

## Stump Diameter and Diameter at Breast Height Relationships for Oriental Beech and Kazdağı Fir at Mixed Stands in Karabük

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### Abstract

**Aim of study:** The aim of this study was to evaluate the relationships between stump diameters ( $d_{0.10}$  and  $d_{0.30}$ ) at two different stump heights (10 cm and 30 cm above ground level) and diameter at breast height ( $d_{1.30}$ ) for mixed stands of Oriental beech (*Fagus orientalis*) and Kazdağı fir (*Abies nordmanniana* subsp. *equi-trojani*) located in Karabük region.

**Area of study:** Study area is located on Büyükdüz Forest Planning Unit of Karabük Forest Enterprise of Zonguldak Regional Directorate of Forestry at Western Blacksea region of Turkey.

**Material and Methods:** A total of 516 sample trees (238 for Oriental beech and 278 for Kazdağı fir) were measured for  $d_{0.10}$ ,  $d_{0.30}$  and  $d_{1.30}$ . To model the relationships between stump diameters and diameter at breast height, ten candidate equations were tested. These equations were ranked according to Coefficient of Determination ( $R^2$ ), Root Mean Square Error (RMSE) and Mean Absolute Error (MAE), and successful models were selected based on average rank values.

**Main results:** Among equations tested, the power equation had the lowest average rank values for determining  $d_{0.10}$ - $d_{1.30}$  and  $d_{0.30}$ - $d_{1.30}$  relationships of both species and provided the best  $d_{1.30}$  predictions.  $R^2$ , RMSE and MAE values of the power equation are 0.981, 3.64 and 2.58 for  $d_{0.10}$ - $d_{1.30}$  relationship and 0.989, 2.01 and 1.36 for  $d_{0.30}$ - $d_{1.30}$  relationship for Oriental beech, and 0.955, 3.80 and 2.81 for  $d_{0.10}$ - $d_{1.30}$  relationship and 0.988, 1.96 and 1.28 for  $d_{0.30}$ - $d_{1.30}$  relationship for Kazdağı fir, respectively.

**Research highlights:** The equations developed can be used to estimate diameters at breast height of trees extracted from the stand for any reason, and volume of these trees can be predicted in a practical way by using single entry volume equations with the estimated diameters at breast heights.

**Keywords:** Diameter at breast height, Stump diameter, Mixed stand, Oriental beech, Kazdağı fir.

## Karabük Yöresi Doğu Kayını-Kazdağı Göknarı Karışık Meşcerelerinde Dip Kütük Çapı-Göğüs Çapı İlişkileri

### Özet

**Çalışmanın amacı:** Bu çalışmanın amacı, Karabük yöresi karışık meşcerelerinde bulunan Doğu kayını (*Fagus orientalis*) ve Kazdağı göknarı (*Abies nordmanniana* subsp. *equi-trojani*) türleri için iki farklı yükseklikten (10 cm ve 30 cm) ölçülen dip kütük çapları ( $d_{0.10}$  ve  $d_{0.30}$ ) ile göğüs çapları ( $d_{1.30}$ ) arasındaki ilişkilerin araştırılmasıdır.

**Çalışma alanı:** Araştırma, Zonguldak Orman Bölge Müdürlüğü'ne bağlı Karabük Orman İşletme Müdürlüğü'nün Büyükdüz Orman İşletme Şefliği'nde yürütülmüştür.

**Materyal ve Yöntem:** Araştırma materyali olarak toplam 516 örnek ağaçta (238 adet Doğu kayını ve 278 adet Kazdağı göknarı) yapılan dip kütük çapı ve göğüs çapı ölçümlerinden yararlanılmıştır. Dip kütük çapları ile göğüs çapı arasındaki ilişkilerin modellenmesinde on regresyon denklemi test edilmiştir. Denklemler Belirtme Katsayısı ( $R^2$ ), Hataların Ortalama Karekökü (RMSE) ve Ortalama Mutlak Hata (MAE) ölçütlerine göre sıralanmış ve en başarılı modeller belirlenmiştir.

