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Growth response of Lebanon cedar (*Cedrus libani*) plantations to thinning intensity in Western Turkey

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Abstract: *This paper presents the growth response of 25 yr old Lebanon cedar (Cedrus libani A. Rich.) plantation to thinnings of different intensities in Isparta in western Turkey. The thinning intensity was measured by using the residual basal area (%) as parameter. In spring of 2005, three treatments were tested; light, moderate and heavy thinning with respectively 10, 25 and 35% of basal area removed. The statistical design of the experiment was a randomized incomplete block with two blocks and three treatments. Variables such as diameter at breast height (diameter) and height were measured. Growth rate ratios of diameter in moderately thinned and heavily thinned stands were 1.02 and 1.03, respectively. Basal area growth rates in moderately thinned and heavily thinned plots were 0.93 and 1.05, respectively. The largest values for the mean tree were observed with the heaviest thinning treatment. Absolute diameter increment was positively correlated with initial diameter in all plots. Relative diameter growth was negatively correlated with initial diameter. Growth rate interpretations were supported by analysis of variance using Duncan's test of range multiple. The results obtained show significant differences between treatments for tree height growth, for the two inventories carried out (2005, 2008). However, diameter, basal area and volume were no found between treatments for tree.*

Key words: *Lebanon cedar, Stand growth, Thinning intensity, Tree growth*
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Introduction

Lebanon cedar (*Cedrus libani* A. Rich.) is one the main species in commercial plantations as a resource of the short-rotation forestry in western Turkey. It also provides a variety of end uses such as poles, pulpwood and saw logs. Presently there are 129,000 ha of Lebanon cedar plantations and because of its productive, ecological and protective roles (Boydak, 2003).

The silvicultural regime of this species (determined by its ecological and technical characteristics) has to allow for the optimization of social needs while avoiding putting stand survival and stability at risk. As a species of intolerant temperament, Lebanon cedar plantation is fast growing in its early stages, and completes its current volume increment at 20-30 years of age, depending on site quality (Evcimen, 1963).

On plantations, the effects of juvenile spacing do not last long because of the competition of the roots and crowns of the younger trees beginning at the onset of crown closure. Crowded trees have to compete for light, water and nutrients, resulting in slower growth or even death of some trees (Oliver and Larson, 1996; Misir *et al*., 2007). Moreover, some weak trees also become vulnerable to insect and disease. To avoid overcrowding and competition, trees are often thinned to increase the growing space available to the remaining trees. Enhancing growth on final crop trees by removing other trees has long been recognized and practiced in commercial thinning.

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. As a result, tree growth is usually increased after thinning. Growth responses to thinning have been modeled to provide increased knowledge to be applied in forestry (Hamilton, 1981; Hibbs and Bently, 1984; Piennar and Shiver, 1984; Whyte and Wollons, 1990; Uner *et al.,* 2009). Thinning effects on tree growth are usually studied in terms of tree diameter, height, volume growth and canopy expansions of the remaining trees have been studied as well. Thinning in plantation has improved the diameter growth of individual trees. Diameter growth response of residual trees increases with increasing intensity of thinning. However, very thinning may lower stand density to the point where basal area growth and volume growth of the residual stand are greatly reduced and recovery of the stand to a fully stocked condition is much delayed. Most research on thinnings of this species has been carried out in Central Europe, where there have been thinning experiments since the beginnings of the 20th century (Assmann, 1970). In Turkey, the general application of thinning in variety pine stands began later, well into century. Approximately 7.18% of the plantation area was covered by Lebanon cedar, therefore, its silviculture practice is of great importance. Forest managers need practical guidelines on thinning. Unfortunately, individual tree and stand level response to thinning in Lebanon cedar plantations are largely unknown, and few guidelines currently exist for successful management of these plantations. The purpose of this study was to investigate third year response to alternative thinning regimes on the growth and stand structure in a 25 year old Lebanon cedar plantation in Isparta.

