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The Relationships between Diameter at Breast Height, Tree Height and Crown Diameter in Lebanon Cedars (*Cedrus libani* A. Rich.) of the Yavsan Mountain, Kahramanmaras, Turkey

[1]Mahmut D. Avsar and [2]Veysel Ayyildiz
[1]Department of Forest Engineering, Faculty of Forestry,
Kahramanmaras Sutcu Imam University, 46100 Kahramanmaras, Turkey
[2]Directorate of Antakya Forest Enterprise, 31040 Antakya-Hatay, Turkey

Abstract: In this study, the relationships between height-Diameter at Breast Height (DBH), crown diameter-DBH and crown diameter-height were investigated in Lebanon cedars (*Cedrus libani* A. Rich.) of the Yavsan Mountain, Kahramanmaras. Six sample plots were selected from pure and mixed stands of Lebanon cedar and DBH, height and crown diameter were measured on Lebanon cedar trees, of which height was ≥5 m, in the sample plots. The regression analysis carried out on the data of 186 trees showed that there were statistically significant ($p<0.0001$) and strong ($R^2>0.50$) relationships between DBH, height and crown diameter variables in Lebanon cedars. The strongest relationship determined was the crown diameter-DBH relationship ($R^2 = 0.72$), followed by the height-DBH ($R^2 = 0.71$) and crown diameter-height ($R^2 = 0.52$) relationships, respectively. The results of the study indicate that the height-DBH and crown diameter-DBH relationships can be described by the power model, while the crown diameter-height relationship can be described by the S-curve model and heights and crown diameters can be estimated from DBH, of which measurement is easy, in Lebanon cedars of the study area.

Key words: *Cedrus libani*, diameter at breast height, tree height, crown diameter, regression analysis

INTRODUCTION

Lebanon cedar (*Cedrus libani* A. Rich.) is one of the four species of the genus *Cedrus* Link. in the family Pinaceae[1]. Lebanon cedar occurs in Turkey, Syria and Lebanon[2], but its main distribution is in the Taurus Mountains of Turkey[2,3]. In Turkey, pure Lebanon cedar forests cover an area of 109440 ha[4]; mixed Lebanon cedar forests also occupy considerable areas. It is a tree species which is drought tolerant, grows fast when young, has valuable wood, shows high establishment ability under suitable climatic conditions outside its natural distribution areas and regenerates easily by artificial method[5]. Therefore, large plantations of Lebanon cedar have been established in both the Taurus Mountains and ecologically suitable areas of Turkey.

Diameter at Breast Height (DBH), tree height and crown diameter are important tree characteristics. It is necessary to measure DBH and height in forest inventory studies and DBH, height and crown diameter in stand structure determination studies. DBH is a variable of which measurement is easy. Measurement of height and crown diameter variables is more difficult and time consuming than that of DBH. On the other hand, there is a close relationship between tree parameters such as diameter, height, crown size and bole volume[6]. Using these allometric relationships, a dimension of which measurement is difficult can be estimated from other dimensions which can easily be measured[7]. For example, using the height-DBH relationship, heights can be estimated from DBHs[8,9]. Thus, the studies of forest inventory and stand structure determination can be made easier and at less cost.

In this study, the relationships between individual tree DBH, height and crown diameter were investigated in Lebanon cedars in the forests of the Yavsan Mountain, Kahramanmaras. Thus, the possibilities of determination of height and crown diameter variables by regression equations for easier study and at less cost in the studies of ground-based forest inventory and stand structure determination to be made in pure and mixed stands of Lebanon cedar of the study area were evaluated.

MATERIALS AND METHODS

The data used in the study were obtained from natural pure and mixed stands of Lebanon cedar in the Yavsan Mountain. The Yavsan Mountain is located in the

Corresponding Author: Dr. Mahmut D. Avsar, Department of Forest Engineering, Faculty of Forestry, Kahramanmaras Sutcu Imam University, 46100 Kahramanmaras, Turkey

Table 1: Some site characteristics of the sample plots

Sample Plot No.	Location	Elevation (m)	Aspect	Slope (%)	Relief
1	Yoncali	1455	West	44	Slope
2	Catalkaya	1420	Northeast	26	Slope
3	Yaylacam Tepe	1495	West	60	Slope
4	Yaylacam Tepe	1570	Northeast	39	Slope
5	Zemzem	1365	Northwest	40	Slope
6	Catalkaya	1565	West	30	Slope

Table 2: Some statistical values of DBH, height and crown diameter data of Lebanon cedars in the sample plots

Variables	N	Mean	SE	SD	Min.	Max.	CV
DBH (cm)	186	17.76	0.54	7.32	6.00	41.00	41.24
Height (m)	186	10.65	0.28	3.88	5.00	22.00	36.46
Crown diameter (m)	186	3.45	0.08	1.16	1.00	6.30	33.46

central district of the Kahramanmaras province, southern Turkey, and its summit has an elevation of 1964 m. Mediterranean climate and Mediterranean mountain climate are seen at lower and upper elevations of the mountain, respectively. The common soil types in the study area are brown forest soil and red brown Mediterranean soil[10]. Six sample plots of 10x50 m each were selected from pure and mixed stands of Lebanon cedar, which had a normal structure, in the direction perpendicular to the contour lines. The sample plots 1, 2, 3-4 and 5-6 were taken from pure *Cedrus libani* and mixed *Cedrus libani-Pinus nigra* ssp. *pallasiana*, *Cedrus libani-Abies cilicica* ssp. *cilicica* and *Pinus nigra* ssp. *pallasiana-Abies cilicica* ssp. *cilicica-Cedrus libani* stands, respectively. Some site characteristics of the sample plots are given in Table 1.

