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DEVELOPING DOUBLE-ENTRY TREE VOLUME TABLE FOR ASH IN TURKEY

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Abstract: The objective of this study is to construct double-entry tree volume table for ash (*Fraxinus angustifolia* subsp. *oxycarpa*) in Turkey. Total 391 sample trees were selected from ash stands in Turkey for this objective. By using Smalian's formula, the volume of each section in a sample tree stem was calculated. Regression Analysis was used and total twenty-six equations were examined according to six performance criteria (Average Residuals or Bias, Average Absolute Residual, Standard Deviation of the Residual or Precision, Percent Variation Explained, Percent Total Error and Percent Absolute Mean Error). Coefficient of determination, standard error, total error and absolute mean error of the best fitted volume equation were found 0.987, 0.312 m^3, -0.02 % and 10.13 % respectively. The equation was also tested with another independent data set and concluded that the equation could be used for other ash stands in Turkey with 0.05 significant level.
Key words: Ash, Smalian's formula, stem volume, volume table.

DİŞBUDAK (*Fraxinus angustifolia* subsp. *oxycarpa*) ÇİFT-GİRİŞLİ AĞAÇ HACİM TABLOSUNUN DÜZENLENMESİ

Özet: Bu çalışmada dişbudak türü için çift girişli ağaç hacim tablosunun düzenlenmesi amaçlanmıştır. Bu amaçla doğal yayılış alanı içerisinde bulunan meşcere ve küçük ağaç topluluklarından toplam 391 adet örnek ağaç üzerinde ölçümler yapılmıştır. Alınan örnek ağaçların hacimleri Smalian formülünü kullanan "Bölümleme (Seksiyon) Yöntemi"ne göre hesaplanmıştır. Bu veriler üzerinde Regresyon analizi yöntemi ile 26 adet denklem denenmiş ve Ortalama Hata, Ortalama Mutlak Hata, Hataların Standart Sapması, Açıklanan Varyans Yüzdesi, Toplam Hata Yüzdesi ve Ortalama Mutlak Hata Yüzdesinden oluşan altı ölçüte göre değerlendirilmiştir**.** Bu ölçütlere göre seçilen en uygun denklemin belirtme katsayısı 0.987, standart hatası 0.312 m^3, toplam hatası % -0.02 ve ortalama mutlak hatası % 10.13 olarak belirlenmiştir. Elde edilen hacim denklemi bağımsız bir veri grubu ile test edilmiş ve 0.05 güven düzeyinde Türkiye'deki dişbudak meşcereleri için de kullanılabileceği sonucuna varılmıştır.
Anahtar Kelimeler : Dişbudak, Smalian Formülü, gövde hacmi, hacim tablosu

1. INTRODUCTION

Turkey forests have been managed according to Forest Management Plans. It is necessary that stand volume is known to prepare forest management plans. There are various methods in calculating stand volume (1, 2). Tree volume tables are generally used to calculate stand volume in Turkey. Standing volume of a tree can be calculated according to only dbh (diameter at breast height) (single-entry tree volume tables) or according to dbh and tree height (double-entry tree volume tables) or diameters at certain heights (e.g. diameter at 6 m or 7 m) in addition to dbh and tree height (multiple-entry tree volume tables).

Single-entry tree volume tables show stem volume depending on only dbh. Apparently, error amount of these tables is greater than that of double and multi-entry volume tables. In double-entry volume tables, tree height takes into consideration in addition to dbh, thus error amounts decrease gradually. Form factors of trees with the same dbh and the same height that cause their volumes are also different. This situation is the disadvantage of double-entry volume tables because it is assumed that the volumes of two trees whose diameter at breast height and height are equal even if form factors of these trees are different.

However measurement of form factor is not practical. In this reason multi-entry tree volume tables are generally used in scientific researches.

The error amounts of single-entry tree volume tables are high. Accordingly, these are not used except for practical calculations. In contrast, double-entry tree volume tables are widely used. A lot of double-entry stem volume tables have been constructed for hardwoods and softwoods in different regions of Turkey except for ash.

The objective of this study is to construct double-entry stem volume table for ash, one of the most important commercial forest species in Turkey.