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Materials and Methods

Study area: The study was conducted in an even-aged, undisturbed Lebanon cedar plantation in Compartment 23 of Isparta (Taurus mountain range of Turkey) Turkish Forestry Ministry, located in the western Turkey (37° 40' N latitude, 30° 33' E longitude). The plantation with 2.5 m x 2.5 m spacing was established in 1980 with an area of 78 ha. Its exposure is south-east, the altitude is 1540 masl and the mean slope is 15%. The meteorological station at Isparta, located at 997 masl, 40 km from the study area, recorded precipitation and temperature values for the period 1940-2007. These values were transformed for study area. Average annual total precipitation and mean annual temperature are 770 mm and 10.0°C, respectively. According to Cepel (1978), 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 soil is rather shallow, sandy- loam with a high stone content. In spring of 2005, the main silvicultural characteristics of after thinning are: mean density, 803 trees per hectare; quadratic mean diameter (Dg), 16.473 cm; mean height (Hg), 9.198 m; mean basal area (BA), 0.021 m^2, mean volume (V), 0.096 m^3, top height (Ho), 10.672 m; site index (SI), medium site quality, 19 m of the top height at 100 years (Evcimen, 1963).

Measurements of growth and thinning: The design of experiment was random incomplete blocks, with two blocks and three treatments. The plot size was 15 m x 15 m (225 m^2) and buffers were 10 m wide. Treatments applied consisted in comparing two degrees of thinning intensity with control. The thinning experiment was carried out during the spring of 2005. This trial consists of eight plots in two blocks. Each block contains four plots. Three treatments were tested: light thinning (10% of basal area removal), moderate thinning (25%) and heavy thinning (35%). This trial consists of light, moderate and heavy thinning plots 2, 3 and 3, respectively.

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 (diameter) 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 in 2005-2008.

For data gathering all trees in the eight 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. 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.* Inventories were carried out 3 years, (2005, 2008) and the following data collected: 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.

The following characters were used for further comparisons and analyses: diameter, height, volume and remaining basal area. The relative values were calculated for each plot. Basal area calculations were made using the diameter measurements for each tree and these calculations were summarized for each plot. Total stem outside bark volume calculations for trees were made using the double entry volume table of Evcimen 1963. All calculations were then averaged for plots contained in each thinning category. These calculations were performed before treatment, immediately after treatment and the third years after treatment only. Quadratic mean diameter was calculated from basal area. We treated plots as our experimental units. Crown classes were assessed on all trees within each measurement plot. In each plot, individual tree BA was calculated using the diameters at 2005 and 2008. This was converted to stand BA ($m^2 ha^{-1}$) for the treatments.

Statistical analysis: Effects of thinning on stem diameter growth rates were tested by an analysis of covariance of individual tree growth rates using initial diameter as a covariate. The model used in the analysis of variance (ANOVA) was the following (Zar, 1999):

$$Y_i = \mu + T_i + \varepsilon_i \qquad (1)$$

Where Y_i is variable analyzed, m is the overall mean effect, T_i is the effect of thinning and ε_i are assumed independently, with random distribution. Duncan's test of multiple range was used to analyze the differences among treatments for the main stand variables (95% of significance level).

Simple analysis of variance was used to detect differences among treatments in trees growth (quadratic mean diameter, height, basal area and volume) and stand growth (diameter, height, basal area and volume). To guard against the effect of autocorrelation in the dependent variable(s), Greenhouse-Geisser and Hunyh-Feldt epsilon estimates were used to correct the P-values. In no case did these corrections affect the result of the analyses and are not reported here. Analyses were performed with the SPSS Ver. 15.0 statistical package.

To gain a better understanding of the effects of the thinning treatments on those trees most likely to become final crop trees, we assessed diameter and volume responses of the dominant and codominant trees only. However, the mean annual increment of diameter, height, basal area and volume was calculated the period 3 yr after thinning. The ratio of the growth rate in the moderate thinned and heavy thinned to lightly thinned plots were analyzed.

