of planted stands. Stand’s height, basal area, mean diameter and number of trees per unit area will be examined as explanatory variables for this purpose.

MATERIALS AND METHODS

This work was carried out in Zawita which is a mountainous area located 17 km Northwest of Duhok city in the northern part of Kurdistan Region of Iraq (Figure 1). It has an average elevation of 885 m above sea level (Mosa, 2016). It has a Mediterranean climate, with hot and dry summer, cold and rainy in winter. The temperature of this area reaches as high as 43 ^{o}C in summer while the low temperature goes below freezing point in winter. The amount of precipitation, on average, is about 820 mm (Directorate of Meteorological station). There is a wide range of densities in calabrian pine forests. Dense stands can be found in some locations while in other locations open stands are found. There are areas that are used for agriculture and urbanization.

Calabrian pine is a native tree species, naturally grown in Zawita-Atrush area which has a total area of about 41 591 hectares of which 30129 hectares covered by this species (Mosa, 2016). It is a tree that reaches 20 m high with an open crown and irregular branches (Shahbas, 2007). Its distribution in Kurdistan Region of Iraq is confined to Zawita-Atrush area. It has a moderate growth and the width of the annual rings is approximately 0.59 cm (Shahbaz et al., 2002).

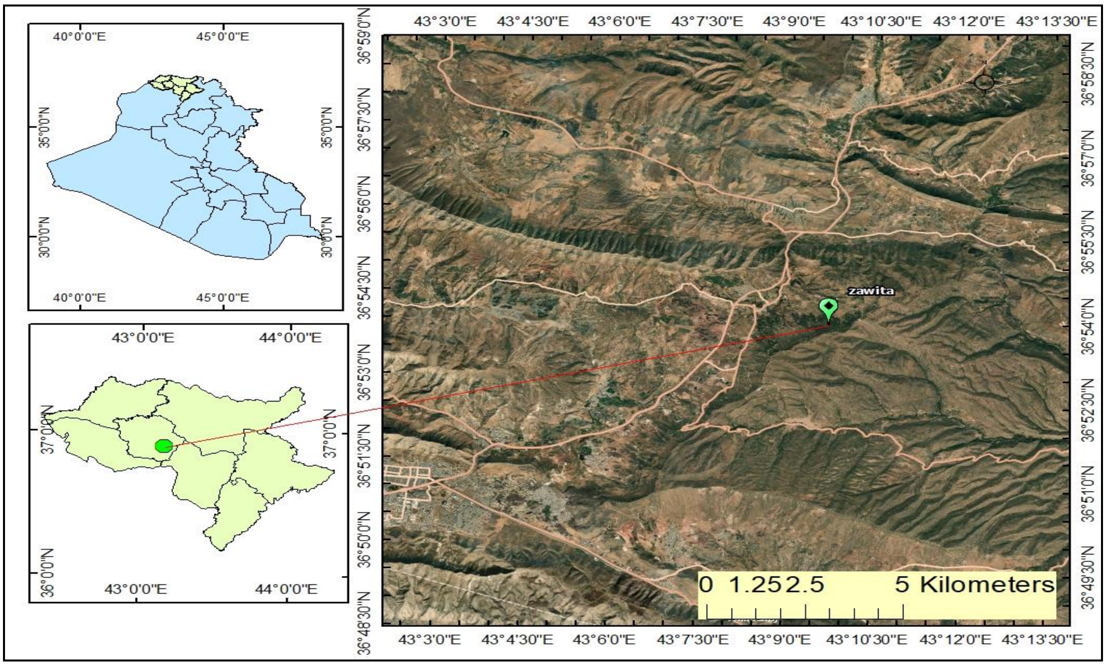

Fig. (1): The location of the study area.

A total of 60 circular plots of 0.05 ha were taken in Zawita area. Circular plots are preferable because marking is confined to the center of the plot and it is often used for native forests because it minimizes the bias (State Forests of New South Wales, 1996). The plots were chosen such that to cover as much variation in stand attributes of mean diameter, height, basal area and number of trees per plot. This wide variation in these attributes is required to obtain an equation that can precisely predict stand volume (Evert, 1983). For each plot, number of trees was recorded then diameter at breast height and height of each tree were measured. The volume of each tree was calculated using the following standard volume equation which was developed by Kelkhan (1982) for calabrian pine naturally grown in Zawita;

$$v = 0.007\,542 + 0.000\,036\,749 * d^2 * h - 0.000\,003\,63 * d * h^2$$

Where v is tree volume, d is the diameter at breast height, and h is tree total height. Then, for each plot, mean diameter, basal area (B), mean height of all trees (H) and volume of trees (TV) were calculated. At last, volume, basal area, and number of trees were expanded to per hectare bases. Table 1 presents statistics of the measured and calculated attributes of the stands.

