Original scientific paper

Effect of Pruning on Diameter Growth in *Pinus brutia* Ten. Plantations in Turkey

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Abstract

Pruning is a technique used to add value to trees growing in forest stands, allowing the formation of clear, knot-free wood. Although many factors affect timber value, knots are the primary cause of reduction in timber quality of conifers. On the other hand, pruning may also cause reduction in the rate of tree growth, depending on pruning intensity.The aim of this study is to assess the effects of different pruning intensities on DBH (diameter at breast height) growth of young Pinus brutia *plantations. For this purpose, three field experimental sites each with different site qualities, were established in three different locations. Four different treatments were applied at each test site: 1) control, no pruning of branches, 2) pruning up to 25% of tree height, 3) pruning up to 50% of tree height, and 4) pruning up to 75% of tree height. The effects of pruning on DBH growth were observed over a period of 14 years. At »Bük« test site, which has the poorest site quality, only those specimens pruned up to 75% of tree height showed significant reduction in DBH growth compared to the control. However, at »Nebiler« and »Kursunlu« test sites, specimens pruned both up to 50% and 75% of tree height showed statistically significant decrease in DBH growth. To recover from pruning stress in terms of DBH growth rate, it took trees 6 years at the poorest test site and 4 years at the relatively better test sites. This indicates that site quality of plantation sites accounts for not only DBH growth differences between sites, but also recovery rate of trees from any disturbances. Results showed that for those trees pruned up to 75% of their height, total DBH growth was reduced by between 6.5% and 9.0% after 14 years compared to the control at the test sites. No negative effect from pruning on DBH increment was observed in the first growing season. This may be due to earlier storage of nutrition in different parts of trees, thereby enabling them to compensate for the stress of crown reduction during the first growing season following pruning.*

Keywords: pruning, Pinus brutia*, diameter growth, growth reduction*

1. Introduction

Silvicultural treatments are defined as various technical operations carried out for different purposes from plantation establishment or regeneration through to final harvest. Pruning is one such operation that removes live and/or dead branches from a certain portion of tree stem, starting from ground level. The most common purpose of pruning is to produce knot-free wood called »clear wood«. It may be an attractive investment for forest management if it is economically feasible. For example in June 1993 in New Zealand, pruned logs were selling for as much as 350 $/m^3$ as opposed to 150 $/m^3$ for good unpruned logs. Even though pruning is expensive and reduces tree diameter growth, managers choose to sacrifice some quantity of wood for superior quality and therefore higher profits (Maclaren 1993). Thinning is another silvicultural treatment that improves wood quality. For example, Guller et al. (2012), studying wood density traits in *P. brutia*, observed that thinning increased annual ring width, latewood proportion and average ring density.

As pruning may be an attractive silvicultural technique from an economic standpoint, it is suggested that it be applied by forest managers. However, since it may reduce total diameter growth due to reduction in the tree leaf area, the most profitable pruning intensity needs to be investigated, depending on site quality and specific tree species (Saatcioglu 1971, Kalipsiz 1982, Savill et al. 1997, Schmidt and Wardle 2002).

In Turkey, the State Forest Service (FS), General Directorate of Forestry (OGM), owns almost all the forests, and regulates thinning, pruning and other silvicultural treatments (OGM 2014). *Pinus brutia* is the most important tree species in Turkish forestry, accounting for approximately 5.8 million ha of natural and planted forest area (OGM 2012) and 4.3 million m^3/year of wood production (OGM 2013). Indeed, the species accounts for 31% of total industrial wood production of Turkey. Due to the uncertainty concerning the economic feasibility of pruning at different intensities, the FS currently runs a restricted pruning programme with a low level of implementation. The FS needs to know the economic effects of different pruning intensities on tree (Miraboglu 1983). Moreover, there is currently a lack of research results on pruning and its effects on tree growth for different forest tree species in Turkey. Accurate scientific information about the effects of different pruning intensities on diameter growth under different site conditions and qualities is needed before any large-scale implementation programme is undertaken. The earlier results of this research, which evaluated data for the first seven years following pruning, were published as a technical bulletin in 2010 by Erkan et al. However, additional evaluation on advanced ages will certainly help to obtain more reliable results.