Results and Discussion

Effects of thinning intensity on tree parameters: In studying the effect of thinning on the characteristics of the average tree, we have analyzed mean diameter, mean height and mean tree volume. To these variables, we have added the basal area and volume, in order to show other aspects of stand structure. The characteristics of the Lebanon cedar plantation immediately before and after thinning are presented in Table 1.

Diameter growth: Mean absolute stem diameter increment during the period 3 yr after thinning was 10.29 mm yr^{-1} (±0.03 SE, n=31) for lightly thinned plots, 10.67 mm yr^{-1} (±0.04 SE, n=45) for moderately thinned plots and 10.75 mm yr^{-1} (±0.04 SE, n=48) for heavily thinned plots (Table 2). An analysis of variance was used to evaluate significant differences due to treatment (light, moderate and heavy thinning). Treatments had a no significant effect ($F_{2;121}$= 0.358, p=0.700). Diameter increments were higher for heavily thinned than for lightly and moderately thinned plots. Heavily and moderately thinned plot increased mean diameter increment by 104% compared to lightly thinned plots during the 3 yr period. Absolute increments (mm yr^{-1}) of the diameter of individual trees during the period 3 yr after thinning were only slightly and positive correlated significantly with initial diameter, all thinned plots. On average, the large trees (diameter >15 cm) had absolute growth rates higher than smaller ones (diameter <15 cm) by 105%. A covariance analysis was performed to test whether thinning still had a significant effect on diameter growth after taking account of the effect of initial diameter and whether there was a significant interaction between thinning and initial diameter. The model included initial diameter as a covariant. This full model gave a no significant effect of initial diameter ($F_{1,118}$= 0.560, p= 0.456) and interaction ($F_{2;118}$= 0.347, p= 0.707). This means that the effect of initial diameter is no different for the three thinning treatments. Absolute increments (mm yr^{-1}) in diameter of individual tree during the period 3 yr after thinning were no significantly and positively correlated with initial diameter, in light thinning, moderate thinning and heavy thinning plots (p=0.468, r=0.135, p=0.841, r=0.031 and p=0.371, r=0.132, respectively).

The effect of initial diameter on growth can also be studied through the relative diameter growth (rdg) for each tree, defined as the percentage of absolute individual diameter increment in a given period divided by the diameter at beginning of the period:

$$rdg21 = \frac{dg2 - dg1}{dg1} x\ 100 \qquad (2)$$

Mean relative diameter increments (rDg) during the period 3 yr after thinning were 6.526, 6.819 and 6.504% in lightly thinned, moderately thinned and heavily thinned plots, respectively (Table 2). No significant differences in mean relative diameter increments were found in the analyses of variance between treatments, showing a similar behavior to absolute increment ($F_{2;121}$= 0.305, p= 0.737).

As opposed to absolute diameter increments, relative diameter growth rates during the period 3 yr after thinning were weakly but negatively and significantly correlated with initial diameter (p<0.001, r= -0.802 for lightly thinned plots, p<0.001, r= -0.570 for moderately thinned plots and p<0.001, r= -0.667 for heavily thinned plots). The ANCOVA gave significant effects of initial diameter ($F_{1;118}$=92.656, p<0.001). Thus, large diameter trees showed on average lower relative growth rates than smaller ones.

Height growth: Height development was generally similar between treatments during the study period. Here the tree height of lightly thinned and heavily thinned developed significantly more slowly than the remaining trees on the moderately thinned plots. An analysis of variance was used to evaluate significant differences those due to treatment in height growth too. There were no differences in height growth between treatments ($F_{2;121}$=2.983, p=0.045). Average annual height growth averaged 33.92 cm, 38.80 cm and 29.17 cm in the lightly thinned, moderately thinned and heavily thinned plots, respectively (Table 2). The same results were obtained with a covariance analysis considering the initial height of the tree as covariant. The ANCOVA gave significant effects of initial height ($F_{1;118}$=9.370, p=0.003). Thus, high height trees showed on average lower relative growth rates than shorter ones.

