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Effects of thinning intensity on the growth of narrow-leaved ash (*Fraxinus angustifolia* subsp. *oxycarpa*) plantations

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Abstract: Narrow-leaved ash (*Fraxinus angustifolia*) is one of the important broadleaved tree species, and it is becoming more important in European forestry because of its valuable wood and fast growing ability. Despite its wide natural range and high economic value, there is little or very limited information about the effects of thinning on the growth and development of ash stands, especially in plantations. In this study, 2 thinning experiments were carried out to determine the effects of thinning intensity on the growth of diameter, height, basal area, and volume in narrow-leaved ash plantations over a 6-year period in Adapazarı, Turkey. In the stands prior to thinning, mean diameter and stem number were about 31 cm and 416 trees ha^{-1} in the first experiment (at 36 years with 3 × 2 m initial spacing), respectively. The values were 24 cm and 544 trees ha^{-1} in the second experiment (at 22 years with 3.7 × 3.7 m initial spacing), respectively. Randomized block design with 3 replications was used in both experiments. The thinning treatments were as follows: removal of the basal area at 0% (control), 22% (moderate), and 39% (heavy) in the first experiment, and 0% (control), 19% (moderate), and 28% (heavy) in the second experiment. The 6-year results showed that thinning increased the diameter increment significantly, and the increase in diameter increment was positively correlated with the thinning intensity in both experiments. However, thinning intensity did not significantly affect increments of height, basal area, and volume. Moreover, increments of diameter, height, basal area, and volume were higher in the second experiment than in the first experiment.

Key words: *Fraxinus angustifolia*, growth, plantation, thinning

1. Introduction

Narrow-leaved ash (NLA; *Fraxinus angustifolia* Vahl) and common ash (*F. excelsior* L.) are becoming important in European forestry due to their fast growing ability and valuable wood. Wood characteristics of NLA show similarities to common ash. It yields white, high-quality wood that is especially preferred in the veneer and furniture industries (FRAXIGEN 2005). The mean annual increment can reach about 25 m^3 ha^{-1} and 15 m^3 ha^{-1} of stem wood over bark without any additional fertilizers or irrigation in plantations and natural stands, respectively; current annual increments can reach 33 m^3 ha^{-1} of stem wood over bark at 15–20 years (Kapucu et al. 1999). NLA occurs naturally in southern Europe, the Balkans, the Caucasus, and Iran. It is the most common ash species in the northern coastal regions of Turkey and dominates the bottomland forests of the northern coastal region of Turkey where rotation age is between 40 and 50 years in plantations (Çiçek and Yılmaz 2002; FRAXIGEN 2005).

Almost all NLA-dominated bottomland forests have been converted to pure NLA plantations in the last 50 years in Turkey. However, thinning practices were not adequately implemented in the plantations. Therefore, considering that some of the NLA plantations have reached 40–50 years of age, the mean stand diameter is still low as a result of inadequate thinning practices or high stand densities. Presently, stand densities are over 350 stem ha^{-1} in plantations that are between 40 and 50 years old. In Europe, 60–80 future or crop trees ha^{-1} is suggested for common ash (*F. excelsior*) (Dobrowolska et al. 2011). NLA is similar to common ash in many respects (FRAXIGEN 2005). Therefore, a similar number of crop trees with harvesting diameters of 50–60 cm should be the target for this species.

Thinning in broadleaved stands can produce large diameter trees, improve stem quality, increase merchantable volume and yield value, and shorten rotation time (Hibbs et al. 1989; Mayor and Rodà 1993; Cameron et al. 1995; Nowak 1996; Oliver and Larson 1996; Miller 1997; Medhurst et al. 2001; Juodvalkis et al. 2005; Rytter and Werner 2007). In broadleaved tree species, the aim of thinning is usually to improve the quality of the

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final crop (Savill et al. 1997). In spite of NLA's fast growth rate, valuable wood, and wide natural distribution, little is known about the effects of thinning intensity on the growth and development of NLA stands, especially in plantations. Bobinac (2000) reported that NLA did not respond to late thinning adequately. Radial growth of NLA during the last 20-year period (approximately 35–55 years) was lower than that of the preceding 20-year period (approximately 15–35 years) (Kremer et al. 2006). Carus and Çiçek (2007) found that the diameter increment of individual NLA trees decreased with increasing plantation age and the competition index. However, more information on the response of NLA plantations to thinning intensity is required to establish appropriate silvicultural practices to produce high-quality stems in NLA plantations. Thus, the objective of this study was to determine the effects of thinning intensity on the growth and increment of NLA plantations.