2. MATERIALS

Total 391 sample trees obtained from both ash stands and free growing ash trees in different age, diameter and height classes, were selected to construct double-entry stem volume table for ash. Sample trees were taken with an effort to equal allocation to each diameter and height classes. Meanwhile, sample trees should be alive, healty-headed and non-pruned. They were taken from four forest Conservancies, Regional Forest Headquarters in Turkey (Amasya, Giresun, Trabzon, and Artvin) and private forests in natural range of ash. 391 sample trees ranging in diameters from 6 to 112 cm and heights from 6 to 40 meters were selected from fourteen different regions, three altitude classes, five slope classes. Distribution of sample trees according to Forest Conservancy, Regional Forest Headquarters was given in Table 1.

Table 1. Distribution of sample trees according to forest conservancy

Regional Forest Headquarters	Directorate of Forest Enterprise	Number of Sample Trees
Amasya	Sinop	251
	Samsun	95
Giresun	Şebinkarahisar	10
Trabzon	Trabzon	10
	Sürmene	5
Artvin	Borçka	5
	Murgul	15
	Total	391

The validation of a model should involve independent data. The present study data were partitioned in two groups, one for model development and one for validation. Many solutions for partitioning of such data are at hand, both with respect to method and with respect to number of observations in the respective data sets (3). In order to secure the range of diameter and height classes in both data sets, simple random sampling was used in the present study. The data set used for model development comprised approximately 77.5 % of the observations (303), while the remaining 22.5 % of the observations (88) were used for validation. Although the number of observations determined for model development was made relatively large in order to provide sufficient data for the model development phase, the number of observations in the test data still should be large enough for validation and appropriate statistical test. Distributions of data set for model development and test data set for validation by diameter and height classes were given in Table 2 and Table 3, respectively.

Tablo 2. Distribution of sample trees by diameter and height classes for model development

Dbh classes (cm)	Height classes (meter)																		Total
	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	
6	1	1	2																4
10		2	3	1		2													8
14			3	2	1	2	1												9
18				1	3	2		2	2										10
22					5	2		3	3	3	2	1		1					20
26					1	2	3	5	6	4	3	3	1						28
30							6	2	1	1	3	4		1	1		1		20
34						1	2		3	1	6	3	2	3	2	2			25
38							2	2	1	2	2	4	5	1	5				24
42									2	4	1	2	1	7	6				23
46								1	1	2	1	3	5	4	5	6	2		30
50												2		4	8	11	2		27
54										1			1	2	7	5	2		18
58													1	3	10				14
62														2	6	4	2	1	15
66										1				2	3	4			10
70																	5		5
74																2			2
78																1			1
82															1				1
86													1				1		2
90															2	1			3
94																			-
98																			-
102																			-
106																2	1		3
110															1				1
Total	1	3	8	4	10	11	14	15	19	19	18	22	17	30	57	38	16	1	303

Diameters of sample trees were measured at ground level, stump level, breast height and in each meter towards top of tree.

Breast height was marked on the trees which were then felled, leaving a stump of 30 cm high. Thereafter, the stem was cut into one meter long sections until the section containing a 0.5 cm diameter o.b. was reached. The length of the remaining portion of the stem above the ground level of the tree was calculated by summing up the length of all sections. The volume of the topmost section was calculated on the assumption that it was conical. The volume of the first butt section was calculated using Huber's formula. The volumes of the remaining sections were calculated using Smalian's formula. Total tree volume, in cubic meter o.b., including stump volume, was obtained by summing the volumes of the sections.

Table 3. Distribution of test data set by diameter and height classes for validation

dbh classes	Height classes (meter)																		Total
(cm)	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	
6	1																		1
10		1	1		1														3
14				4															4
18					3														3
22				1	2	1				1	1	1							7
26						2	1			1	1	1							6
30					1				1	2	2	1				1			8
34									1	3		3	1	1					9
38					1	1		1	3		1	1	1	1					10
42							1			1	1		1		1				5
46									1		1		1	1					4
50									1			2					2		5
54										3			1			1			5
58													2		1	1	1		5
62														1	2		1		4
66																			-
70														1					1
74																			-
78															1				1
82																			-
86																1	1		2
90														1					1
94																			-
98																			-
102																1			1
106																		2	2
110																1			1
Total	1	1	1	5	8	4	2	1	7	11	7	9	7	6	5	6	5	2	88