Basal area growth: An analysis of variance was used to evaluate significant differences those due to treatment in basal area growth too. There were no differences in basal area growth between treatments ($F_{2;121}$=0.984, p=0.377). Average annual basal area growth averaged 26.110, 26.295 and 28.208 cm^2 in the lightly thinned, moderately thinned and heavily thinned plots, respectively (Table 2). The same results were obtained with a covariance analysis considering the initial height of the tree as covariant. The ANCOVA gave significant effects of initial basal area ($F_{1;118}$=72.176, p<0.001). Thus, large trees showed on average higher relative growth rates than shorter ones.

Volume growth: An analysis of variance was used to evaluate significant differences those due to treatment in volume growth too. There were no differences in volume growth between treatments ($F_{2;121}$=0.700, p=0.498). Average annual basal area growth averaged 15.905 dm^3, 17.310 dm^3 and 17.486 dm^3 in the lightly thinned, moderately thinned and heavily thinned plots, respectively (Table 2). The same results were obtained with a covariance analysis considering the initial volume of the tree as covariant. The ANCOVA gave significant effects of initial volume ($F_{1;118}$=57.192, p<0.001). Thus, large trees showed on average higher relative growth rates than shorter ones.

Effects of thinning intensity on stand structure: The main stand variables per plot at the beginning of the experiment and the evolution of the means per treatment of the main stand variables after thinning and of total stand production is presented in Tables 3. Before thinnings there are significant differences between treatments only for mean tree size but not for the other variables such as stand density, basal area or height. The analysis of variance for each inventory shows no statistical differences among treatments for mean diameter, current and relative increment of Dg (IcDg and rdg respectively) and mean volume per tree, with higher growth in the heaviest thinning (Table 3).

Diameter growth: We were unable to detect any statistical differences among the treatments in quadratic mean diameter during the 3 yr period following thinning. However, analysis of variance did reveal a significant treatment term, indicating that the rate of change in quadratic mean diameter differed significantly among the three treatments. Quadratic mean diameter of the heavily thinned plot is increasing at a more rapid pace than in either the lightly thinned or the moderately thinned plots. Heavy thinning increased quadratic mean diameter by 3.224 to 20.459 cm in the 3 yr following thinning; increases in quadratic mean diameter of 3.137 and 3.204 cm were observed in the lightly thinned and moderately thinned plots, respectively, over the same period (Table 3). Because the

Table - 1: Stand variables per plot at the beginning of the treatments in the spring of 2005

Treatments	Stand before thinning					Stand removed		
	N	Dg	Hg	G	V	N	G	V
Light	622	13.56	7.20	19.58	75.26	44	0.78	2.39
Light	1066	17.78	8.37	27.63	122.28	133	2.90	12.81
Moderate	978	13.06	6.83	16.04	58.78	267	2.84	3.58
Moderate	933	15.65	7.86	18.62	77.81	222	4.13	16.68
Moderate	978	16.84	8.54	23.46	104.50	222	5.24	23.28
Heavy	1155	15.46	7.71	26.95	100.76	311	6.65	11.58
Heavy	1245	16.67	8.31	27.82	121.93	356	7.93	34.53
Heavy	1022	16.33	8.31	22.34	99.57	311	6.36	27.61

N: stem number per hectare (stems ha^{-1}), Dg: quadratic mean diameter (cm), Hg: Mean height (m), G = Basal area ($m^2 ha^{-1}$), V = Total stem volume (m^3 ha^{-1})

Table - 2: Growth response of the Lebanon cedar trees 3 yr after thinning

Treatments	Quadratic mean diameter ($mmyr^{-1}$)	Mean height ($cmyr^{-1}$)	Mean basal area (cm^2yr^{-1})	Mean volume (dm^3yr^{-1})	n
Light	10.29^{a}	33.92^{ab}	26.11^{a}	15.91^{a}	31
Moderate	10.67^{a}	38.80^{b}	26.30^{a}	17.31^{a}	45
Heavy	10.75^{a}	29.17^{a}	28.21^{a}	17.49^{a}	48