2. Materials and methods

2.1. Study area

The study was carried out in pure NLA plantations on a good bottomland hardwood site (site index I) in Hendek-Adapazarı, Turkey (40°45′N, 30°35′E; 25 m). Up until the time of the study, weak low thinning practices had been applied in the plantations (Çiçek et al. 2010). The site has heavy textured soil with a pH of 7.0–7.8. The alluvial soil is deep with weak drainage, and the Ah horizon is too thin due to rapid decomposition. The ground water level can rise above ground from February through April depending on seasonal rainfall (Çiçek et al. 2010). The Adapazarı Meteorological Station (40°46′N, 30°23′E; 30 m) is about 15 km southwest of the study site. According to station records, the area has a warm climate and receives approximately 846 mm of rainfall each year, with about 50% falling from April through October. Summers often include dry periods from mid-summer to early fall. The mean annual temperature is 14.3 °C, and the mean temperature during the growing season (April–October) is 18.8 °C. Mean relative humidity is 72% (Çiçek et al. 2010).

2.2. Methods

The 2 thinning experiments were conducted in 2 different plantations. The first experiment was carried out on a 36-year-old plantation established with 3 × 2 m initial spacing (1666 trees ha^{-1}) and the second at a 22-year-old plantation established with 3.7 × 3.7 m initial spacing (730 trees ha^{-1}). Prior to thinning, the stem numbers and basal areas of the stand were 416 and 544 trees ha^{-1} on the first plantation and 32.562 and 24.418 $\text{m}^2\ \text{ha}^{-1}$ on the second, respectively. Randomized block designs with 3 blocks and 3 treatments were established in each plantation. The low thinning intensities were removal of initial basal area at 0% (control), 22.3% (moderate), and 39.4% (heavy) in the first experiment, and 0% (control), 18.9% (moderate), and 28.2% (heavy) in the second experiment (Table 2; Figure 1). The thinning intensities coincided with stem number removal of 0%, 31%, and 48% in the first experiment and 0%, 21%, and 32% in the second experiment. The 3 thinning treatments were randomly assigned to 9 treatment plots for each experiment. Experimental units were 80 × 70 m (0.560 ha) and 63 × 63 m (0.397 ha) in the first and second experiments; within these units, 40 × 30 m (0.120 ha) and 33 × 33 m (0.109 ha) measurement plots were centered, respectively.

Trees were selected and marked for thinning in October and November 2005. Prior to thinning, all residual trees in the measurement plots were tagged. Breast heights (1.30 m) were also marked, and stem diameter was measured at this point during each inventory. Low thinning was applied, whereby trees were mainly removed from the lower diameter classes (Figure 1). The diameters at breast height of all trees to the nearest millimeter, and the heights of 30–35 trees representing all diameter classes to the nearest 0.25 m, were measured in each measurement plot. Stand height was calculated as top height, which is the mean height of the 100 largest trees ha^{-1}. Height measurements represented all diameter classes, and the height of the remaining trees was estimated for a volume calculation based on the relationship between diameter and height curves. Because the relationship between diameter and height is known to be affected by both silvicultural treatments and time, different equations were calculated for each measurement in both experiments. The nonlinear model was:

$$h = \mathrm{a}d^{\mathrm{b}}\,, \tag{1}$$

where h is the tree height (m), d is the diameter at breast height over bark (cm), and a and b are constants. Diameter and height were measured again in November 2011. Stand height was calculated as the mean height of dominant and codominant trees. Basal area and volume were calculated for each tree and stand total basal area and total volume were determined by summing the values of all trees in the measurement plot, and then these values were converted to hectares. The stem volume of each tree was calculated from the equation for this species presented by Şentürk (1998):

$$V = 0.000395dh + 0.000023d^2h\,, \tag{2}$$

where V is the over bark volume (m^3), d is the diameter at breast height over bark (cm), and h is the tree height (m). The differences between the 2005 and 2011 measurements were calculated as 6-year increments.