DBH, height and crown diameter of Lebanon cedar trees, of which height was ≥5 m, in the sample plots were measured; DBH, height and crown diameter were determined to the nearest 1 cm, 0.1 m and 0.1 m, respectively. DBH was found by taking the mean of the two measurements that were made in the direction perpendicular to each other by a caliper; tree height was measured by a heightmeter. Crown diameter was calculated by measuring and adding the radii of the crown projection areas in four directions and then by dividing into 2 the value obtained. Some statistical values of DBH, height and crown diameter data are presented in Table 2.

The regression analysis was applied to determine whether there was a statistical relationship between DBH, height and crown diameter in Lebanon cedars[11]. The data of a total of N = 186 trees measured in all sample plots were included in the analysis; thus, the relationships between individual tree height-DBH, crown diameter-DBH and crown diameter-height were tried to determine. In the study, linear, logarithmic, inverse, quadratic, cubic, compound, power, S-curve, growth and exponential regression models were tested. The selection of the regression model was based on the coefficient of determination of the model (R^2) and the standard error of estimate ($S_{y.x}$)[12]. In all statistical analyses, a confidence level of p = 0.05 was used for statistical significance; and the analyses were carried out by using SPSS 11.0 package.

RESULTS

The height-DBH relationship: In this relationship, Diameter at Breast Height (DBH) and tree Height (H) were taken as the independent and dependent variables, respectively. The results of the regression analysis revealed that the power regression model established between these two variables was statistically significant ($F = 457.11$; $p<0.0001$).

The regression equation was:

$$H = 1.35(DBH)^{0.72} \quad (1)$$

It was found that the coefficient of determination and the standard error of estimate were $R^2 = 0.71$ and $S_{y.x} = 0.20$, respectively. The regression coefficients (b_0, b_1) were also statistically significant ($p<0.0001$). Thus, it is seen that there is a strong positive, nonlinear relationship between height and DBH (Fig. 1). Because, DBH explained 71.30% of the variation observed in height.

The crown diameter-DBH relationship: In this relationship, Diameter at Breast Height (DBH) and Crown Diameter (CD) were taken as the independent and dependent variables, respectively. The results of the regression analysis revealed that the power regression model established between these two variables was statistically significant ($F = 477.96$; $p<0.0001$).

The regression equation was:

$$CD = 0.47(DBH)^{0.70} \quad (2)$$

It was found that the coefficient of determination and the standard error of estimate were $R^2 = 0.72$ and $S_{y.x} = 0.19$, respectively. The regression coefficients (b_0, b_1) were also statistically significant ($p<0.0001$). Thus, it is seen that there is a strong positive, nonlinear relationship between crown diameter and DBH (Fig. 2). Because, DBH explained 72.20% of the variation observed in crown diameter.

The crown diameter-height relationship: In this relationship, Height (H) and Crown Diameter (CD) were taken as the independent and dependent variables, respectively. The results of the regression analysis