Means followed by the same letter are not significantly different at the 0.05 level of probability

Table - 3: Growth response of the Lebanon cedar plots 3 yr after thinning

Treatments	Quadratic mean diameter ($mmyr^{-1}$)	Mean height ($cmyr^{-1}$)	Mean basal area (cm^2yr^{-1})	Mean volume (dm^3yr^{-1})	n
Light	10.50^{a}	34.00^{a}	1.89^{a}	11.73^{a}	2
Moderate	10.70^{a}	38.80^{a}	1.75^{a}	11.54^{a}	3
Heavy	10.80^{a}	29.20^{a}	1.98^{a}	12.43^{a}	3

Means followed by the same letter are not significantly different at the 0.05 level of probability

rate at which quadratic mean diameter is changing differed among treatments, we expect to find significant differences in quadratic mean diameter between the thinned stands in the near future. On the other hand, residual trees in the lightly thinned plot grew an average of 1.050 cm in 3 yr, whereas residual trees in the heavily thinned plot grew an average of 1.080 cm 3 yr. Three year cumulative diameter growth did not differ significantly between the three thinning treatments ($F_{2,5}$= 0.103, p=0.904).

The technical effect on stand parameter produced by thinning is clearly shown by comparing the mean tree values before and after thinning, while the response of tree to the thinning treatments is shown through the evolution of the variables over time. At the ending of the experiment, the smallest mean tree was found in the light thinning, the mean size in dbh and volume of trees increasing significantly with the thinning intensity (Table 3). Because low thinning was used to remove the smaller, less vigorous trees, primarily from the lower crown classes, quadratic mean diameter in the thinned plots was higher immediately after thinning than in those same plots before thinning. Quadratic mean diameter in the lightly thinned plots increased from 15.67 to 16.71 cm immediately following thinning, whereas quadratic mean diameter in the heavily thinned plots increased from 16.15 to 17.24 cm after thinning. Quadratic mean diameter in the heavily thinned plots was initially high (17.24 cm), such that no significant differences in quadratic mean diameter were detected among the three treatments after thinning. Although the same sample of trees was used to measure height for each inventory, we did not find relation between growth height and treatments. The ratio of the growth rate in the moderate thinned and heavy thinned to lightly thinned plots was j=1.07/1.05=1.02 and j=1.08/1.05=1.03, respectively. The corresponding diameter growth rates in the 3 yr after thinning increased to 2 and 3%, respectively.

Height growth: Height development was generally similar between treatments during the study period. Here the tree height of heavy thinning developed no significantly more slowly than the remaining trees on the lightly and moderately thinned plots ($F_{2,5}$=0.480, p=0.645). Average annual height growth averaged 34.00, 38.80 and 29.20 cm in the lightly thinned, moderately thinned and heavily thinned plots, respectively (Table 3). However, the diameter development showed the reverse pattern. Because stem diameter developed more slowly in the lightly thinned plot than in the moderately thinned and highly thinned plots and height development was little affected, the stem form, expressed as the ratio between diameter and height, became different. The ratios of height growth of the moderately thinned and heavily thinned to the lightly thinned plots were 1.14 and 0.86, respectively. These increased to 14 and -14% in the moderately thinned and heavily thinned plots, respectively.

Basal area growth: During the period 3 yr after thinning, mean basal area of the tree layer increased in the lightly thinned plots from 20.670 to 36.936 m^2ha^{-1} (Table 3). As before, an analysis of variance was used with absolute and, separately, relative basal area increments as dependent variables. The latter was calculated dividing the absolute basal area increment of each plot by the basal area at the start of the considered period, and expressing the result as a percentage (Table 3). Absolute basal area increments were no significant ($F_{2,5}$=0.285, p=0.763). For relative basal area increments for thinning were no significant ($F_{2,5}$=0.308, p=0.748). Relative basal area increment had to be lower in heavily thinned plots, as we found, since absolute basal area growth was affected by thinning whilst initial basal area was much reduced by it. However, analysis of variance detected a no significant treatment term, indicating that the rate of basal area growth over the 3 yr period did differ among treatments. In fact, stand basal area growth rates averaged 1.885, 1.753 and 1.983 $m^2 ha^{-1} yr^{-1}$ in the lightly thinned, moderately thinned and heavily thinned plots, respectively. If these basal area growth rates continue, we expect to find significant treatment differences in cumulative basal area growth in the near future. The growth rate ratios of basal area in these plots were =1.753/1.885=0.93 and j=1.983/1.885=1.05. These results prove that heavy thinning considerably affected the growth rate of the basal area.