The study under report was conducted on *Pinus brutia* Ten. at age of 14 years. The aim of the study is to quantitatively describe the effects of different pruning intensities on diameter growth and increment at breast height (DBH) of *P. brutia* plantations growing on three sites, each with different site qualities.

2. Material and Methods

2.1 Study sites

The study sites (»Bük«,»Nebiler« and »Kursunlu«) were located in three different areas of *P. brutia* plantations in Antalya Region in Southwestern Turkey (Table 1). The region has a typical Mediterranean climate with a relatively hot, dry summers, and mild and wet winters. The mean minimum temperature in the coldest month (January) is 5°C, and the mean maximum temperature of the hottest month (July) is 34°C. Annual rainfall, which is about 1091 mm, is mainly concentrated in the winter months, rainfall contribution in the summer months (from June to September) only accounts for 22 mm of the total annual precipitation. The means of climate data represent a 35 year period, from 1975 to 2010. Some of the other properties of test sites are given in Table 1.

2.2 Pruning regimes and measurements

Pruning was performed prior to the growing season in February 2000 by removing all branches (live and dead) from outside the branch collar without damaging the main stem tissue, starting from ground level up to 25, 50 and 75% of total tree height. This gave control: unpruned, intensity 1: 25%, intensity 2: 50%, intensity 3: 75%. Total height was recorded as a reference to indicate the intensity of pruning because row spacing used in *P. brutia* plantations was 2.0×3.0 m and green branches closer to ground level on trees were still growing at this development stage.

Annual DBH increment and total diameter growth were taken as dependent variables to investigate the effects of pruning on DBH growth. This response of forest trees to pruning is mainly reflected in diameter growth (Harold and Paul 1952, Kozlowski and Pallardy 1990, Kukpa 2007) whereas height growth, which is determined largely by site quality, is affected

Table 1 Test sites and some associated properties

Test sites	Stand age*	Mean stand DBH over bark*, cm	Site index top height at age 30, m	Mean stand height, m*	Soil type	Altitude m	Aspect	Coordinates
»Bük«	25	10.4	9.7	6.9	Sandy clay loam	692	NW	N 36°57′51.45″ E 30°24′42.42″
»Nebiler«	12	11.9	23.0	7.9	Sandy clay loam	310	Flat	N 36°57′23.38″ E 30°34′13.54″
»Kursunlu«	13	12.0	22.8	7.8	Clay	90	Flat	N 37°00′59.90″ E 30°49′36.99″

* Values are for the time of pruning in year 2000

little by pruning unless the treatment is so severe that the tree vigour is reduced to the point where it simply stops its terminal growth (Schmidt and Wardle 2002).

Total and pruning heights (cm) of all the treatment trees were obtained by using a CRAIN telescopic height measurement device. Total DBH growth under bark (cm) and annual DBH increment – ADI (mm) were measured for all treatments (including control trees) over a period of 14 years (from the beginning of the 2000 growing season to the end of 2013).

Two increment cores were taken from opposing sides (North and South) from each sampled tree after the completion of the 2013 growing season. PRESSLER increment borers were used to obtain core samples. The annual DBH increment for the related year (annual tree ring width as the sum of the widths of two rings from two cores taken from opposite sides of a sample tree) was measured from fine sanded core samples to the nearest 0.01 mm using a PREISSER DIGI-MET measurement machine. Annual diameter increment (ADI) was determined for each tree as follows:

$$ADI_k = RW_{k1} + RW_{k2} \quad (1)$$

Where, for the related year:

ADI_k annual diameter increment at breast height under bark of k^{th} tree

RW_{k2} ring width measured from the opposite side (1 and 2) of k^{th} tree

2.3. Experimental design and data analyses

The trees were initially planted at 2.0×3.0 m spacing on the test sites. Individual stands at each test site were at the early stages of their development, mean DBH being not greater than 12.0 cm over bark in the pruning year, 2000. Test site ages varied from 12 to 25 years in the start of the pruning experiment (Table 1). Age differences between the test sites with similar diameters were due to differences in site qualities of given test site pairs. Site index was determined using site index table prepared for *P. brutia* plantations by Usta (1991).