Table (1): Statistics of the stand attributes of the sampling plots (per hectare).

Variable	Mean	Minimum	Maximum	SD	CV
Total Volume (m3/ha)	88.0	9.2	283.5	67.0	76.2
Mean Diameter (m)	28.8	8.5	65.5	14.0	48.6
Basal Area (m2/ha)	12.2	2.0	34.0	8.2	67.1
Mean Height (m)	12.6	5.5	18.2	3.1	24.5
Number of trees	158.3	80.0	300.0	47.6	30.1

At the outset, correlation analysis is used to manifest the strength and direction of the relationship between stand volume in one hand and each of stand's basal area, height, mean diameter, and number of trees in the other hand. Correlation between each pair of independent variables was also explored. Then graphs were drawn for each pair of these variables to reveal the type of relationship between each pair of these variables. In addition, stepwise procedure was used to regress stand volume in its original form, logarithmic, and weighted on stand's basal area, mean height, mean diameter, number of trees, and all their interactions, in their original forms and transformed to logarithmic.

Depending on the results obtained in the previous analyses, three groups of equations were developed. In the first group, stand volume was in the original form, in the second group it was in logarithmic form and in the last group it was weighted. The best equation in each group was selected on the bases of adjusted coefficient of determination (Adj. R^2) as it account for number of independent variables in contrary to coefficient of determination. Since coefficient of determination cannot be used to compare the performance among equations that have dependent variable in different forms, Furnival Index was used to select the best model among the three different groups. The smaller the value of furnival index the better the equation is. The best equation was then tested to ensure it does not violate the assumptions of least square procedure. Homoscedasticity was tested via White test (Studenmund, 2006) and graph of residuals distribution around regression line, normality of error term was tested via developing the histogram of the residuals (Neter et al, 1996), while the serial autocorrelation of the error was tested using Durbin-Watson statistic. In addition, stand volume equation with fixed form factor associated with product of stand basal area and height will be developed (Husch et al., 2003) and test for the variation of plots form factor was made.

Statistical Analysis

To select the best model that predicts stand volume efficiently, the developed models were distributed over three groups. In the first group stand volume was in the original form, in the second group logarithmic transformation were conducted on stand volume, in the last group all the variables were weighted in order to eliminate the problem of heteroscedasticity inherited in the residuals of the stand volume data. Adjusted coefficient of determination (Adj R) is a statistics that measures the amount of variation in the dependent variable that was explained by the equation adjusted to account for the number of independent variables used in the model. This criterion was used to detect the best modes of each group. Since this criteria cannot be used to evaluate equations with dependent variable in different form, furnival index which is an index

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that account for the form of the dependent variable and for the degree that the residuals depart from normality, homoscedasticity and autocorrelation, in comparing among equations of different form. Root mean square of error (RMSE) was also given.