Volume growth: Ultimately, the success of these thinning treatments will be judged by their effects on stand volume, volume growth, and yield (Table 3). Prior to thinning, stand volume averaged 95.111 m^3ha^{-1} across the entire plantation, with no significant differences among treatment plots ($F_{2,5}$= 1.144, p=0.390). Light thinning removed 7.600 m^3ha^{-1}, about 7% of the volume, to a residual volume of 98.770 m^3ha^{-1}; moderate thinning removed 16.602 $m^3 ha^{-1}$, about 21% of the volume, to a residual volume of 80.363 $m^3 ha^{-1}$ and heavy thinning removed 22.514 m^3ha^{-1}, about 21% of the volume, to a residual volume of only 107.420 $m^3 ha^{-1}$. By the end of the third year after treatment, average annual volume growth averaged 11.734, 11.541 and 12.432 $m^3 ha^{-1} yr^{-1}$ in the lightly thinned, moderately thinned and heavily thinned plots, respectively. The growth rate ratios of volume in these plots were j=11.541/ 11.734=0.98 and j=12.432 /11.734= 1.06. These results prove that heavy thinning considerably affected the growth rate of the volume.

An analysis of variance with absolute and, separately, relative volume increments as dependent variables yielded the same results as described for basal area growth. Absolute volume increments were no significant ($F_{2,5}$=0.242, p=0.794). For relative volume increments for thinning were no significant ($F_{2,5}$= 0.641, p=0.565). Relative volume increment had to be lower in heavily thinned plots, as we found, since absolute volume growth was affected by thinning whilst initial basal area was much reduced by it. Average annual volume growth averaged 18.240, 19.996 and 16.249% in the lightly thinned, moderately thinned and heavily thinned plots, respectively.

Growth of dominant/co-dominant component: Thinning did not increase the quadratic mean diameter of the dominant / co-dominant component of the plantation. Thinning treatments increased 3 yr cumulative diameter growth of individual dominant and co-dominant trees, but no significant differences among the three levels of thinning could be detected ($F_{2,5}$=0.193, p=0.830). Upper crown class in the lightly thinned plot grew 1.035 cm in diameter in 3 yr, whereas those in the moderately thinned and heavily thinned plot grew 1.052 and 1.069 cm, respectively. This poor diameter growth within the dominant/codominant component of the lightly thinned plot will likely lead to further reductions in the density of upper crown class trees as marginally healthy trees drop to the intermediate and suppressed classes. Continued poor diameter growth of dominant and codominant trees in the lightly thinned plot is expected to continue in the future, such that the differences in diameter growth among the three thinning treatments plots will likely continue to widen. In fact, stand basal area growth rates averaged 1.144, 0.965 and 1.464 $m^2 ha^{-1} yr^{-1}$ in the lightly thinned, moderately thinned and heavily thinned, respectively.

Differences in volume within the dominant/co-dominant component were created. Mean volume in the lightly thinned plots increased 6.918 $m^3 ha^{-1} yr^{-1}$. Mean volume increment was 6.558 and 9.165 $m^3 ha^{-1} yr^{-1}$ in moderately thinned and heavily thinned plots, respectively. Even though both total stand volume and the volume within just the dominant/co-dominant component were greater in the heavily thinned plot. Thinning intensity had no significant effects on the average annual volume growth of the dominant/ co-dominant component ($F_{2,5}$= 0.781, p=0.507). Dominant and co-dominant trees accounted for 56.8% of the total volume growth in the total volume growth in the moderately thinned plot and 73.7% of the total volume growth in the heavily thinned plot, whereas only 58.9% of the total volume in the lightly thinned plot was distributed among upper crown class tree. Consequently, both thinning treatments allowed a much greater proportion of the total wood production of the stand to be concentrated in those trees most likely to produce high quality sawtimber as final crop trees.