**Sonuçlar:**  $d_{0.10}$ - $d_{1.30}$  ve  $d_{0.30}$ - $d_{1.30}$  ilişkileri için incelenen denklemler arasında her iki ağaç türü için de power denklemi en başarılı denklem olmuştur. Bu denkleme göre elde edilen  $d_{0.10}$ - $d_{1.30}$  ve  $d_{0.30}$ - $d_{1.30}$  ilişkilerine ilişkin  $R^2$ , RMSE ve MAE değerleri; Doğu kayını için sırasıyla 0.981, 3.64 ve 2.58 ile 0.989, 2.01 ve 1.36 iken, Kazdağı göknarı için sırasıyla 0.955, 3.80 ve 2.81 ile 0.988, 1.96 ve 1.28'dir.

**Araştırma vurguları:** Çalışma kapsamında geliştirilen denklemler, meşcereden uzaklaştırılan ağaçların göğüs çapı tahmininde kullanılabilir ve hacim hesaplamalarında bu tahminlerden yararlanılabilecektir.

**Anahtar kelimeler:** Göğüs çapı, Dip kütük çapı, Karışık meşcere, Doğu kayını, Kazdağı göknarı.



## Introduction

Forest inventory is the main way of obtaining information needed to ensure the sustainability of the forest resource utilization (Köhl, 2004). Forest inventory constitutes the basis of all planning processes in forestry (Firat, 1973). One of the most important issues of forest inventory is stand volume. Although there are a number of methods to estimate stand volume in the forestry literature, tree volume tables are generally preferred due to their practicality. Depending on the number of independent variables used, tree volume tables are usually classified into three types as single, double and multiple-entry tree volume tables. Single-entry tree volume tables depend on only diameter at breast height of trees, double-entry tree volume tables depend on tree height and diameter at breast height, while multiple-entry tree volume tables as a function of some other tree size as well as additional diameter at breast height and tree height (Kalıpsız, 1999).

Single-entry volume tables are more preferred, because diameter at breast height is an easily and accurately measured parameter (Vanclay, 1994; Kalıpsız, 1999). However, many features (e.g. diameter at breast height and tree height) of trees removed from the field as a result of planned or illegal cuttings cannot be revealed and hence the tree volume cannot be estimated with these tables. Since trees are usually cut at the stump height, determining the relationships between stump diameter and diameter at breast height in order to compute the volume using the diameters at breast height of the trees is of very great importance (Yavuz, 2000). Stump diameter shows a high correlation with diameter at breast height, so the equations using stump diameter as independent variable are useful tools to estimate diameter at breast height of removed trees. Then, estimated diameters at breast height with these equations can be used for volume predictions. There are many researches on relationships between stump diameter and diameter at breast height for various tree species (e.g. Alemdag and Honer, 1977; Bylin, 1982; Demaerschalk and Omule, 1982; Omule and Kozak, 1989; Kozak and Omule, 1992; Weigel and Johnson, 1997; Corral-Rivas et al., 2007; Uğurlu and Özer, 1977; Özer, 1981; Giray, 1982; Yavuz, 1996;

Yavuz, 2000; Özçelik, 2005; Durkaya and Durkaya, 2011; Şenyurt, 2012; Ercanlı et al., 2015; Sağlam et al., 2016). The studies on this subject, conducted in Turkey, were only interested in stump diameter at 30 cm height except one of Durkaya and Durkaya (2011) who explained the relationships between stump diameter and diameter at breast height for different stump heights range from 10 cm to 60 cm. Considering that trees are cut as close to the ground as possible recently, the relationships between some other stump diameters at other heights than 30 cm and diameter at breast height are also important.

Oriental beech (*Fagus orientalis* Lipsky.) and Kazdağı fir (*Abies nordmanniana* subsp. *equi-trojani* (Asc. & Sint. ex Boiss.) Coode & Cullen) are both of main forest tree species in Turkey. They are very important in terms of economically and ecologically. Kazdağı fir is an endemic species of Turkey and spreads northwestern and western parts of country, and the main distribution area of Oriental beech in Turkey is Blacksea region. In these regions, these species form large pure stands as well as mixed stands together (Anşın and Özkan, 1993).

The aim of this study was to evaluate the relationships between stump diameters at two different stump heights and diameter at breast height for mixed stands of Oriental beech and Kazdağı fir located in Karabük region. For this purpose, stump diameters and diameters at breast height of sample trees were measured. Depending on the data obtained, the various regression equations were tested and the equations that giving the best results were determined for both tree species. These equations can be used to estimate diameter at breast heights required for volume predictions.