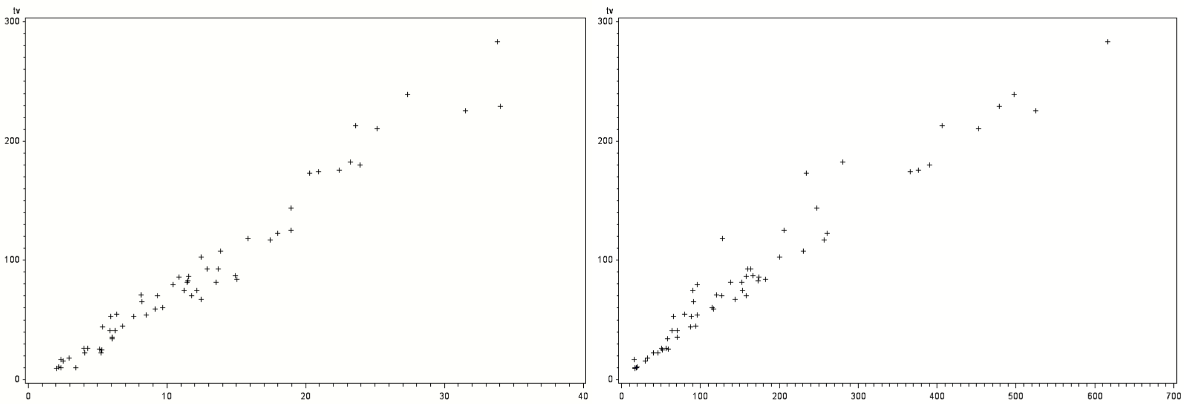
RESULTS AND DISCUSSION

The data of the calibrian stands' attributes used in this work had good variation. Table 1 reveals that stand volume had the widest variation with range between 9.2 – 283.5 m3/ha. Therefore, the developed model can be used for open stands, moderately stocked and moderately dense stands which are the dominant type of stocking of Zawita forest. With regard to independent variables, the variation in basal area was the greatest (CV = 67%) followed by mean diameter (CV = 48.6%) while stand height had the lowest variation (CV = 24.5%).

The correlation analysis (Table 2) revealed that total volume had significant linear correlation with all the stand attributes evaluated in this work. The highest correlation was with stand basal area (correlation coefficient, r, was 0.98) followed by mean diameter (r = 0.91). This indicates that stand basal area can explain more variation in stand volume than stand mean diameter if linear equation is used. Stand height came in third place (r = 0.665) while the lowest correlation was with number of trees per hectare (r = - 0.34). The latter correlation indicates that there is a negative relationship between stand volume and number of trees per hectare which sound to be peculiar. Number of trees had negative relationship with basal area and mean diameter too. But the strongest relationship was with mean diameter. This indicates that plots of greater number of trees are more associated with plots of smaller mean diameter. The scatter plots obtained for stand volume with each explanatory variable and all their interaction shown that the strongest relationship was obtained with stand basal area and with the product of stand's basal area and stand height (Figures 2)

Table (2): Correlation analysis for the response and explanatory variables.

	Total Volume	Basal Area	Mean Diameter	Mean Height	Number of Trees
Total Volume	1	0.98	0.91	0.67	- 0.34
P-value		<.0001	<.0001	<.0001	0.0087
Basal Area	0.98	1	0.90	0.61	- 0.27
P-value	<.0001		<.0001	<.0001	0.0347
Mean Diameter	0.91	0.90	1	0.74	- 0.57
P-value	<.0001	<.0001		<.0001	<.0001
Mean Height	0.67	0.61	0.74	1	-0.4
P-value	<.0001	<.0001	<.0001		0.0015
Number of Trees	-0.34	-0.27	-0.57	-0.4	1
P-value	0.0087	0.0347	<.0001	0.0015	



Basal Area (a)

Basal Area*Height (b)

Fig. (2): Scatterplots of stand volume and each of stand basal area (a) and product of stand´s basal area and height (b).

The functional forms that were selected to predict stand volume were based on the stepwise procedure, correlation analysis, and scatter plots of the different combinations of stand attributes. Table 3 shows the selected equations in each group along with the values of the adjusted coefficient of determination, root mean square of error (RMSE) and furnival Index (FI). With respect to the stand volume in its original form, the product of basal area and height explained 97.8% of variation in stand volume (adjusted R^2 = 0.978) but the model considerably improve when basal area added to the model (adjusted R^2 = 0.99). The polynomial model with basal area, height and number of trees has also a good adjusted coefficient of determination (R^2 = 0.989). Negative relationship between number of trees and stand volume within limited range of number of trees was obtained. This peculiar result can be attributed to the fact that as trees increase in diameter its volume increases at increasing rate and since plots of greater number of trees are more associated with plots of smaller mean diameter this negative relationship was obtained. Identical result was obtained by Younis (2019) who developed stand volume equations for oak stands. Equation 3 was selected as the best one in this group. With respect to logarithmic equations, the double log function with the product of stand's basal area square and height as explanatory variable (Equation 5) had the best performance (Adj R^2 = 0.9699) beside the equation with logarithm of stands basal area and logarithm of stand height (Adj R^2 = 0.9695). With regard to the weighted equations, weighting by $(BH)^2$ had the best performance compared to B, BH, and B^2H. Table 3 shows the best two equations in this group, equation 7, however, was slightly better than equation 6.