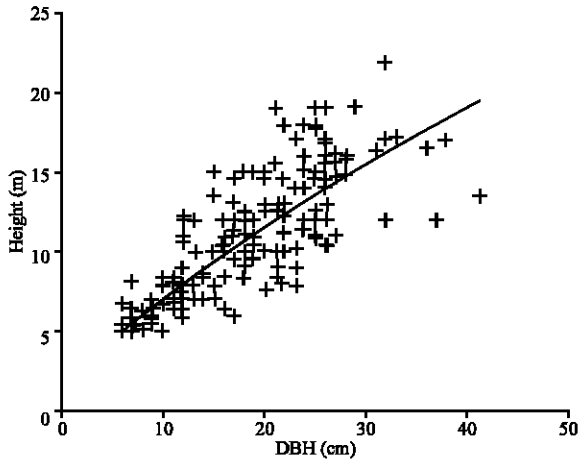

Fig. 1: The relationship between height and DBH

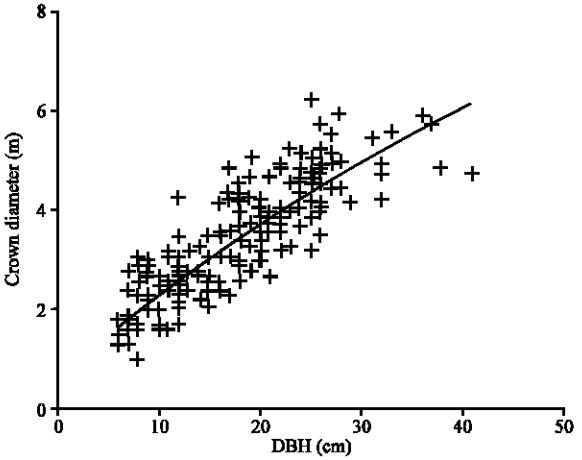

Fig. 2: The relationship between crown diameter and DBH

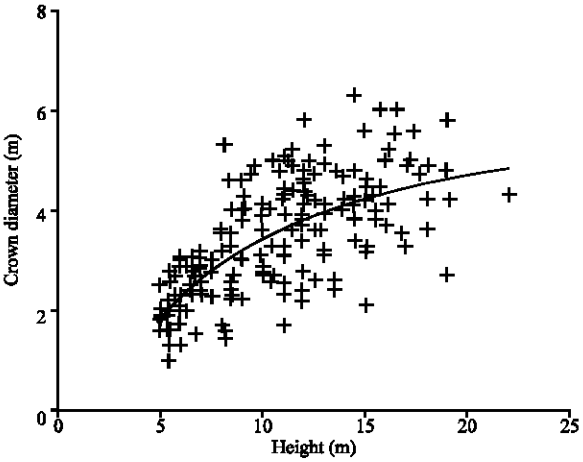

Fig. 3: The relationship between crown diameter and height

revealed that the S-curve regression model established between these two variables was statistically significant ($F = 198.23$; $p<0.0001$).

The regression equation was:

$$CD = e^{(1.86-6.29/H)} \quad (3)$$

It was found that the coefficient of determination and the standard error of estimate were $R^2 = 0.52$ and $S_{y.x} = 0.25$, respectively. The regression coefficients (b_0, b_1) were also statistically significant ($p<0.0001$). Thus, it is seen that there is a strong positive, nonlinear relationship between crown diameter and height (Fig. 3). Because, height explained 51.86% of the variation observed in crown diameter.

DISCUSSION

It was determined that the regression models established between DBH, height and crown diameter variables of Lebanon cedars in the study area were statistically significant ($p<0.0001$). That the R^2 value is more than 0.50 in the models established indicates that there are strong relationships between these three variables[11]. The strongest relationship determined was the crown diameter-DBH relationship ($R^2 = 0.72$), followed by the height-DBH ($R^2 = 0.71$) and crown diameter-height ($R^2 = 0.52$) relationships, respectively. In Calabrian pine (*Pinus brutia* Ten.), it was reported that the strongest relationship was the height-DBH relationship ($R^2 = 0.82$), followed by the crown diameter-DBH ($R^2 = 0.74$) and crown diameter-height ($R^2 = 0.62$) relationships, respectively[13]. The crown diameter-height relationship was less strong than the other two relationships in both the present and previous[13] study.

The relationships between height and DBH were investigated in many studies[13-19]. In these studies carried out on various tree species, it was determined that there was a strong relationship between height and DBH and this relationship was described by various nonlinear regression models. Kalipsiz[7] stated that the relationship between height and DBH could be described by the second-degree polynomial model in even-aged and one-storied stands. This relationship was also described by the second-degree polynomial model in Calabrian pine by Demirci and Gul[15] and Avsar[13]. In the present study, the height-DBH relationship was described by the power model, a nonlinear model.

There are many studies investigating the relationships between crown diameter and DBH[13,14,20-23]. Francis[24] and Foli *et al.*[25] also investigated the crown

radius-DBH and crown diameter-bole diameter (3.96 m above ground) relationships, respectively. In these studies carried out on various tree species, it was reported that there was a strong relationship between crown diameter and DBH (bole diameter) or crown radius and DBH and this relationship was generally described by the simple linear model, nonlinear models were also used in some studies. In the present study, the crown diameter-DBH relationship was described by the power model as in the height-DBH relationship. Similarly, the crown diameter-DBH relationship was described by the power model by Bragg[23] for various tree species and by Avsar[13] for Calabrian pine.

On the other hand, Hasenauer[22] determined that the relationship between crown diameter and height was generally strong in various tree species and this relationship could be described by the simple linear model. Avsar[13] found that there was a strong relationship between crown diameter and height and this relationship could be described by the power model in Calabrian pine. In the present study, the crown diameter-height relationship was described by the S-curve model, a nonlinear model.

Consequently, it was concluded that heights and crown diameters could be estimated from DBH, of which measurement is easy, in the studies of ground-based forest inventory and stand structure determination to be made in pure and mixed stands of Lebanon cedar of the study area. The crown diameter-DBH relationship, which is stronger than the crown diameter-height relationship, should be used in the estimate of crown diameter. In addition, the height-DBH and crown diameter-DBH relationships can be described by the power model ($Y = b_oX^{b1}$), while the crown diameter-height relationship can be described by the S-curve model ($Y = e^{bo+b1/X}$) in Lebanon cedars of the study area.

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