The trees are located in rows (2.0×3.0 m) on each test site. First, we have chosen 10 rows within a given test site. Each row (replication) consisted of 12 observation (treatment) trees (4 pruning types × 3 observation trees), in addition to buffer trees surrounding the observation trees. Each row in a given test site serves as a replication in the experiment. Each observation tree within a given row was randomly assigned to one of the four pruning types in such a way that each observation tree was surrounded by unpruned buffer trees. This measure was taken in order to avoid any border effect, and also to more or less imitate a selective pruning regime as proposed by FS regulations (OGM 2014).

Treatment trees were selected and marked amongst co-dominant trees within each test site. The mean DBH of observation trees for different treatments was not greater than 10 cm under bark, ranging from 7.9 cm to 9.9 cm. Differences amongst mean tree DBH values (under bark) within each treatment group were less than 2.0 cm. Such a measure was taken in order to minimize growth differences that may arise purely due to differences in initial DBH values of separate treatment groups. Other site variables (such as spacing, stand density, canopy closure and crown structure) that have a primary effect on growth (Erkan 1996, Erkan 1998) were supposed to be more or less similar for all treatment trees.

The ANOVA (Analysis of Variance) Model for within site comparisons was as follows:

$$y_{ik} = \mu + \alpha_i + \varepsilon_{ik} \quad (2)$$

Where:

y_{ik} DBH increment of k^{th} tree within i^{th} pruning intensity

y mean DBH increment of trees

α_i effect of pruning intensity and ε_{ik} random error.

Prior to selecting candidate test sites for the pruning experiment, a detailed field survey of available plantations sites in the region was undertaken. One of the criteria for selecting a test site was that each should be as homogenous as possible within itself in respect of its site characteristics as reflected in uniform plantation growth and ground cover properties.

Effects of pruning on DBH increment were evaluated within each test site separately by using one-way ANOVA in SPSS 22.0 (SPSS Inc. 2015). ANOVA tests were performed for each of the measurement years between 2000 and 2013. Different pruning intensities were compared by applying Duncan's multiple range tests.

3. Results

ANOVA results showed that DBH increment in *P. brutia* was reduced by different degrees at all the test sites as a result of different pruning intensities. Differences in DBH increment were statistically significant ($p<0.05$) among pruning treatments starting from 2 to 7 years following pruning at the »Bük« test site (Table 2 and 3, Fig. 1). The same was true from 2 to 5 years both at »Nebiler« and »Kursunlu« test sites.

