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Response to Different Thinning Intensity in Calabrian Pine (*Pinus Brutia* Ten.) Plantations in Turkey

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ABSTRACT

Calabrian pine (*Pinus brutia* Ten.) is one of the main species, under commercial plantation in western of Turkey. These plantations are cover an area of 0.707 million ha. This paper presents the growth response of 25 yr old Calabrian pine plantation to thinnings of different intensities in Burdur in western of Turkey. The thinning intensity was measured by using the residual basal area (%) as parameter. In spring of 1990, 1995 and 2000, three treatments were tested; unthinned, moderately thinned and heavily thinned with respectively 0%, 15-20% and 35-40% of basal area removed. The statistical design of the experiment was a randomized incomplete block with two blocks and three treatments. In 2005, the sample trees data were collected from each of three different thinning intensities: unthinned (n=372), moderately thinned (n=243) and heavily thinned (n=214). Variables such as diameter at breast height (dbh), tree height and tree volume were measured. Growth rate ratios of dbh in moderately thinned and heavily thinned stands were 1.07 and 1.30, respectively. Tree height and tree volume growth rates were 0.97 and 1.06 for moderately thinned and 1.23 and 1.64 heavy thinned plots, respectively. The largest values for the mean tree were observed with the heaviest thinning treatment. This analysis indicated that heavily thinned drastically affects the dbh, tree height and tree volume growth rate. Growth rate interpretations were supported by statistical multivariate analysis of variance using Wilk's ($\wedge$) and Hotelling's T^2 tests. The Wilk's test was carried out on mean vector of 3 variables in three study populations. The null-hypothesis (F_c =31.679> F_t=3.743) was rejected at the 0.001 level of significance. Growth rate interpretations were supported by analysis of variance using Duncan's test of range multiple. Thus, the results indicated that heavily thinned was significantly influenced the rapid growth rates of planted Calabrian pine stands.

Key Words: Calabrian pine (*Pinus brutia* Ten.), multivariate analysis, growth rate, thinning.

INTRODUCTION

Calabrian pine (*Pinus brutia* Ten.) is one the main species in commercial plantations as a resource of the short- rotation forestry in western Turkey. In these plantations, thinning of populations is often carried out as an operational practice of plantation management. The general propose of thinning is to enhance the growing space for production of maximum volume and stand quality. Thinning was also found to be necessary to reduce the competition for sunlight, soil water and nutrients, as these requirements become critical as the trees get larger. If the stand remains unthinned, the growth rate slows down, stagnation develops, and many dead trees eventually occur. Calabrian pine is reported to be the most commercially important forest species ever in the western Turkey. The species responds well to silvicultural treatments and can be managed as either even- aged or can be regenerated artificially and managed in plantations. A variety of approaches exists for thinning stands. These approaches vary in the method, intensity and timing of thinning and can substantially differ in costs, feasibility and potential responses [1].

The thinning method can be defined as a specific strategy of selecting trees for removal. The selective method is one in which tree are removal according to specifications of size, spacing or quality. Selective methods generally remove trees lower growth potential, such as smaller, diseased or overtopped ones.

There has been research interest in Calabrian pine plantations since 1991 [2,3] as observed in the recent literature. These plantations are cover an area of 0.707 million ha. The main advantages of these forests are wood production and various intangible social benefits that are frequently termed the forest influence. The main objective of this study was to carry out a statistical analysis of thinning intensity effects on planted Calabrian pine in western Turkey.

MATERIALS AND METHODS

Study area

The study was conducted in an even- aged, undisturbed Calabrian pine plantation in Compartment #87 of Burdur (Taurus mountain range of Turkey) Turkish Forestry Ministry, located in the western Turkey (37° 32' 16'' N latitude, 30° 45' 59'' E longitude). The plantation with 3 m x 1.5 m spacing was established in 1980 with an area of 60 ha. Its exposure is south- east, the altitude is 354 m a.s.l. and the mean slope is 15%. The meteorological station at Isparta, located at 997 m a.s.l., 40 km from the study area, recorded average annual total precipitation of 477 mm, with a maximum in summer and a minimum in winter and mean annual temperature of 16.0 ºC for the period 1940-2007. According to Çepel [4], while the research area is in an arid (must be semi-humid) zone water deficiency is observed during the June-August period of the year. The bedrock is limestone and soils are rather shallow, sandy-loam with a high stone content. In 2005, top height is 15.672 m; site index (SI), medium site quality, 18 m of the top height at 30 years [2].