3. METHODS

The Regression Analysis method was used for construction of double-entry stem volume table for ash. The Regression Analysis method requires both dependent variable and independent (explicatory) variables. Dependent variable was stem volume calculated according to section method using Smalian's formula for each tree. Independent (explicatory) variables were diameter, total tree height, and some combinations of diameter and total height. With more detailed expression; diameter (D), total tree height (H), multiplication of diameter and total tree height (DH), square of diameter (D^2), square of tree height (H^2), multiplication of total tree height and square of diameter (D^2H), multiplication of diameter and square of total tree height (DH^2), inverse of diameter (1/D), inverse of total tree height (1/H), the logarithm of diameter (LogD), the logarithm of total tree height (LogH), square of logarithm of diameter (Log^2D), square of logarithm of total tree height (Log^2H), fourth power of logarithm of diameter (Log^4D), fourth power of logarithm of total tree height (Log^4H)

and the logarithm of multiplication of total tree height and square of diameter ($LogD^2H$) were independent variables.

The literature on volume equations is abundant. The estimation of parameters of these equations, which were quite complicated, and determining most suitable equations take a long time. 26 various equations those of 11 (1-11) are involved in literature and 15 (12-26) are new, were examined to construct double-entry stem volume tables for ash. Various model forms used in the past and firstly in the present study to estimate tree volume were given as followings:

$V = b_1 D^2 H$ (Constant Form, S.G. Spurr 1952) (1)

$V = b_0 + b_1 D^2 H$ (Combined Variable, S.H. Spurr 1952) (2)

$V = b_0 + b_1 D^2 + b_2 H + b_3 D^2 H$ (Generalized Com. Var. Stoate) (3)

$V = b_0 D^{b_1} H^{b_2}$ (Schumacher-Hall 1953) (4)

$V = D^2 / (b_0 + b_1 H^{-1})$ (Honer transformed Variable) (5)

$V = D^2 (b_0 + b_1 H)$ (Ogaya 1968) (6)

$V = b_1 D^2 + (b_2 H + b_3 DH + b_4 D^2) H$ (Naslund) (7)

$V = b_0 + b_1 D + b_2 D^2 + (b_3 DH + b_4 D^2) H$ (Meyer 1953) (8)

$V = (D^2 H) / (b_0 + b_1 D)$ (Takata) (9)

$LogV = b_0 + b_1 Log(D^2 H)$ (S.H. Spurr) (10)

$LogV = b_0 + b_1 LogD + b_2 (LogD)^2 + b_3 LogH + b_4 (LogH)^2$ (Prodan) (11)

$V = b_0 + b_1 D^2 + b_2 H^2 + b_3 DH^2 + b_4 D^2 H$ (12)

$V = b_1 D + b_2 D^2 + b_3 DH + b_4 D^2 H$ (13)

$V = b_1 D^2 + b_2 H^2 + b_3 DH^2 + b_4 D^2 H^2$ (14)

$LogV = b_0 + b_1 LogD + b_2 LogH + b_3 (1/D)$ (15)

$LogV = b_0 + b_1 LogD + b_2 LogH + b_3 (LogD)^4$ (16)

$LogV = b_0 + b_1 LogD + b_2 (LogD)^4 + b_3 LogH + b_4 (LogH)^4$ (17)

$LogV = b_0 + b_1 LogD + b_2 D^2 + b_3 LogH$ (18)

$V = b_1 DH + b_2 D^2 H$ (19)

$LogV = b_0 + b_1 LogD + b_2 LogH + b_3 (LogH)^2$ (20)

$LogV = b_0 + b_1 LogD + b_2 LogH + b_3 (LogH)^4$ (21)

$LogV = b_0 + b_1 LogD + b_2 LogH + b_3 (1/H)$ (22)

$LogV = b_0 + b_1 LogD + b_2 LogH + b_3 D^2$ (23)

$LogV = b_0 + b_1 LogD + b_2 LogH + b_3 D^2 H$ (24)

$LogV = b_0 + b_1 LogD + b_2 LogH + b_3 H^2$ (25)

$LogV = b_0 + b_1 LogD + b_2 LogH + b_3 DH^2$ (26)

Six performance criteria based on differences between observed volume and estimated volume from equations were used in choosing the best fitted volume equation. First four criteria were general criteria used for all regression equations in choosing best model. The remaining two criteria were used as a criterion for volume equations (2). The criteria were presented as followings.