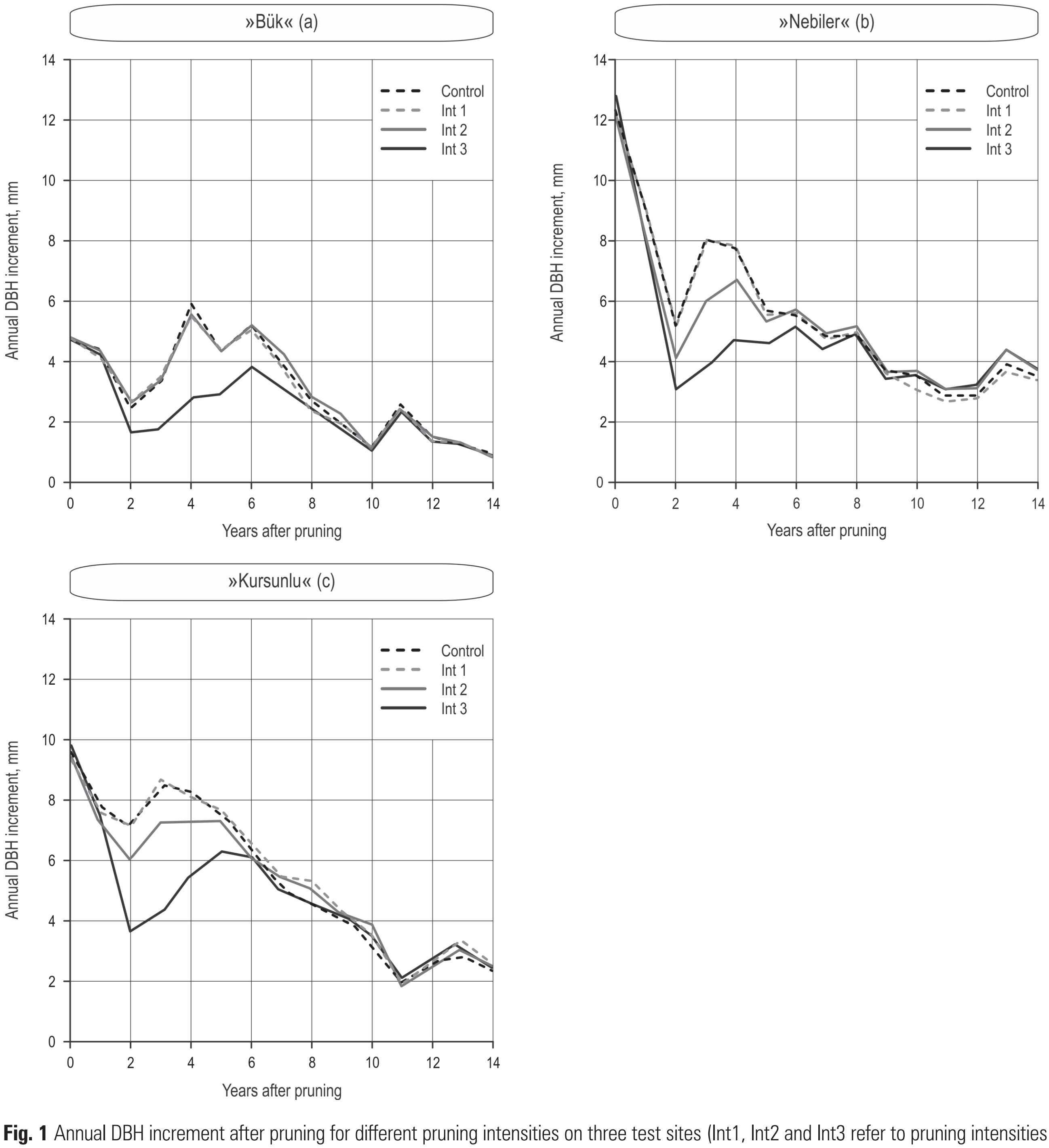

Fig. 1 Annual DBH increment after pruning for different pruning intensities on three test sites (Int1, Int2 and Int3 refer to pruning intensities of 25, 50 and 75% of tree height, respectively)

According to Duncan's tests, there were no statistically significant ($p<0.05$) differences between the control and the 25% pruning treatment at all experimental sites. In »Bük«, which is a relatively poor site, only the highest intensity (75%) pruning treatment showed a significant ($p<0.05$) decrease in diameter increment compared to the control (Fig. 1a). The inhibiting effect of 75% pruning treatment lasted for six years, after which annual DBH increments were equal to that of control trees. During this six years, trees pruned to 75% of total height showed about 9% less growth in total DBH on average compared to the control group