## Material and Method

Study area is located in Karabük Forest Enterprise of Zonguldak Regional Directorate of Forestry at Western Blacksea region of Turkey. The total area of Karabük Forest Enterprise is 113,746.20 ha, and 75% of total area (85,111.60 ha) is covered by forests (URL, 2017). Main tree species of these forests are *Pinus nigra*, *Fagus orientalis*, *Abies nordmanniana* subsp. *equi-trojani* and *Quercus* sp.

To model the relationships between stump diameters ( $d_{0.10}$ ,  $d_{0.30}$ ) at two different stump heights (10 cm and 30 cm above ground level) and diameter at breast height ( $d_{1.30}$ ), the data obtained from measurements in Oriental beech-Kazdağı fir mixed stands located on Büyükdüz Planning Unit of Karabük Forest Enterprise were used. For this purpose, a total of 516 sample trees (238 for Oriental beech and 278 for Kazdağı fir) were measured for  $d_{0.10}$ ,  $d_{0.30}$  and  $d_{1.30}$ . Separately for both species, 75% of the data (178 and 208 sample trees for beech and fir, respectively) were randomly selected and used for model development, and remaining 25% (60 and 70 sample trees for beech and fir, respectively)

were used for testing the validation of the tested models. Descriptive statistics of the model development and validation data are given in Table 1. The table shows that the mean  $d_{0.10}$ ,  $d_{0.30}$  and  $d_{1.30}$  values of beech sample trees are 52.1 cm, 46.6 cm and 43.9 cm for model development data and 51.6 cm, 46.7 cm and 44.4 cm for validation data, respectively. For fir sample trees, the mean values are 54.4 cm, 47.4 cm and 44.4 cm for model development data and 53.7 cm, 46.6 cm and 43.5 cm for validation data, respectively.  $d_{0.10}$ - $d_{1.30}$  and  $d_{0.30}$ - $d_{1.30}$  relationships obtained from sample trees are given in Figure 1. For the purpose of modeling these relationships, equations given Table 2 were tested.

Table 1. Descriptive statistics for the model development and validation data

Species	Data Group	Variable	n	Min. (cm)	Max. (cm)	Mean (cm)	Std Dev. (cm)
<i>Fagus orientalis</i>	Model Development	Stump diameter at 10 cm ( $d_{0.10}$ )	178	15.8	98.2	52.1	18.3
		Stump diameter at 30 cm ( $d_{0.30}$ )	178	12.9	91.4	46.6	16.9
		Diameter at breast height ( $d_{1.30}$ )	178	10.1	88.5	43.9	16.4
	Validation	Stump diameter at 10 cm ( $d_{0.10}$ )	60	17.7	88.8	51.6	17.5
		Stump diameter at 30 cm ( $d_{0.30}$ )	60	15.1	82.1	46.7	16.4
		Diameter at breast height ( $d_{1.30}$ )	60	14.0	80.1	44.4	15.9
	All	Stump diameter at 10 cm ( $d_{0.10}$ )	238	15.8	98.2	52.0	18.1
		Stump diameter at 30 cm ( $d_{0.30}$ )	238	12.9	91.4	46.7	16.8
		Diameter at breast height ( $d_{1.30}$ )	238	10.1	88.5	44.0	16.2
<i>Abies nordmanniana</i> subsp. <i>equi-trojani</i>	Model Development	Stump diameter at 10 cm ( $d_{0.10}$ )	208	16.0	115.5	54.4	19.4
		Stump diameter at 30 cm ( $d_{0.30}$ )	208	13.0	104.0	47.4	17.9
		Diameter at breast height ( $d_{1.30}$ )	208	11.4	100.1	44.4	17.4
	Validation	Stump diameter at 10 cm ( $d_{0.10}$ )	70	18.0	95.7	53.7	19.1
		Stump diameter at 30 cm ( $d_{0.30}$ )	70	13.9	89.0	46.6	18.0
		Diameter at breast height ( $d_{1.30}$ )	70	10.8	84.7	43.5	17.3
	All	Stump diameter at 10 cm ( $d_{0.10}$ )	278	16.0	115.5	54.2	19.3
		Stump diameter at 30 cm ( $d_{0.30}$ )	278	13.0	104.0	47.2	17.9
		Diameter at breast height ( $d_{1.30}$ )	278	10.8	100.1	44.2	17.3