Analyses of variance (ANOVA) were performed to determine the effects of thinning intensity on growth and increments in the plantations ($P < 0.05$). Data analyses were at stand level. The normality distribution test was controlled for all variables before ANOVA. Because no indication of nonnormality was found, there was no need to transform the variables before evaluation. Where significant differences occurred, treatment means were separated by Duncan's new multiple range test ($P < 0.05$).

3. Results

Analyses of variances showed that there were no significant differences among treatments in terms of initial stand density, mean stand diameter and height, and total basal area and volume in both experiments ($P > 0.05$, Table 1). This means that the plantations had homogeneous structures (Figure 1; Table 1). However, thinning significantly affected the stand density, diameter, basal area, and volume of the residual stand after thinning and the stand diameter, basal area, and volume after 6 years of growth ($P < 0.05$, Table 2). On the other hand, there were no significant differences among the treatments in terms of initial and final stand height in both experiments ($P > 0.05$, Tables 1 and 2).

As a result of low thinning practice, diameters of the residual stands increased significantly in thinned plots in both experiments (Figure 1; Table 2). Residual stand diameters were different among all treatments in the first experiment, but there was no difference between moderate and heavy treatments in the second experiment (Table 2). Basal area and volume of the residual stands were lowest in heavy treatments and highest in control treatments in both experiments (Table 2).

Table 1. Various stand characteristics of NLA plantations prior to thinning (BA: basal area).

Treatment	Stand density (trees ha^{-1})	Diameter (cm)	Height (m)	BA (m^2 ha^{-1})	Volume (m^3 ha^{-1})
First experiment (age: 36 years; 3 × 2 m initial spacing)					
Control	412	31.2 (±5.283)	34.7 (±1.311)	32.237	493.238
Moderate	424	30.6 (±5.409)	34.9 (±1.680)	32.157	491.594
Heavy	414	31.5 (±5.393)	35.0 (±1.494)	33.293	507.379
P-value	0.436	0.051	0.468	0.600	0.628
Second experiment (age: 22 years; 3.7 × 3.7 m initial spacing)					
Control	568	23.0 (±3.762)	24.0 (±2.290)	24.241	280.849
Moderate	530	24.2 (±3.641)	23.8 (±1.914)	24.985	286.933
Heavy	535	23.6 (±3.860)	24.3 (±1.359)	24.030	276.986
P-value	0.244	0.291	0.375	0.698	0.747

In all cases $P > 0.05$; standard deviation in parentheses.

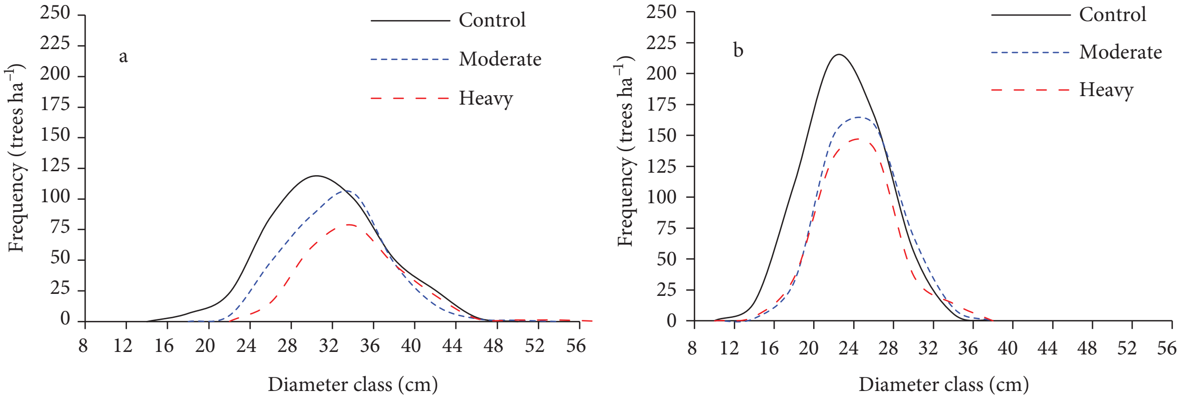

Figure 1. Distribution of stems on initial diameter classes in first (a) and second (b) experiment with respect to thinning intensity.