Table (3): list of stand volume equations

	Parameters of the Selected Equations	Adj. R²	RMSE	FI
Dependent Variable in Original form				
1	TV = 0.497 BH P-val. (<.0001)	0.978	16.5	16.5
2	TV = 7.54 B + 1.17 H – 0.11 T P-val. <(0.0001) (.0048) (<.0001)	0.989	11.6	11.6
3	TV = 4.36 B + 0.21 B H P-val. <(0.0001) (<.0001)	0.99	10.96	10.9
Dependent Variable in Logarithmic form				
4	Ln TV = 0.569 + 1.068 Ln B + 0.469 Ln H P-val. (<.0069 (<.0001) (<.0001)	0.9695	0.15351	9.798
5	Ln TV = 0.457 + 0.527 Ln B²H P-val. (<.0001) (<.0001)	0.9699	0.1527	9.715
Weighted Equations				
6	$TV/(B^2H) = 0.0779+0.00021\ T^2/(B^2H) + 0.0242BH^2/(B^2H) - 0.00454\ (BH)^2/(B^2H)$ P-val. (<.0001) (<.0001) (<.0001) (<.0001)	0.964	0.01436	16.002
7	$TV/(BH)^2 = 0.0016 – 0.0312\ T/(BH)^2 + 0.0116\ BT/(BH)^2 + 0.011\ BH^2/(BH)^2$ P-val. (.0017) (<.0001) (<.0001) (0.0031)	0.9703	0.00179	24.261

TV = Total volume, B = stand basal area, H= Stand height, T = number of trees per hectare.

Based on Adj. R^2 equations with dependent variable in the original form had the best performance. However, this criterion cannot be used to compare equations when the dependent variables are in deferent forms. In the contrary, furnival index can be used for this purpose. It encompasses the contribution of the equation in explaining the variation in the dependent variable, and degree of departure of the residuals from normality and from the homogeneity in evaluation of each equation. According to this criterion, equation with dependent variable in the logarithmic form had the best performance. Equation 5 had the lowest value for the furnival index (9.715), therefore it was selected to estimate stand volume of natural calibrian pine. When the error term of this equation was evaluated to confirm its compliance with least square assumptions, three outliers were found in the data set. Therefore, theses outliers were

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removed from the data set in order to remove the distortion caused by these outliers (Neter et al., 1996). When regression performed on the new data set, the following model was obtained

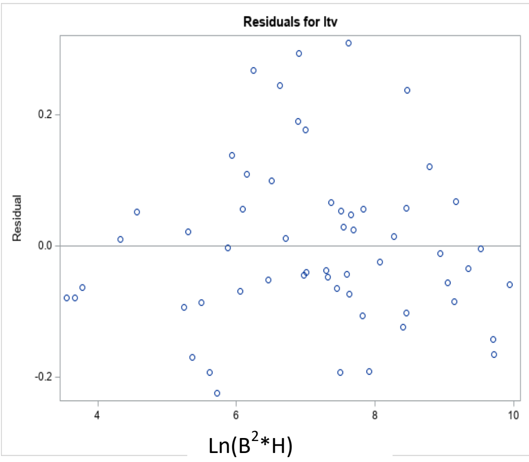
$$Ln (TV) = 0.40241 + 0.53334 \; Ln (B^2H)$$

Removing these outliers significantly improved the model, the adjusted R^2, RMSE, and furnival index associated with new model were 0.978, 0.12561, and 7.991 respectively. The assumption of serial autocorrelation of the residuals was detected via Durbin Watson statistic and the value of this criterion turned out to be 2.007 and the first order of correlation for this model was -0.009. this indicate that this model is free from autocorrelation. With respect to the homoscedasticity of the residual, figure 2 shows the distribution of the error term over the independent variable which indicates that there is no sign of hetroscedasticity in the residuals. This was confirmed by white test which gave identical result. Finally the graph of distribution of the residuals (figure 3) does not advocate sever deviation from normality. Yield table was constructed from the chosen model (table 4) which provides a simple mean to estimate stand volume for given combinations of stand's basal area and height.

With respect to the stand form factor equation (Husch, 2003), the following equation was obtained when stand volume was regressed on the product of stand basal area and height (Table 4);

$$TV = 0.49722 \; BH$$

The stand form factor obtained in this equation (0.497) is in consistent with other values found in the literature.