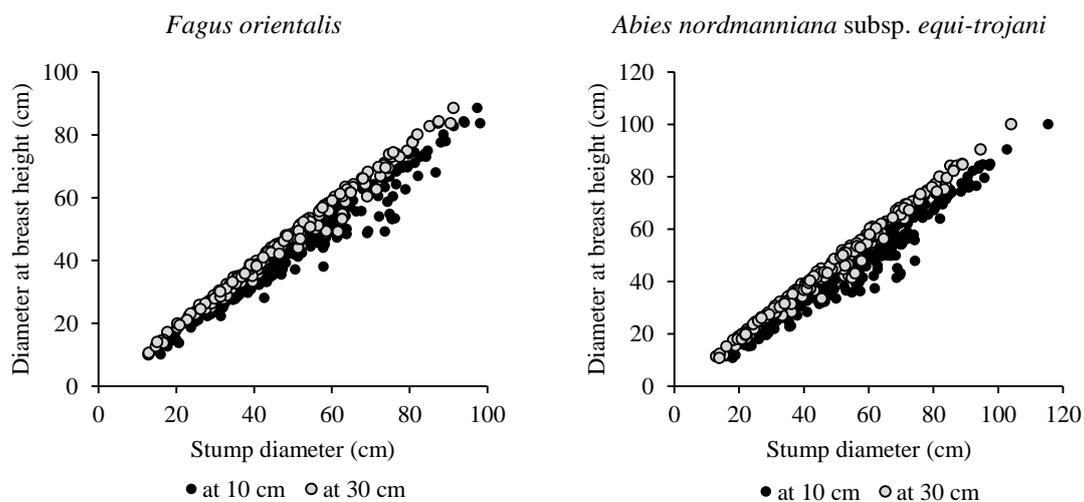


Figure 1. Stump diameters and diameter at breast height relationships

Table 2. Equations used for modeling the relationships\*

Model name	Model form	No.
Linear	$d_{1.30} = b_0 + b_1 d_i$	(1)
Logarithmic	$d_{1.30} = b_0 + b_1 \ln d_i$	(2)
Inverse	$d_{1.30} = b_0 + b_1 / d_i$	(3)
Quadratic	$d_{1.30} = b_0 + b_1 d_i + b_2 d_i^2$	(4)
Cubic	$d_{1.30} = b_0 + b_1 d_i + b_2 d_i^2 + b_3 d_i^3$	(5)
Compound	$d_{1.30} = b_0 b_1^{d_i}$	(6)
Power	$d_{1.30} = b_0 d_i^{b_1}$	(7)
S	$d_{1.30} = e^{b_0 + b_1 / d_i}$	(8)
Growth	$d_{1.30} = e^{b_0 + b_1 d_i}$	(9)
Exponential	$d_{1.30} = b_0 e^{b_1 d_i}$	(10)

\*  $d_{1.30}$ : Diameter at breast height (cm),  $d_i$ : Stump diameter ( $d_{0.10}$  or  $d_{0.30}$  according to stump heights, cm),  $b_i$ : Equation parameters.

For the selection of successful models among the tested equations, Coefficient of Determination ( $R^2$ ), Root Mean Square Error ( $RMSE$ ) and Mean Absolute Error ( $MAE$ ) were utilized. Corresponding mathematical forms of statistical criteria used were defined as:

$$R^2 = 1 - \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2} \quad (11)$$

$$RMSE = \sqrt{\frac{\sum(y_i - \hat{y}_i)^2}{n-p}} \quad (12)$$

$$MAE = \frac{\sum|\hat{y}_i - y_i|}{n} \quad (13)$$

In these equations;  $y_i$ : observed value,  $\hat{y}_i$ : estimated value,  $p$ : number of parameters, and  $n$ : sample size.

The models were ranked from 1 to 10 based on each criterion. The model with the highest  $R^2$  was ranked as 1 and the lowest  $R^2$  was ranked as 10 for coefficient of determination, while the model with the lowest value was ranked as 1 and the highest value was ranked as 10 for  $RMSE$  and  $MAE$ . The average of these three ranks for a given model was then calculated. Comparing the average ranks of the models, the best models were determined for both stump diameters, separately.

Validity of equations developed were tested using Paired Samples t-Test. IBM SPSS Statistics 23 software was used for statistical analyzes conducted during the study.