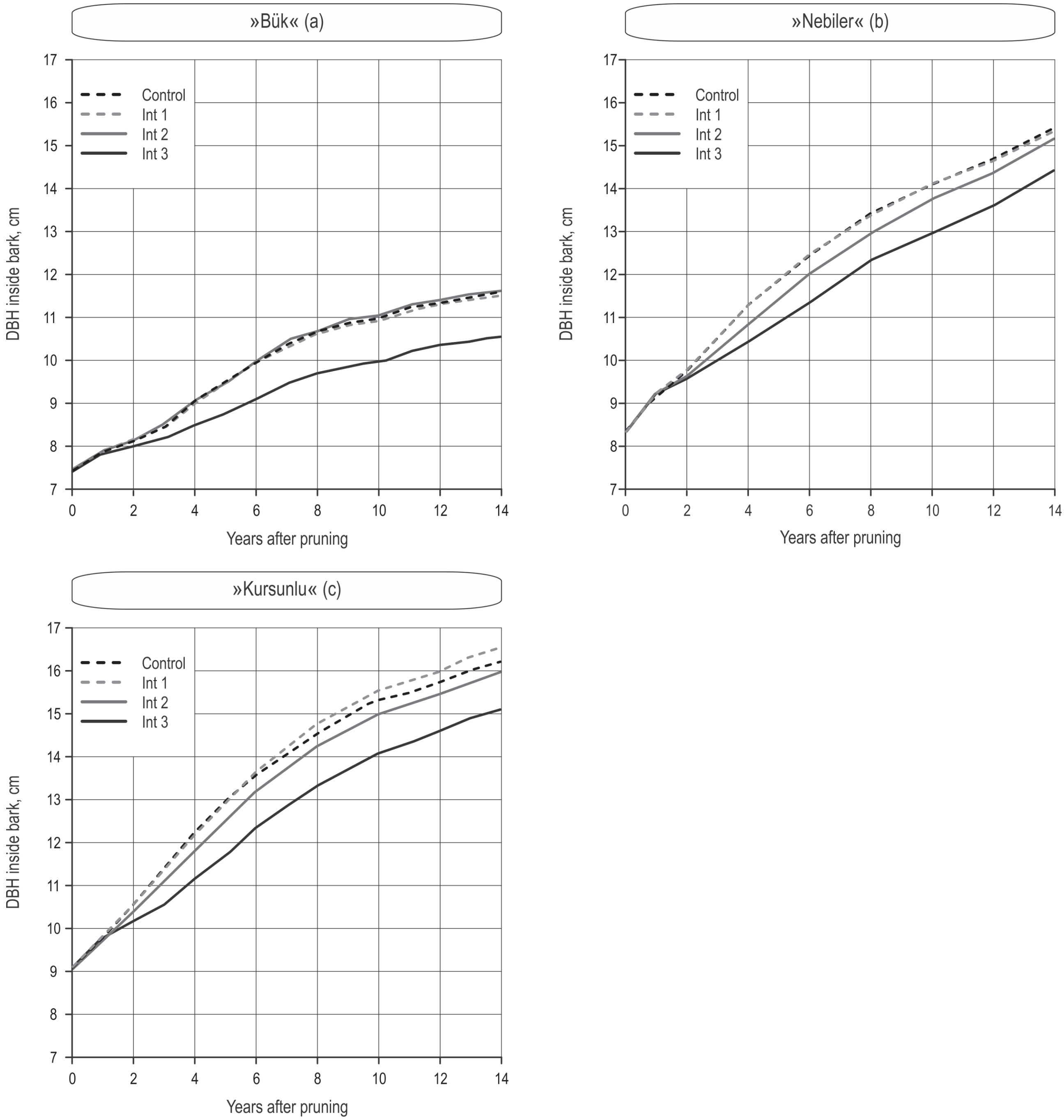

Fig. 2 Cumulative DBH growth for 14 years following different pruning intensities on three test sites (Int1, Int2 and Int3 refer to pruning intensities of 25, 50 and 75% of tree height, respectively)

in »Bük« (Fig. 2a). In »Nebiler« 50 and 75% pruning treatments had significantly (p<0.05) different effects from the control in years two-four and two-five after pruning, respectively. Similarly, in »Kursunlu«, 50 and 75% pruning treatments were significantly (p<0.05) different from the control in the third year and for the period of two-five years after pruning, respectively (Table 3, Fig. 1b, 1c). Total DBH growth loss at the end of year 14, due to the reduction of DBH increment after pruning, for intensity 3 (75% pruning) compared to the control group was 6.5 and 6.7% at »Nebiler« and »Kursunlu«, respectively.