Experiment design

The design of experiment was random incomplete blocks, with two blocks and three treatments. The plot size was 30m x 30 m (900 m^2) and buffers were 10 m wide. Treatments applied consisted in comparing two degrees of thinning intensity with unthinned (control). The thinning experiment was carried out during the winter of 1990. This trial consists of six plots in two blocks. Each block contains three plots. Three treatments were tested: control (0% of basal area removal), in the moderately thinning process, 15-20% of stand basal area was removed, while in the heavily thinning process about 35-40% of stand basal area was removed. Thinned trees were felled to waste using chainsaws. The thinning type was from low, eliminating small trees, trees with badly shaped crowns, twisted stems, diseased trees, etc. Unthinned (T_0), moderately thinned (T_1) and heavily thinned stands (T_2) were selected as the 3 statistical populations for this study. Thinning was carried out in 1990, 1995 and 2000, respectively, and this study was carried out in 2005.

Measurements and data analysis

At the beginning of the experiment, all the standing stems were included in the inventory and all stems were permanently numbered. In each plot, the following measurements were made: diameter at breast height (dbh) and height for all trees.

Within the plot, each tree was mapped and stand characteristics associated with tree growth and stand structure were measured immediately before and annually after the thinning from 1990 to 2005.

For data gathering all trees in the six plots are identified by a number and marked at a height of 1.3 m with an upside down T-shape in order to ensure that diameters are always measured at the same point. This greatly increased the accuracy of stem diameter increments determined from repeated measurements. In 2005, data were collected from Different variables such as dbh, tree height and volume of each tree were measured.

Inventories were carried out 5 years, (from 1990 to 2005) and the following data collected 829 trees from six Calabrian pine plots: diameter at breast height of all trees to the nearest millimeter, heights of all trees in each plot in order to estimate average height (hg) to the nearest 0.25 m.

Total stem outside bark volume calculations for trees were made using the double entry volume table of Usta [2]. All calculations were then averaged for plots contained in each thinning category. These calculations were performed before treatment, immediately after treatment and the fifth years after treatment only. Basal area calculations were made using the diameter measurements for each tree and these calculations were summarized for each plot. The mean annual growth observations were calculated by dividing the growth by the length of the growth interval (age). In addition, computed for each individual tree and some individual tree characteristics (dbh, mean height and mean volume) were given in Table 1.

Table 1. Statistical analysis of the measured variables (p= 3) of Calabrian pine

	T_0		T_1		T_2	
Variable	$\bar{X}_{1i}$	± SE	$\bar{X}_{2i}$	± SE	$\bar{X}_{3i}$	± SE
dbh (cm)	12.52	0.29	13.45	0.36	16.24	0.38
height (m)	11.60	0.17	11.29	0.21	14.32	0.22
volume (dm^3)	89.07	4.97	94.65	6.15	146.02	6.55

Statistical analysis

Multivariate Ho telling's T^2 test : Foresters are often interested in determining the hypothetical equality of measured variables of populations, classes, ecological groups and species [5,6]. Multivariate Hotelling's T^2 test is one of the methods used for the multivariate analysis of variance (MANOVA). This statistical method is used to test the equality of 2 population (k=2) mean vectors with p- measured variables. This test was applied for pair- wise testing of the 3 study areas of unthinned, moderately thinned and heavily thinned stands with p=3 in this study. Towards this goal, the following equations were used:

$$T^2 = \frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2} (X^{(1)} - X^{(2)}) / W^{-1} (X^{(1)} - X^{(2)}),$$

computed F: $F_c = \frac{(n_1 + n_2 - p - 1)}{(n_1 + n_2 - 2)\, p} T^2$

and tabulated F: $F_t = F_{\alpha(t), P, n_1, n_2 - p - 1}$;

where p is the number of measured variables in each study area or population, n_1 is the sample size in population 1, n_2 is the sample size in population 2, N is n_1+n_2 (the total sample), k is 2 (no. of population), W^{-1} is the inverse of the within group SSCP matrix, F_c is the calculated F value, F_t is the tabulated F- value, $\overline{X}^{(1)}$ is the mean vector of the measured variables in population 1, and $\overline{X}^{(2)}$ is the mean vector of the measured variables in population 2.