### Results and Discussion

Values of the parameter estimates ( $b_i$ ), Coefficient of Determination ( $R^2$ ), Root Mean Square Error ( $RMSE$ ) and Mean Absolute Error ( $MAE$ ) for the developed models to

determine the relationships between stump diameters and diameter at breast height for Oriental beech and Kazdağı fir in mixed stands located Büyükdüz Forest Planning Unit are given in Table 3. As seen in the table, the large majority of the equations explained more than 90% of the observed variation in diameter at breast height for both species. Equations with stump diameter for 30 cm stump height have better statistical results than for 10 cm stump height. Power equation (Model 7) had the lowest average rank values ( $p < 0.05$ ) for determining  $d_{0.10}$ - $d_{1.30}$  and  $d_{0.30}$ - $d_{1.30}$  relationships of both species and provided the best  $d_{1.30}$  predictions.  $R^2$ ,  $RMSE$  and  $MAE$  values of the best model (power equation) are 0.981, 3.64 and 2.58 for  $d_{0.10}$ - $d_{1.30}$  relationship and 0.989, 2.01 and 1.36 for  $d_{0.30}$ - $d_{1.30}$  relationship for Oriental beech trees, and 0.955, 3.80 and 2.81 for  $d_{0.10}$ - $d_{1.30}$  relationship and 0.988, 1.96 and 1.28 for  $d_{0.30}$ - $d_{1.30}$  relationship for Kazdağı fir trees, respectively.

The validities of the developed equations were tested with Paired Samples t-Test using independent data sets obtained from 60 and 70 sample trees for beech and fir, respectively. The estimated and observed  $d_{1.30}$  values were compared with this test and consequently it was decided that the equations which had statistically non-significant differences between estimated and observed values could be used (Table 4). As seen in the table, there are no significant differences ( $p > 0.05$ ) between observed and estimated values of the most of the equations modeling  $d_{0.10}$ - $d_{1.30}$  and  $d_{0.30}$ - $d_{1.30}$  relationships for both species. As a result, because of their statistical successes, power equations (Model 7) can be used for

diameter at breast height estimations based on both stump diameters. In addition, linear equations (Model 1) had also lower average ranks and can be used practically.

Residual plots based on the differences between observed and estimated diameter at breast heights calculated with the power equations for the entire sample trees are given in Figure 2 for Oriental beech and in Figure 3 for Kazdağı fir. When Figure 2 and 3 are

examined, it is seen that the residuals increase together with the increase in diameter at breast height and then decrease again for high diameter at breast height values. When the diameter at breast height estimations based on stump diameters at two different stump heights are compared, the residuals of estimations based on stump diameter at 30 cm are lower for both species. Mean residuals are very close to zero for all estimations.

Table 3. Parameter estimations, goodness of fit statistics and ranks based on fit statistics of models\*