1-Average Residual or Bias: $\overline{\mathrm{D}} = (\sum D_i) / N$ (27)

2-Average Absolute Residual: $\left|\overline{D}\right| = (\sum \left|D_i\right|) / N$ (28)

3-Standard Deviation of the Residual:

$$S_D = \{[(\sum D_i^{\,2}) - (\sum D_i)^2 / N] / N - 1\}^{1/2} \quad (29)$$

4-Percent Variation Explained :

$$\%\mathrm{PVE} = \{[\sum (\mathrm{V_i} - V_{ort})^2 - (\sum D_i^{\,2})] / \sum (V_i - V_{ort})^2\} * 100 \quad (30)$$

5-Error: $\mathrm{E} = 100 \times (\sum (\hat{\mathrm{V}}_\mathrm{i} - V_i) / \sum V_i)$ (4) (31)

6-Absolute Error: $\mathrm{AE} = \frac{100}{N} \times (\sum \left|(\hat{V}_i - V_i) / V_i\right|)$ (5) (32)

where $D_i = \hat{V}_i - V_i$, $\mathrm{V_i}$: observed stem volume, $\hat{V}_i$: predicted stem volume, $\mathrm{V_{ort}}$: average of observed stem volume and N: number of sample tree.

The least squares method was used in estimation of parameters of equations because all of the volume equations were linear. Estimations of parameters, the significant level of estimations, F-ratio, coefficient of determination (R^2), standard error of estimation (SE), Durbin-Whatson- value and values of criteria were calculated using the Regression Analysis procedure in SPSS software.

Validation of the best fitted volume equation determined according to above six performance criteria was tested by means of Student's paired t test was calculated as (6, 7):

$$t = \frac{\overline{d}}{S_{\overline{d}}} \quad (33)$$

where $\overline{d}$ is the average of residuals between predicted and observed stem volumes in test data set and $S_{\overline{d}}$ is Standard error of residuals, Large t values provided evidence of lack of fit.

4. RESULTS

Total twenty-six volume equations were examined. Estimations of parameters, significant levels of parameters, and correction factor –only for logaritmic equations- were given in Table 4.

The results of six performance criteria were given in Table 5. Rank of every volume equation determined according to these six criteria was also shown in Table 5.

All of the equations were evaluated according to each criterion. Each equation was assigned a score, calculated as a function of each criterion. A scoring schema was developed according to error terms of each equation. The scoring scale runs from 1 (the lowest error rate) to 26 (the highest score). Given a specific error criterion, 26 equations were evaluated. Then, the error rate of the criterion was scaled for all the equations from top to bottom. For example, Equation #1 was scored 26 for average residual ($\overline{D}$) criterion since its value was the highest among 26 equations. Similarly, a score was calculated for each criterion for a given equation and all scores were summed (the RANK column in Table 5) to indicate the fittness of the equation. Then, all equations were ranked according to the total score (RANK) received. Equation that had the lowest total rank value was assumed to be the best fitted volume equation. The best fitted volume equation selected form among twelve-six volume

equations was Equation #19 (Table 5). Equation #19 whose F-ratio calculated as 11066.0 had an appropriate level of reliability (α=0.001).