Table 2. Thinning effects on stand density, diameter, height, basal area, and volume after thinning and 6 years of growth (RSD: residual stand density, RD: residual diameter, D: diameter, H: height, RBA: residual basal area, BA: basal area, RV: residual volume, V: volume).

Treatment	RSD (trees ha^{-1})	RD (cm)	D 2011 (cm)	H 2011 (m)	RBA (m^2 ha^{-1})	BA 2011 (m^2 ha^{-1})	RV (m^3 ha^{-1})	V 2011 (m^3 ha^{-1})
First experiment (age: 36 years; 3 × 2 m initial spacing)								
Control	412 c	31.2 a (±5.283)	33.7 a (±5.973)	37.3 (±1.685)	32.237 c	36.786 c	493.238 c	598.634 c
Moderate	295 b	32.5 b (±4.594)	35.7 b (±5.284)	37.3 (±2.069)	24.980 b	29.509 b	379.734 b	475.680 b
Heavy	216 a	34.2 c (±4.310)	38.2 c (±4.901)	37.4 (±1.660)	20.165 a	24.463 a	305.051 a	394.940 a
P-value	**0.001**	**0.000**	**0.000**	0.873	**0.002**	**0.003**	**0.002**	**0.003**
Second experiment (age: 22 years; 3.7 × 3.7 m initial spacing)								
Control	568 c	23.0 a (±3.768)	25.9 a (±4.428)	28.9 (±2.398)	24.242 c	30.143 a	280.849 c	404.555 c
Moderate	418 b	24.6 b (±3.536)	28.3 b (±4.258)	28.6 (±1.832)	20.258 b	26.211 b	232.122 b	349.429 b
Heavy	366 a	24.2 b (±3.646)	28.5 b (±4.248)	27.4 (±1.694)	17.244 a	23.164 c	197.982 a	308.504 a
P-value	**0.002**	**0.000**	**0.000**	0.532	**0.008**	**0.010**	**0.007**	**0.008**

Within each experiment, means followed by a different letter in a column are significantly different ($P < 0.05$); standard deviation in parentheses.

After 6 years of growth, as in the residual stand after thinning, stand diameters were the highest in heavy treatments and the lowest in control treatments in the first experiment (Table 2). Heavy treatment increased the stand diameter by 13% compared to the control (Table 2). In the second experiment, stand diameters were similar in moderate and heavy treatments, where stand diameter was higher by 10% than the control at the end of the growth period. Stand diameters in the first experiment increased by 8%, 10%, and 12% in control, moderate, and heavy treatments, respectively, relative to the residual stand after thinning. Those increases were 13%, 15%, and 18% in the second experiment treatments, respectively. Accordingly, the diameter increase percentage in the control treatments of the second experiment was higher than the diameter increase in the heavy treatments of the first experiment (Tables 1 and 2). Compared to the control, thinning increased the stand diameter by 4.5 cm and 2.5 cm in the first and second experiments, respectively (Table 2).

Contrary to the stand diameter, stand basal area and volume were highest in the control and lowest in the heavy treatments in both experiments after 6 years of growth, as in the residual stand after thinning (Table 2). Relative to the residual stand after thinning, basal area increased by 14%, 18%, and 21% in control, moderate, and heavy treatments in the first experiment and by 24%, 29%, and 34% in the second experiment, respectively. Relative to the residual stand, volume increase percentages in the first experiment were 22%, 25%, and 30% in control, moderate, and heavy treatments, respectively. These values were 44%, 51%, and 56% in the second experiment treatments, respectively (Table 2).