Model No.	$b_0$	$b_1$	$b_2$	$b_3$	$F$	$p$	$R^2$	RMSE	MAE	Average Rank
<i>Fagus orientalis</i>										
Diameter at breast height - Stump diameter at 10 cm										
1	-1.660	0.874			3472.105	0.000	0.952 (3.5)	3.61 (2)	2.62 (2.5)	2.67
2	-113.603	40.535			1631.426	0.000	0.903 (6)	5.13 (6)	3.93 (5)	5.67
3	75.869	-1437.746			525.876	0.000	0.749 (10)	8.24 (10)	6.40 (10)	10.00
4	-1.468	0.866	0.00007		1726.310	0.000	0.952 (3.5)	3.62 (3)	2.62 (2.5)	3.00
5	-9.581	1.407	-0.011	0.00006	1177.344	0.000	0.953 (2)	4.39 (5)	3.30 (4)	3.67
6	13.205	1.022			1449.409	0.000	0.892 (8)	2.16 (1)	4.38 (7)	5.33
7	0.647	1.068			4571.443	0.000	0.981 (1)	3.64 (4)	2.58 (1)	2.00
8	4.608	-40.678			2168.601	0.000	0.925 (5)	5.70 (7)	4.12 (6)	6.00
9	2.581	0.022			1449.409	0.000	0.892 (8)	6.69 (9)	4.46 (8.5)	8.50
10	13.205	0.022			1449.409	0.000	0.892 (8)	6.68 (8)	4.46 (8.5)	8.17
Diameter at breast height - Stump diameter at 30 cm										
1	-0.898	0.961			12226.043	0.000	0.986 (3)	1.95 (1)	1.37 (3)	2.33
2	-106.014	39.769			2308.931	0.000	0.929 (6)	4.38 (6)	3.21 (5)	5.67
3	74.097	-1201.816			510.321	0.000	0.744 (10)	8.33 (10)	6.35 (10)	10.00
4	-1.609	0.993	-0.0003		6100.885	0.000	0.986 (3)	1.96 (2)	1.34 (1)	2.00
5	-5.007	1.245	-0.006	0.00003	4133.596	0.000	0.986 (3)	2.66 (5)	2.04 (4)	4.00
6	13.562	1.024			1790.393	0.000	0.910 (8)	2.10 (4)	3.97 (7)	6.33
7	0.791	1.045			15356.347	0.000	0.989 (1)	2.01 (3)	1.36 (2)	2.00
8	4.564	-34.240			2365.309	0.000	0.931 (5)	5.34 (7)	3.71 (6)	6.00
9	2.607	0.024			1790.393	0.000	0.910 (8)	6.61 (8.5)	4.02 (8.5)	8.33
10	13.562	0.024			1790.393	0.000	0.910 (8)	6.61 (8.5)	4.02 (8.5)	8.33
<i>Abies nordmanniana</i> subsp. <i>equi-trojani</i>										
Diameter at breast height - Stump diameter at 10 cm										
1	-3.032	0.873			4079.401	0.000	0.952 (4)	3.82 (2)	2.77 (2)	2.67
2	-120.020	41.889			1588.995	0.000	0.885 (9)	5.91 (5)	4.36 (8)	7.33
3	77.951	-1566.848			560.389	0.000	0.731 (10)	9.05 (10)	6.74 (10)	10.00
4	1.833	0.680	0.002		2128.257	0.000	0.954 (2.5)	3.96 (3)	2.71 (1)	2.17
5	-0.653	0.833	-0.001	0.00002	1415.911	0.000	0.954 (2.5)	4.20 (4)	2.88 (4)	3.50
6	13.202	1.021			2074.500	0.000	0.910 (6)	6.08 (6)	4.21 (5)	5.67
7	0.637	1.060			4355.176	0.000	0.955 (1)	3.80 (1)	2.81 (3)	1.67
8	4.616	-42.295			1796.476	0.000	0.897 (8)	6.66 (9)	4.57 (9)	8.67
9	2.580	0.021			2074.500	0.000	0.910 (6)	6.41 (7.5)	4.27 (7.5)	6.67
10	13.202	0.021			2074.500	0.000	0.910 (6)	6.41 (7.5)	4.27 (7.5)	6.67
Diameter at breast height - Stump diameter at 30 cm										
1	-1.197	0.963			16017.242	0.000	0.987 (3)	1.97 (3)	1.29 (3)	3.00
2	-110.528	40.984			2554.118	0.000	0.925 (9)	4.77 (5)	3.51 (5)	6.33
3	77.243	-1317.848			639.609	0.000	0.756 (10)	8.62 (10)	6.39 (10)	10.00
4	-0.101	0.914	0.0005		8050.939	0.000	0.987 (3)	1.96 (1.5)	1.28 (1.5)	2.00
5	-1.316	0.999	-0.001	0.00001	5356.985	0.000	0.987 (3)	2.08 (4)	1.31 (4)	3.67
6	13.934	1.023			2570.478	0.000	0.926 (7)	6.12 (7)	3.82 (6)	6.67
7	0.827	1.032			16316.699	0.000	0.988 (1)	1.96 (1.5)	1.28 (1.5)	1.33
8	4.597	-35.565			2637.493	0.000	0.928 (5)	5.78 (6)	3.83 (7)	6.00
9	2.634	0.023			2570.428	0.000	0.926 (7)	6.58 (8.5)	3.85 (8.5)	8.00
10	13.934	0.023			2570.428	0.000	0.926 (7)	6.58 (8.5)	3.85 (8.5)	8.00

\*Values in parenthesis indicate ranks of the models based on statistical criteria.