Table 4. Estimated parameters for double-entry volume equations

E.No	b_0	b_1	b_2	b_3	b_4	f
1		0.000029 ***				
2	0.208957 ***	0.000028 ***				
3	-0.169603 *	0.00007 NS	0.016498 ***	0.000024 ***		
4 f	-4.019432 ***	1.724667 ***	0.989414 ***			1.00794019
5	486.880492 ***	16731.359 ***				
6	0.000274 ***	0.00023 ***				
7		0.000147 NS	0.000241 NS	0.0000038 ***	0.000021 ***	
8	0.088812 NS	-0.011138 NS	0.000203 NS	0.000637 *	0.000018 **	
9	20873.931 ***	214.66033 ***				
10 f	-3.988636 ***	0.894898 ***				1.00809123
11 f	-4.094379 ***	1.934226 ***	-0.067602 NS	0.878834 **	0.035614 NS	1.0079493
12	-0.013989 NS	0.000156 NS	0.000271 NS	0.0000032 NS	0.000021 ***	
13		-0.002507 NS	0.000074 NS	0.000467 **	0.000021 ***	
14		0.000463 ***	0.000147 NS	0.0000070 NS	0.0000003 ***	
15 f	-3.883623 ***	1.671148 ***	0.968413 ***	-0.709568 *		1.00785218
16 f	-4.053127 ***	1.767425 ***	0.978383 ***	-0.002657 NS		1.00795114
17 f	-4.069685 ***	1.75541 ***	-0.00186 NS	1.009427 ***	-0.003247 NS	1.00797584
18 f	-4.014035 ***	1.71628 ***	8.7199E-7 NS	0.993657 ***		1.00796473
19		0.000395 ***	0.000023 ***			
20 F	-4.097055 ***	1.725893 ***	1.112878 ***	-0.048861 NS		1.00795713
21 F	-4.071229 ***	1.726258 ***	1.043271 ***	-0.006306 NS		1.00795366
22 F	-3.979853 ***	1.725352 ***	0.965717 ***	-0.171431 NS		1.00796303
23 F	-4.014035 ***	1.71628 **	0.993657 ***	8.7198E-7 NS		1.00796473
24 F	-4.011505 ***	1.714794 ***	0.993309 ***	3.2219E-8 NS		1.00863952
25 F	-4.056092 ***	1.726789 ***	1.02219 ***	-0.000016 NS		1.00795164
26 F	-4.024474 ***	1.72788 ***	0.990358 ***	-3.453E-8 NS		1.00796613

Note: f = Correction Factor, NS = p>0.05, * = p<0.05, ** = p<0.01, *** = p<0.001

Table 5. Criteria Values for Double-Entry Volume Equations

Equation No	$\overline{D}$ (m^3)	$\overline{D}$ (m^3)	S_D (m^3)	PVE (%)	E (%)	AE (%)	RANK
19	-0.000 2.5	0.198 1.5	0.312 3	97.14 3.5	-0.020 4	10.13 2	16.5
8	-0.000 2.5	0.200 4.5	0.312 3	97.15 1	-0.000 2	10.21 5	18.0
12	0.000 2.5	0.200 4.5	0.312 3	97.14 3.5	0.000 2	10.19 3	18.5
7	0.001 7	0.200 4.5	0.312 3	97.14 3.5	0.057 7	10.20 4	29
13	-0.002 11	0.198 1.5	0.312 3	97.14 4.5	-0.090 9	10.12 1	29
18	0.001 7	0.201 10.5	0.318 10.5	97.03 10.5	0.044 5.5	10.24 8	52
23	0.001 7	0.201 10.5	0.318 10.5	97.03 10.5	0.044 5.5	10.24 8	52
24	0.003 13.5	0.200 4.5	0.317 9	97.04 9	0.160 12	10.23 6	54
3	0.000 2.5	0.203 20	0.313 6	97.13 6	0.000 2	10.34 19	55.5
4	-0.001 7	0.201 10.5	0.321 13	96.97 12.5	0.059 8	10.28 13.5	64.5
22	-0.002 11	0.201 10.5	0.321 13	96.97 12.5	-0.126 11	10.28 13.5	71.5
10	0.007 21	0.201 10.5	0.314 7	97.10 7	0.371 20	10.24 8	73.5
20	-0.004 16	0.201 10.5	0.321 13	96.96 15	-0.181 14	10.27 11	79.5
21	-0.004 16	0.201 10.5	0.322 16	96.96 15	-0.209 15	10.27 11	83.5
25	-0.004 16	0.201 10.5	0.322 16	96.96 15	-0.228 16	10.27 11	84.5
26	-0.002 11	0.202 16.5	0.322 16	96.95 17	-0.112 10	10.29 15	85.5
14	0.005 18	0.203 20	0.315 8	97.08 8	0.269 17	10.38 21	92
15	-0.001 7	0.202 16.5	0.331 21	96.78 21	-0.604 22	10.32 17	104.5
17	-0.006 19.5	0.202 16.5	0.326 18	96.87 18	-0.320 18	10.31 16	106
16	-0.006 19.5	0.202 16.5	0.328 19.5	96.83 19	-0.324 19	10.33 18	111.5
5	0.003 13.5	0.225 24	0.359 24	96.21 23	0.165 13	11.47 24	121.5
11	-0.009 22	0.203 20	0.333 22	96.74 22	-0.473 21	10.36 20	127
2	0.024 23	0.224 23	0.328 19.5	96.82 20	1.248 23	11.43 23	131.5
9	-0.038 24	0.216 22	0.381 25	95.69 25	-1.926 24	11.03 22	142
1	-0.108 26	0.242 26	0.343 23	96.19 24	5.523 26	12.36 26	151