In both experiments, the differences among treatments in terms of mean diameter increments were significant ($P < 0.05$); however, they were not significant in terms of mean height, basal area, and volume increments in both experiments ($P > 0.05$, Table 3). In both experiments the maximum and minimum diameter increments were found in the heavy and control treatments, respectively (Table 3). Compared to the control, the heavy and moderate treatments gained 63% (1.54 cm) and 29% (0.70 cm) more diameter increment in the first experiment, respectively; they gained 50% (1.41 cm) and 31% (0.88 cm) more diameter increment in the second experiment, respectively (Table 3). Mean periodic annual increments of diameter for the treatments were 0.41, 0.53, and 0.67 cm year^{-1} in the first experiment, respectively, and 0.48, 0.62, and 0.71 cm year^{-1} in the second experiment, respectively (Table 3). Mean periodic annual increments of height were 0.4 and 0.8 m year^{-1} in the experiments, respectively.

Although important parts of the initial stand basal area (or volume) in parallel with the stem numbers were removed (Tables 1 and 2), treatments gained similar basal area and volume increments within each experiment (Table 3). However, with increasing thinning intensity there was a slight decrease in volume increment, although it was not statistically significant (Table 3). Periodic annual increments of stand basal area and volume were 0.743 m^2 ha^{-1} and 16.180 m^3 ha^{-1} in the first experiment and 0.987 m^2 ha^{-1} and 19.530 m^3 ha^{-1} in the second experiment,

Table 3. Thinning effects on increments of diameter, height, basal area (BA), and volume (V).

Treatment	Diameter increment (cm)	Height increment (m)	BA increment ($m^2\ ha^{-1}$)	V increment ($m^3\ ha^{-1}$)
First experiment (age: 36 years; 3 × 2 m initial spacing)				
Control	2.45 a (±1.028)	2.6 (±1.242)	4.549	105.396
Moderate	3.15 b (±1.212)	2.4 (±1.275)	4.529	95.946
Heavy	3.99 c (±1.180)	2.4 (±1.425)	4.298	89.889
P-value	**0.000**	0.656	0.357	0.065
Second experiment (age: 22 years; 3.7 × 3.7 m initial spacing)				
Control	2.85 a (±1.222)	4.9 (±1.849)	5.901	123.706
Moderate	3.73 b (±1.448)	4.8 (±1.505)	5.953	117.307
Heavy	4.26 c (±1.421)	4.1 (±1.553)	5.920	110.522
P-value	**0.000**	0.562	0.977	0.073

Within each experiment means followed by different letter in a column are significantly different ($P < 0.05$); standard deviation in parentheses.

respectively (Table 3). As with height increments, basal area increments were higher in the second experiment.

Before the study, mean annual increments of stand diameter were 0.86 cm $year^{-1}$ in the first plantation (36 years) and 1.07 cm $year^{-1}$ in the second plantation (22 years). At the end of the study, mean annual increments of stand diameter were 0.89 and 0.93 cm $year^{-1}$ in control treatments and 1.00 and 1.02 cm $year^{-1}$ in heavy treatments in the first and second experiments, respectively. Accordingly, the mean annual increments of diameter decreased in the control treatments as they could solely be attained in heavy treatments in both experiments, compared to prethinning values (Tables 1 and 2).

In the first experiment, very low (<1%) natural mortality occurred only in the control treatment, and a very low number of trees (0.5%) had fallen in moderate and heavy treatments. Mortality occurred in suppressed trees in the lowest tree diameter classes. However, no tree mortality or fallen trees occurred in all treatments in the second experiment.