Fig, (3): The distribution of the residuals.

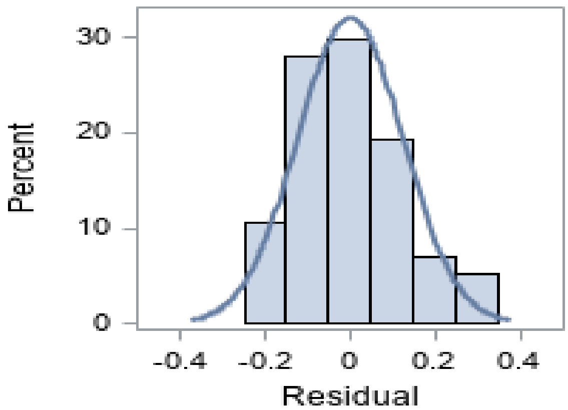


Fig. (4): The histogram of the relative distribution of the residuals.

Table (4): Stand volume of calibrian pine obtained from Ln (TV) = 0.40241 + 0.53334 Ln (B^2H) model.

Stand Basal Area (m^2/ha)	Stand Height (m)													
	6	7	8	9	10	11	12	13	14	15	16	17	18	19
2	8	9	9	10	11	11	12	12						
5	22	23	25	27	28	30	31	33	34	35	37	38		
8	36	39	42	44	47	49	52	54	56	58	60	62	64	
11	50	54	59	62	66	69	73	76	79	82	85	87	90	
14		70	76	81	85	90	94	98	102	106	110	113	117	
17			93	99	105	110	116	121	125	130	135	139	143	
20					125	131	137	143	149	155	160	165	171	
23						152	160	166	173	180	186	192	198	
26							182	190	197	205	212	219	226	232
29											238	246	254	261
32										256	265	273	282	290
35										281	291	301	310	319
38											318	328		

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هەلسەنگاندنا پێکهاتا داری یا دارا بەرییا خوارنێ ل پارێزگەها دهوکێ، هەرێما کوردستانێ- عیراق

پوخته

دارا کاژێ ب شێوەیەکێ سروشتی شین دبیت لدەڤەرا زاویتە ل هەرێما کوردستانا عیراقێ. د سەر هندێ را کو گرنگیەکا زور یا هەی دبریاردانا دا ل رێڤەبرنا دارستانا دا بەلێ با حەتا نوکە چ هەڵسەنگاندن بو بەرهەم ئینانا ڤی جوری نەهاتینە دانان. دڤێ خاندنێ دا هەلسەنگاندن بو پێشبینیا قەبارا داری ل یا دارێن زاویتە هاتیە کرن کو ئەڤ یاسایە یا یەکسان بو دگەل پێشبینیێن . Least square method وەکی گەلەك هەڵسەنگاندنا د قەبارێ داران دا کو هاتینە دانان بو گەلەگ جورێن دارا و روبەرێ داران وبلنداهیا داران کو هەردوو باشترین گورانکاری نە د شلوڤەکرنا بهایێ قەبارێ داران دا . و دانانا خشتکی بەرهەمی دناڤبەرا قەبارێن دارێن جیاواز بو پێشبینیا روبەرێ و بلنداهیا داران.

معادلة حجوم مشاجر الصنوبر في منطقة زاويته، إقليم كردستان العراق

الخلاصة

تعيش أشجار الصنوبر بشكل طبيعي في منطقة زاويته / أقليم كردستان العراق. و مشاجر هذ النوع و خاصة الطبيعية منها بحاجة الى وضع معادلة الانتاج و ذلك لأهميتها في أتخاذ القرارات الازمة في أدارة الغابات. في هذه الدراسة تم أعداد معادلة لتقدير حجم الخشب في مشاجر الصنوبز و قد كانت هذه المعادلة متماشية مع أفتراضات Least square method . و كما هو الحال مع معظم معادلات حجوم الاشجار التي وضعت لمختلف أنواع الاشجار فقد كانت المساحة القاعدية و أرتفاع المشجر هما المتغيران الافضل في تفسير التباين في قييم حجوم المشاجرز و قد تم وضع جدول يبين حجم الخشب في المشاجر لمختلف توليفات المساحة القاعدية و أرتفاع المشجر.