Multivariate Wi lk's t est (∧): Wilk's test is another technique of MANOVA. This procedure is used to test the equality of mean vectors of measured variables with more than 2 populations. In this study, Wilk's test was initially used to determine if the mean vector of the measured variables of the 3 study areas of Calabrian pine were equal or not. If the null hypothesis (H_0) was rejected, it would be appropriate to attempt further analysis (pair- wise testing) between study populations. The Wilk's likelihood- ratio criterion or Wilk's lambda (∧) was used as the F- test criterion:

$$\Lambda = \frac{|W|}{|T|} = \frac{\det.W \text{ matrix}}{\det.T \text{ matrix}},$$

Computed F:

$$F_c = \frac{1 - \Lambda^{1/S}}{\Lambda^{1/S}} \frac{ms - p\,(k-1)/2 + 1}{p\,(k-1)}$$

$$s = \sqrt{\frac{P^2 (k-1)^2 - 4}{P^2 (k-1) - 5}},$$

$$m = N - 1 - (P + k)/2,$$

Tabulated F: $= F_{\alpha(t), p(k-1), ms - p(k-1)/2 + 1;}$;

where all terms are as defined above.

Multivariate normality tests: The multivariate tests of equality of the population centroids assume that the population variance-covariance matrices are equal. It is robust and desirable to be able to test the null hypothesis of equality of Hotelling's T^2 test and Wilk's likelihood-ratio test for equality of the population centroids. A multivariate generalization of Bartlett's test of homogeneity of k population variances is available for this purpose.

The null hypothesis for the present experiment with unthinned, moderately thinned and heavily thinned populations was as follows:

$$H_0 : \Sigma_1 = \Sigma_2 = \Sigma_3$$

against the alternative that not all of the population variance-covariance matrices were equal where Σ_1 is the variance-covariance matrix of unthinned stands, Σ_2 is the variance- covariance matrix of moderately thinned stands, Σ_3 is the variance- covariance matrix of heavily thinned stands and H_0 is the null hypothesis.

RESULTS

Statistical analysis of the measured variables

The statistical parameters $\overline{X}$ and SE were computed for the measured variables (p=3) of the 3 study populations and the results are given in Table 1 where T_0 is unthinned stands, T_1 is moderately thinned stands, T_2 is heavily thinned stands, $\overline{X}_{1i}$ is the mean of variable i population 1, $\overline{X}_{2i}$ is the mean of variable i in population 2, $\overline{X}_{3i}$ is the mean of variable i in population 3, i= 1-3 and SE is the standard error.

The statistical univariate analysis of variance (ANOVA) was carried out on each of the 3 measured variables in the 3 populations. The results in Table 2 indicate that the variables of dbh, tree height and tree volume significantly differed. Therefore, at least 1 of the variables differed from the others, it is appropriate to consider that variables in a pair- wise manner using Duncan's test and results are given in Table 2.

Table 2. ANOVA test on each measured variables (p= 3) of the 3 populations (k= 3) and Duncan's (pair- wise) test. Means followed by the same letter are not significantly different at the 0.05 level of probability.

Variable	$\overline{X}_{1i}$	$\overline{X}_{2i}$	$\overline{X}_{3i}$	F-value	Pr>F
dbh (cm)	12.52^a	13.45^a	16.24^b	30.85	0.00***
height (m)	11.60^a	11.29^a	14.32^b	63.83	0.00***
volume (dm^3)	89.07^a	94.65^a	146.02^b	26.14	0.00***

Multivariate analysis

The equality of the variance- covariance matrices of the 3 study populations was considered. The computed Chi-square (χ^2=31.093) was greater than the Chi-square distribution with 30 degrees of freedom (18.493). The null hypothesis of equality of the variance- covariance matrices of populations was rejected at the 0.05 level of significance. Therefore, at least 1 of the variance-covariance matrices differed from the others.

Wilk's test is potentially more useful for comparing the mean measured variable vectors, X_1, when more than 2 populations classes, ecological groups and species are involved (k≥ 3).