4. Discussion

NLA plantations responded to thinning, and the greatest diameter increments occurred following heavy thinning in both plantations. However, diameter increments were higher in the younger plantation (Table 3). Similar to the findings of this study, diameter increments increased with increasing thinning intensity, especially in younger broadleaved stands (Mayor and Rodà 1993; Bréda et al. 1995; Hibbs et al. 1995; Rytter 1995; Kerr 1996; Medhurst et al. 2001; Clatterbuck 2002; Meadows and Goelz 2002; Juodvalkis et al. 2005; Makineci 2005; Tufekcioglu et al. 2005; Rytter and Werner 2007). The positive effects of thinning intensity on increment of diameter can be attributed to the greater light, water, and nutrient availability for thinned trees. The increased diameter growth in response to thinning was associated with an increased net photosynthetic rate and water and nitrogen use efficiency among thinned trees (Wang et al. 1995). Although stand density was higher in the second experiment than in the first experiment, the higher diameter increments in the second experiment can be attributed the lower stand age, or, in other words, to its high growth potential. Carus and Çiçek (2007) reported that the diameter increment of NLA decreases with increasing plantation age and competition index among trees, which verifies our study results. Thinning at the young stage enables individual trees to grow faster and develop stand resistance to biotic and abiotic damages. Kremer et al. (2006) found that radial growth of NLA during the last 20-year period was lower than in the preceding 20-year period. Bobinac (2000) did not record faster increments in future NLA trees based on the comparison of diameter, height, and volume increment values before thinning and 5 years after thinning in a 40-year-old stand, which contradicts our study. This result was attributed to the absence of previous tending measures; it can also be seen as a thinning shock that occurred as a result of late thinnings (Pothier and Margolis 1991; Mahadev et al. 2006). In order to harness the maximum increment potential of future NLA trees, thinnings should focus on young stands (Bobinac 2000).

Height increment was unaffected by thinning intensity in both plantations (Table 3). Similar results were found in various broadleaved species (Graham 1998; Medhurst et al. 2001; Rytter and Werner 2007). It is a well-known fact that stand density has significant effects on diameter growth, but not on height growth, except for very high and very low stand densities. In our study, thinning did not affect height increments in either plantation, meaning that stand densities are at a level that does not affect height growth. As stated above, thinning does not affect height growth generally because the carbon allocation for height growth is more primary than the carbon allocation for diameter growth (Lanner 1985). On the other hand, height growth occurs early in the season when resources are not limited, and diameter growth occurs in summer when resources that restrict photosynthesis are limited (Wang et al. 1995). Thus, stand density reduction by thinning increases soil water availability in summer, which primarily affects diameter increment. Bréda et al. (1995) found that thinning enhanced radial growth as a result of less severe water deficits in the thinned plot in late summer than in the control plot. Soil water measurements in our experimental plots showed that volumetric soil water contents were higher in thinned plots than in unthinned plots from July through September (Çiçek et al. 2010). Stone et al. (1999) also reported that thinning increased soil volumetric water content between May and August in the first year after thinning.

In our study, increments of basal area and stem volume were similar at all thinning intensities within each plantation (Table 3). The younger plantation had greater diameter, height, and basal area increments than the older plantation, which could be explained by the higher growth potential of the younger plantation. Unlike the results produced by our study, thinning increased basal area growth in some broadleaved tree species (Cañellas et al. 2004; Pretzsch 2005; Boncina et al. 2007), and in another study increments of basal area and volume decreased with thinning (Simard et al. 2004). In other studies, similar biomass production was obtained in control and thinned plots in grey alder (*Alnus glutinosa*) plantations and holm oak (*Quercus ilex*) stands (Mayor and Rodà 1993; Rytter 1995). Cañellas et al. (2004) also found that thinning increased biomass production. The variability in increments of basal area, volume, and biomass in reaction to thinning can be explained by differences among tree species, site, stand age, stand tending, thinning type, and intensity. Our results support known information about the effects of thinning on stand production. Total stand production and volume increment per unit area do not vary much within a wide range of treatments, and unthinned dense stands consume more assimilated carbon for respiration than thinned stands; thus, net production will be reduced in dense stands (Savill et al. 1997).