6	0.075 25	0.240 25	0.400 26	95.14 26	3.830 25	12.24 25	152

The Durbin-Whatson test was used to see that if the residual terms of the best fitted volume equation were related to. The DW-value was then calculated as 1.85. Thus, it seemed that residual terms have a random distribution.

Coefficient of determination (R^2) and standard error (SE) of the best fitted volume equation were 0.99 and 0.312 m^3, respectively.

Average residual, average absolute residual, standard deviation of residual, percent variation explained, percent error, and percent absolute error of the best fitted volume equation (Equation #19) were found as –0.000 m^3, 0.198 m^3, 0.312 m^3, 97.14%, -0.020%, and 10.13%, respectively.

Student's paired t test gave no evidence of lack of fit between predicted and observed volume values (t-value= 0.810, p>0.05). Thus, it was concluded that the best fitted equation could be used for other ash stands in Turkey.

Ash Double-Entry Stem Volume Table constructed according to Equation #19 was given in Table 6.

Table 6. Double-entry volume table for ash

dbh	TOTAL TREE HEIGHT (m)											
cm	7	10	13	16	19	22	25	28	31	34	37	40
6	0.022											
10	0.044	0.063	0.081									
14	0.070	0.100	0.131	0.161								
18		0.146	0.189	0.233	0.277							
22		0.198	0.258	0.317	0.377	0.436	0.496					
26			0.336	0.413	0.491	0.568	0.646	0.723				
30			0.423	0.521	0.619	0.716	0.814	0.911	1.009			
34				0.640	0.760	0.880	1.000	1.121	1.241	1.361	1.4807	
38				0.772	0.916	1.061	1.206	1.350	1.495	1.640	1.7842	
42					1.086	1.258	1.429	1.601	1.772	1.944	2.1150	
46					1.270	1.470	1.671	1.872	2.072	2.273	2.4730	
50						1.700	1.931	2.163	2.395	2.627	2.8583	
54						1.945	2.210	2.475	2.740	3.006	3.2707	
58						2.206	2.507	2.808	3.109	3.410	3.7104	
62						2.484	2.823	3.161	3.500	3.839	4.1774	
66							3.157	3.535	3.914	4.293	4.6715	
70								3.930	4.351	4.772	5.1930	
74								4.345	4.811	5.276	5.7416	
78								4.781	5.293	5.805	6.3175	
82								5.237	5.798	6.359	6.9206	
86									6.326	6.939	7.7509	
90										7.543	8.2085	8.8740
94										8.172	8.8932	9.6143
98										8.827	9.6053	10.384
102										9.506	10.345	11.183
106										10.210	11.111	12.012
110										10.940	11.905	12.870

5. CONCLUSIONS

In the present study, successful results were obtained for ash that was a forked tree species and has not a straight bole.

The best volume equation (Equation #19) had a very high coefficient of determination (R^2=0.99) and a low standard error (SE=0.312 m^3) of which percent error and percent absolute error was –0.020% and 10.13%, respectively.

The residuals between predicted from the volume equation and observed volume values have shown normal distribution.

The average of the residuals was insignificant at $p>0.05$. In other words, selected volume equation which was tested by means of Student's paired t test has an appropriate level of reliability.

With this study was developed double-entry stem volume table for ash, one of the most important commercial forest species in Turkey. Thus, it was dealt with an important lack of forestry applications, especially forest management plannings.

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