Table 4. The t-test results for the equations tested

	Model No.									
	1	2	3	4	5	6	7	8	9	10
<i>Fagus orientalis</i>										
Diameter at breast height - Stump diameter at 10 cm										
<i>t</i>	1.839	1.095	0.229	2.744	5.408	1.172	1.602	1.835	0.151	0.178
<i>p</i>	0.071	0.278	0.820	0.008*	0.000*	0.246	0.114	0.072	0.880	0.859
Diameter at breast height - Stump diameter at 30 cm										
<i>t</i>	1.949	0.329	-0.096	2.020	3.969	0.119	1.630	1.338	-0.891	-0.909
<i>p</i>	0.056	0.744	0.924	0.048*	0.000*	0.906	0.108	0.186	0.377	0.367
<i>Abies nordmanniana</i> subsp. <i>equi-trojani</i>										
Diameter at breast height - Stump diameter at 10 cm										
<i>t</i>	-0.626	-0.567	-0.568	-2.957	-1.128	-0.114	-0.096	0.383	-1.010	-1.035
<i>p</i>	0.533	0.572	0.572	0.004*	0.263	0.910	0.923	0.703	0.316	0.304
Diameter at breast height - Stump diameter at 30 cm										
<i>t</i>	-0.634	-0.162	-0.115	-0.647	-3.578	-0.457	-0.664	0.624	-1.325	-1.389
<i>p</i>	0.528	0.871	0.909	0.520	0.001*	0.649	0.509	0.535	0.190	0.183

\*:  $p < 0.05$

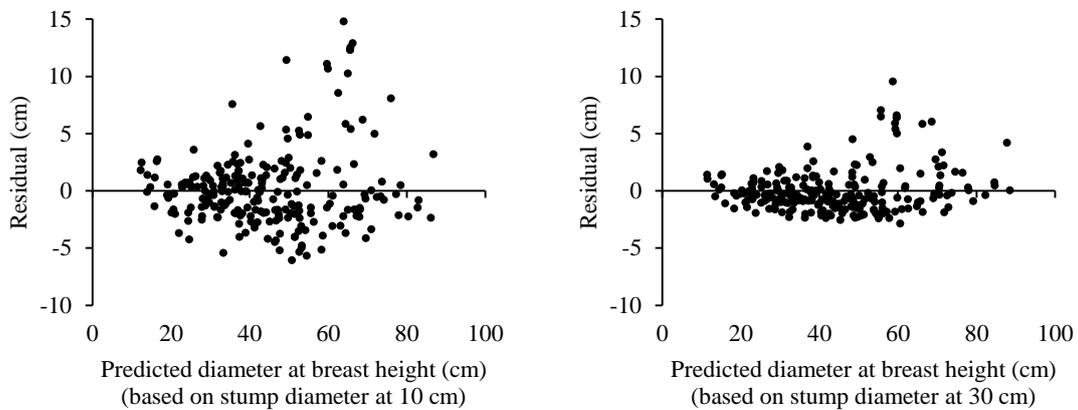


Figure 2. Residuals of diameter at breast height estimations for *Fagus orientalis*

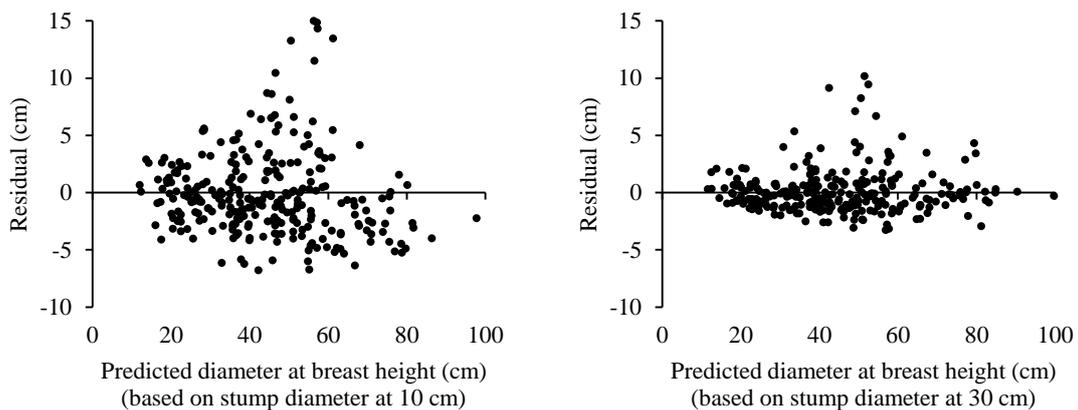


Figure 3. Residuals of diameter at breast height estimations for *Abies nordmanniana* subsp. *equi-trojani*

Figure 4 shows the differences for diameter at breast height estimations between tree species studied. When stump diameter at 10 cm height is used as predictor variable, there are increasing differences in favor of

beech in diameter at breast height estimations. If stump diameter at 30 cm is used as it, the differences are quite small.