Because of its fast growing ability and valuable wood, NLA should be grown for quality and thick saw log. For common ash, a harvesting diameter of 50–60 cm for 60–80 future trees ha^{-1} is suggested (Dobrowolska et al. 2011). The diameter of NLA plantations is low as a result of neglected tending practices, especially thinning, because plantations have very high stand densities (Figure 1; Table 1). Rotation age of NLA is increased from 40 years to 50 years to increase stand diameter (OGM 1992, 2004). Thinning practices are applied every 5 years, and about 8%–10% of the standing volume is removed in conventional thinnings on NLA plantations (OGM 2004). Conventional thinnings will not ensure the adequate harvesting diameter stated above. However, some dominant trees reached diameters of 50–55 cm in the first experiment before thinning. This means that a 40-year rotation is reasonable on good sites (Figure 1). Thus, NLA plantations can grow 1 cm in diameter annually and 1 m in height under no thinning or very weak low thinning regimes (Kapucu et al. 1999; Çiçek 2004; Figure 1; Table 1). In these stands, diameter increments of dominant future trees were greater than the mean increment of the stand. If the harvesting diameter is 50 cm, future trees should grow 1.25 cm in diameter yearly, and most dominant trees ensure this diameter increment. Presently, however, the number of future trees is not sufficient (Figure 1).

The normal thinning period begins when the stand reaches the thinning stage and ends before the age of maximum annual increments, when current annual increments are at the highest levels. During this period, 70% of the maximum mean annual increment can be removed annually without decreasing future production (Savill et al. 1997). These relationships for NLA plantations on good sites are presented in Figure 2. NLA plantations can reach 8–10 cm in diameter (and 8–10 m in height) at 8–10 years (Çiçek 2004). In other words, thinnings can start as early as at 10 years. A stand can be thinned without a loss in potential production in intolerant species when the total standing volume reaches 70 m^3 ha^{-1} (Savill et al. 1997). NLA can reach the aforementioned volume before age 10 in plantations (Kapucu et al. 1999). Accordingly, the normal thinning period for NLA should be between 10 and 30 years, thinnings should be applied substantially during this period, and about 70% of the maximum annual increment (approximately 15 m^3 ha^{-1}) should be removed yearly (Figure 2). Annual thinning yields before and after the normal thinning period will be lower. In other words, until the intersection of mean annual increment and current annual increment, stand density should be reduced to a density level that roughly

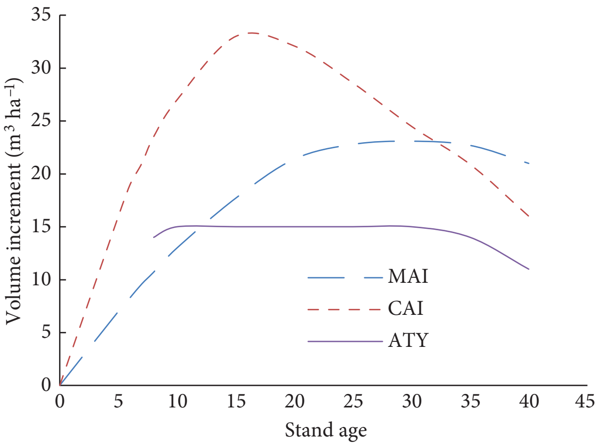

Figure 2. Relationships between age and mean annual increment (MAI), current annual increment (CAI), and annual thinning yield (ATY) in NLA plantations at good sites in Turkey (CAI and MAI adapted from Kapucu et al. 1999).

represents the number of crop trees. The importance of early silvicultural treatments on the future growth of young broadleaved stands (natural or plantation) was stressed in many studies (Schönau and Coetzee 1989; Juodvalkis et al. 2005; Rytter and Werner 2007). Schönau and Coetzee (1989) suggested that thinning should start early, recommended thinning at frequent intervals, and noted that the first thinning should be heavier than later ones. Early thinning can result in greater growth response, provided that the residual trees are vigorous (Oliver and Larson 1996). Savill (1991) stressed that ash (*F. excelsior*) did not respond to delayed thinning, that thinning should be heavy to keep crowns entirely free, and that the stand should be at its final density by age 30–35. Dobrowolska et al. (2011) also reported that ash (*F. excelsior*) responds quickly to thinning only at young ages. Leak and Solomon (1997) also found that ash (*F. americana*) showed no significant effect in response to late thinning. Thinning during the young stage enables trees to grow faster and resist damaging agents. Thus, thinning practices should focus on young NLA stands when the current annual increment is at its highest levels (Figure 2). Accordingly, future trees should be selected when the first thinnings are applied, and then attention should be concentrated on the crown development of future trees in order to maintain a desirable diameter increment and obtain enough stem diameter at the end of the rotation period.

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