Wilk's test was carried out on 3 variables (p= 3), namely, dbh, tree height and tree volume mean vectors of the 3 study populations (T_0, T_1 and T_2). The null hypothesis (H_0) is as follows:

$$H_0 : \overline{X}^{(T_0)} = \overline{X}^{(T_1)} = \overline{X}^{(T_2)}$$

$$= \begin{bmatrix} 12.52 \\ 11.60 \\ 89.07 \end{bmatrix} = \begin{bmatrix} 13.45 \\ 11.29 \\ 94.65 \end{bmatrix} = \begin{bmatrix} 16.24 \\ 14.32 \\ 146.02 \end{bmatrix};$$

where $\overline{X}_0$, $\overline{X}_1$, $\overline{X}_2$ are mean vectors of the measured variables in the unthinned, moderately thinned and heavily thinned stands, respectively. The statistical Wilk's test ($\wedge$) results are given in Table 3. The hypothesis of equality of the mean vector of the measured variables of populations was rejected. Therefore, at least 1 of the mean vector measured variables differed from the others. It is appropriate to consider the variables in a pair-wise manner in the multivariate Hotelling's T^2 test. The null hypothesis and results are given in Table 4.

Table 3. Statistical Wilk's test (Λ) results on the 3 study populations

Statistics	Value	F-value	Hypothesis df.	Error df.	Pr>F
Wilk's lambda (Λ)	0.804	31.679	6	1648	0.001
Pillai's trace	0.202	30.940	6	1650	0.001
Hotelling Lawley trace	0.236	32.418	6	1646	0.001
Roy's greatest root	0.198	54.371	3	825	0.001

Table 4. Results of pair- wise test using multivariate Hotelling's T^2 test

Ho		Value	F-value	Hypothesis df.	Error df.	Pr>F
$\overline{X}^{(T_0)} = \overline{X}^{(T_1)}$	H. Lawley	0.110	22.418	3	611	0.001
$\overline{X}^{(T_0)} = \overline{X}^{(T_2)}$	H. Lawley	0.214	41.546	3	582	0.001
$\overline{X}^{(T_1)} = \overline{X}^{(T_2)}$	H. Lawley	0.269	40.589	3	453	0.001

Growth and yields of planted Calabrian pine

The mean annual increments (MAIs) of the 3 measured variables were analyzed as the growth and yield of the Calabrian pine plantations and results are given in Table 5. MAI of dbh, tree height and tree volume growth rates were 1.08, 0.98 and 1.06 for moderately thinned and 1.30, 1.24 and 1.64 heavily thinned plots, respectively.

Table 5. Mean annual increment (MAI) of 25-yr-old Calabrian pine

	Unthinned		Moderately thinned		Heavily thinned	
Variable	$\overline{X}_i$	MAI	$\overline{X}_i$	MAI	$\overline{X}_i$	MAI
dbh (cm)	12.52	0.50	13.45	0.54	16.24	0.65
height (m)	11.60	0.46	11.29	0.45	14.32	0.57
volume (dm^3)	89.07	3.56	94.65	3.79	146.02	5.84

DISCUSSION

Different growth rates of Calabrian pine were analyzed in this study. Calabrian pine's dbh growth rates in 25-yr old plantations (Tables 1 and 5) were approximately 0.50, 0.54 and 0.65 cm/yr in T_0, T_1 and T_2, respectively. The ratio of the growth rate in the moderately thinned and heavily thinned to unthinned stands was φ=0.54/0.50=1.08 and φ=0.65/0.50=1.30, respectively. The corresponding dbh growth rates in the 15 yr after thinning increased to 8% and 30%, respectively. The dbh growth rate of the heavily thinned stands drastically increased by an order of 35- 40% of the basal area of stand. The height growth rates were about 0.46, 0.45 and 0.57 m/yr in the 3 statistical populations. The ratios of height growth of the moderately thinned and heavily thinned to the unthinned stand were 0.98 and 1.24, respectively. The growth rate ratios of tree volume in these stands were φ=3.79/3.56=1.06 and φ=5.84/3.56=1.64. These results prove that heavy thinning considerably affected the growth rate of the tree volume. The results of this study also indicate that heavy thinning increased the growth rate of stands by approximately (30+ 24+ 64)/3 = 39.33%.

Silvicultural thinning effects were supported by statistical MANOVA techniques using Wilk's ($\wedge$) and Hotelling's T^2 tests on silvicultural thinning data. Since F_c=31.679> F_t=3.743, the null hypothesis (H_0) was rejected at the 0.001 level of significance. Therefore, at least 1 of the mean vectors was found to differ from the others (Table 3). Therefore, it is appropriate to conduct pair- wise tests using the multivariate Hotelling's T^2 test. The null hypothesis (H_0) between unthinned and moderately thinned stands (Table 4) was (F_c=22.418> F_t=3.743) which statistically differs. The null hypothesis (H_0) between the unthinned and heavily thinned stands (F_c=41.546> F_t=3.743) was rejected at the 0.001 level of significance. In statistical terms, 15- 20% moderate thinning was effective at increasing growth rates of planted Calabrian pine stands when using the 3 measured variables. But heavy thinning at 35- 40% of stand basal area also had highly significant effects.