Lebanon cedar 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 (Pukkala *et al.*, 1998; Davis *et al.*, 2007). 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.

Lebanon cedar showed a positive growth response to thinning, as evidenced by enhanced growth rates for diameter, basal area and volume. Similar results were found by Eler (1990) and Usta (1996) in Lebanon cedar and Calabrian pine (*Pinus brutia* Ten.) stand in western Turkey. The mean diameter increment during 3 yr period was 10.00 $mmyr^{-1}$ (Eler, 1990). Our results for the heavily thinned plots are very similar 10.80 mm yr^{-1}. However, in both studies, height appeared unaffected by thinning intensity, as it was the case in our study. A slight height growth increase was only observed for the largest trees. Similar results were reported by studies in Scots pine (*Pinus sylvestris* L.) stands at Spain (Rio *et al.,* 2008) and north Karelia, Finland (Pukkala *et al.*, 1998).

Among the treatments evaluated in this study, heavy thinning produced the most desirable combination of individual tree diameter growth and stand level basal area growth and volume growth. Reducing basal area proves to be effective in increasing the growth rates of red maple, however, caution should be taken not to open the site too much. These results expand and substantiate the work of Usta (1996) in which he concluded Calabrian pine diameter growth increased after thinning. Consistent with these results, similar work by Eler (1991) with Lebanon cedar and Calabrian pine showed increases no significant in tree growth and stand growth after thinning.

Basal area increment is greater with heavily thinned plot than in the lightly thinned plot and with moderately thinned, and behaves differently than increment in volume (Zhang and Oliver, 2006). The results indicate differences in mean height increment between treatments. This height increases with intensity of thinning as a result of removing the thinning type was from low, eliminating small trees, trees with badly shaped crowns, twisted stems, diseased trees, etc., through this difference is statistically significant (Table 2). In very even-aged and homogeneous stands height usually varies little with diameter, which means that sometimes, even with moderate thinning, mean height significantly vary. This strong competition has meant that after 25 years practically all dominated trees and very suppressed have died, resulting in a more regular stand. In other words, the strong differentiation of sociological classes is found in the early years, while after 30-40 years, low thinning helps to achieve greater uniformity.

Heavily thinned plots grew more in diameter than the lightly thinned plots. We found that periodic annual increment was no significant for quadratic mean diameter, basal area and volume among three thinning levels and among years 2005 and 2008 (Tables 2 and 3). Interactions between thinning level and period were significant for only periodic annual increment height. As we expected, heavily thinned plots increased more in diameter than the lightly thinned plots (Table 2). The same trends occurred for annual volume increment; trees accelerated in volume growth more in the heavily thinned plots than trees in the lightly thinned plots. Periodic annual increment basal area was higher in the heavily thinned plots than in the lightly thinned plots (Table 3). A strong positive relationship between stand basal area and periodic annual increment basal area also suggests more stand basal area growth in the highest stand basal area. This trend may continue until the onsets of self thinning with strong inter tree competition. Thinning enhances the growth of not only small trees, but also the dominant trees (Rio *et al*., 2008).

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 of Lebanon cedar is determined by technical criteria, intensive thinning helps to reduce the length of rotation by 20-25 years in comparison with barely treated or lightly thinned stands, particularly in high quality sites.

The results of this study indicate that moderate and heavy thinning had effect on the growth rates of Lebanon cedar plantation. Therefore, thinning is necessary to avoid growth rate slow down and the death of too many trees. In the moderately thinned plots, there is a slight fall in increment by basal area and volume with respect to the lightly 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 diameter, resulting in larger size timber.

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