For some tree species in Turkey, similar results were also obtained for Scots pine and

Crimean pine (Yavuz, 1996), Ash (Yavuz, 2000), Cedar and Calabrian pine (Özçelik, 2005), Oriental beech (Ercanlı et al., 2015) and Chestnut (Sağlam et al., 2016) for using the power equations. Besides, quadratic equation was found successful for Crimean pine (Özçelik, 2005) and Scots pine (Şenyurt, 2012).

Results found in this study are also similar to the results of Durkaya and Durkaya (2011), in which relationships between diameter at

breast height and stump diameters at six different stump heights were studied for mixed stands of three species (fir, beech and black pine) at an area close to our study area. In their research, power equation was also the most successful model to develop stump diameters and diameter at breast height relationships and statistical successes of the models increased with increasing stump heights, especially for beech and fir trees, like present study.

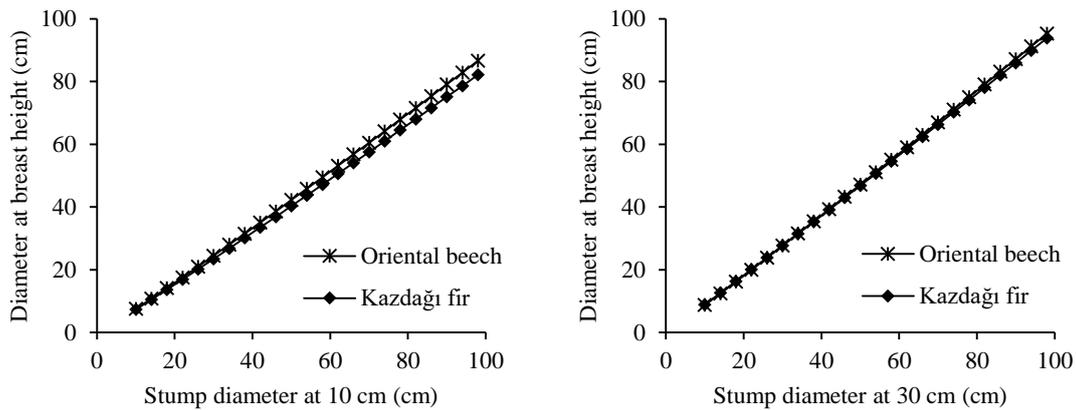


Figure 4. Diameter at breast height estimations for different stump diameters

### Conclusions

In order to determine the relationships of two different stump diameters with diameter at breast height for mixed stands of Oriental beech and Kazdağı fir in Karabük region, 10 regression equations were tested and power equation was selected according to statistical criteria for both relationships. Equations developed for diameter at breast height estimations from stump diameters at 10 cm and 30 cm are expressed as follows.

*Fagus orientalis*:

$$d_{1.30} = 0.647(d_{0.10})^{1.068}$$

$$d_{1.30} = 0.791(d_{0.30})^{1.045}$$

*Abies nordmanniana* subsp. *equi-trojani*:

$$d_{1.30} = 0.637(d_{0.10})^{1.060}$$

$$d_{1.30} = 0.827(d_{0.30})^{1.032}$$

These equations can be used to estimate diameters at breast height of trees extracted from the stand for any reason. In this way, volume of these trees may be predicted in a practical way by using single entry volume equations with the estimated diameters at breast heights.

Because of their successful results, linear models can also be used for practicality. Equation forms of linear models are as follows.

*Fagus orientalis*:

$$d_{1.30} = -1.660 + 0.874d_{0.10}$$

$$d_{1.30} = -0.898 + 0.961d_{0.30}$$

*Abies nordmanniana* subsp. *equi-trojani*:

$$d_{1.30} = -3.032 + 0.873d_{0.10}$$

$$d_{1.30} = -1.197 + 0.963d_{0.30}$$

As other stand characteristics, stump diameter and diameter at breast height relationships vary according to tree species and site conditions. Therefore, it should be established these relationships for different tree species, sites and regions in order to reflect on the results of aforesaid differences and to obtain reliable results.

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