Calabrian pine responded to thinning differently according to tree size. In absolute terms, growth of large stems was stimulated by thinning more than that of smaller trees. Large trees probably have a greater capacity for resources acquisition, and are thus more able to take advantage of the increase of resources availability that takes place after thinning, and to eventually use these resources for growth [7]. In these cited studies size and differences between diameter classes were statistically significant for the study period. More specifically, a higher uptake of water and nutrients from a larger root system are probably involved in this response.

Calabrian pine showed a positive growth response to thinning, as evidenced by enhanced growth rates for dbh, tree height and tree volume. We found that mean annual increment was significant for mean diameter, tree height and volume among three thinning levels (Table 1 and 5).

The same trends occurred for periodic annual increment height; trees accelerated in height growth more in the heavily thinned plots than trees in the unthinned and moderately thinned stands, as did annual growth in tree volume.

Similar results were found by Eler [8] and Usta [2] in Lebanon cedar (*Cedrus libani* A. Rich.) and Calabrian pine stand in western Turkey. The mean diameter increment during 3 yr period was 6.3 mm/yr [9]. Our results for the heavily thinned plots are very similar 6.5 mm/yr. However, in our study, tree height and tree volume appeared affected by thinning intensity. Height and volume growth increase was especially observed on the largest trees.

Among the treatments evaluated in this study, moderately thinning produced the most desirable combination of individual tree diameter growth and tree height growth and volume growth. Rates of increase in tree height and tree volume growth are greatest in the most heavily thinned stands. Reducing basal area proves to be effective in increasing the growth rates of Calabrian pine, however, caution should be taken not to open the site too much. These results expand and substantiate the work of Usta [9] in which he concluded Calabrian pine diameter growth increased after thinning. Consistent with these results, similar work by Eler [8] and Eler and Keskin [10] with Lebanon cedar and Calabrian pine showed increases no significant in tree growth (dbh, height and volume) and stand growth after thinning.

Low thinning naturally increases mean tree size in the main crop, the more so the more intensive the thinning: on the one hand crop growth becomes concentrated on fewer individuals, while on the other the extraction of smaller trees brings up the mean (technical growth). The first is one of the aims of thinning, and in order to evaluate it is necessary to analyze current increment in diameter, a true indicator of mean tree growth.

Tree volume increment is greater with heavily thinned plot than in the unthinned plot and with moderately thinned, and behaves differently than increment in volume [11]. The results indicate differences in mean height increment between treatments. Among the many aims of thinning, one of the most important is that of producing larger trees in order to increase the stand's yield quality. Table 2 and 3 shows the greater increment in diameter of the average tree in the most intensive thinning regime. Though seemingly trivial, this fact is of great practical importance from the silvicultural point of view, since it enables the entire productive capacity of the site to be concentrated on the production of trees of greater girth and higher quality, already selected for their better technical characteristics. If, as is often the case, the final rotation (age=50) of Calabrian pine is determined by technical criteria, intensive thinning helps to reduce the length of rotation by 10-15 years in comparison with barely treated or moderately thinned stands, particularly in high quality sites.

CONCLUSION

The results of this study indicate that heavy thinning at 35-40% had a highly significant effect on the dbh, tree height and tree volume growth rates of planted Calabraian pine. Therefore, thinning is necessary to avoid growth rate slow down and the death of too many trees. Furthermore, the investment required to obtain these growth rates are economically feasible Multivariate Wilk's ($\wedge$) and Hotelling's T^2 tests were applied to support the growth rate analysis in this study. These tests are strong and robust statistical techniques to hypothesize the equality of measured variables of different forest populations. In general, the current growth rates of planted loblolly pine are satisfactory in northern Iran after thinning operations were carried out.

In the moderately thinned plots, there is a slight fall in increment by basal area and volume with respect to the unthinned plots. However, this regime thus exceeds the density limit below which there is loss of yield by volume. Acceptable basal area reduction is compensated by the positive effect of intensive low thinning on dbh, resulting in larger size timber. This regime also produces noticeable improvement in the vigour of the stand and its resistance to abiotic damage. In middle to high quality sites, we propose an early initial age and heavy low thinnings.

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