Table 2 ANOVA results for DBH increment for various years after pruning under four different pruning intensities (groups) at three test sites (»Bük«, »Nebiler« and »Kursunlu«)

Years after pruning	Source of variance	»Bük«				»Nebiler«				»Kursunlu«			
		Sum of squares	*DF*	*F*	*p*	Sum of squares	*DF*	*F*	*p*	Sum of squares	*DF*	*F*	*p*
1	Between treatments	1.4	3	0.38	0.764	5.4	3	0.53	0.659	5.4	3	0.38	0.768
	Within treatments	137.1	115			384.5	115			555.4	116		
	Total	138.5	118			389.9	118			560.9	119		
2	Between treatments	19.0	3	18.75	0.000	86.9	3	12.44	0.000	250.0	3	17.8	0.000
	Within treatments	38.9	115			267.6	115			541.0	116		
	Total	57.9	118			354.4	118			791.1	119		
3	Between treatments	58.8	3	31.26	0.000	376.1	3	34.18	0.000	402.2	3	22.71	0.000
	Within treatments	72.1	115			421.7	115			684.8	116		
	Total	130.9	118			797.8	118			1087.0	119		
4	Between treatments	181.5	3	31.09	0.000	189.8	3	19.70	0.000	152.6	3	9.61	0.000
	Within treatments	223.7	115			369.2	115			613.7	116		
	Total	405.2	118			558.9	118			766.3	119		
5	Between treatments	45.2	3	14.29	0.000	24.6	3	5.84	0.001	37.5	3	2.78	0.044
	Within treatments	121.2	115			161.5	115			520.9	116		
	Total	166.4	118			186.1	118			558.4	119		
6	Between treatments	40.4	3	7.13	0.000	7.4	3	1.34	0.265	5.2	3	0.42	0.739
	Within treatments	216.9	115			212.8	115			481.4	116		
	Total	257.2	118			220.3	118			486.7	119		
7	Between treatments	17.4	3	4.69	0.004	6.2	3	1.36	0.258	8.7	3	0.88	0.455
	Within treatments	141.9	115			175.6	115			383.8	116		
	Total	159.3	118			181.8	118			392.5	119		
8	Between treatments	5.1	3	2.27	0.084	1.4	3	0.25	0.859	10.7	3	1.05	0.371
	Within treatments	85.9	115			216.4	115			391.9	116		
	Total	91.0	118			217.8	118			402.6	119		
10	Between treatments	1.2	3	1.93	0.129	6.8	3	0.38	0.762	4.5	3	0.516	0.672
	Within treatments	24.1	115			225.7	110			301.5	103		
	Total	25.3	118			232.6	113			306.1	106		
12	Between treatments	0.6	3	0.67	0.572	3.1	3	0.60	0.615	1.7	3	0.253	0.859
	Within treatments	37.6	115			191.7	110			233.8	103		
	Total	38.2	118			194.9	113			235.5	106		
14	Between treatments	0.4	3	1.02	0.378	2.9	3	0.435	0.728	1.1	3	0.268	0.848
	Within treatments	15.7	115			247.1	110			136.7	103		
	Total	16.1	118			250.0	113			137.8	106		

4. Discussion

The diameter increment in *P. brutia* was reduced by pruning when the above intensities were applied. Annual diameter increments for 50% and 75% pruning intensities were statistically different from the control, unlike the 25% pruning intensity treatment (Fig. 1). Thus, it can be concluded that, in all cases, pruning of about 25% of the lower crown of trees from ground level has no effect on diameter growth. Under low levels of light intensity, needles on lower branches may respire as much or conceivably more than they can

Table 3 Duncan test results for DBH increment following pruning year for different pruning intensities at three test sites ($p < 0.05$ level)

Experimental sites	Years*	2000 (1)		2001 (2)		2002 (3)		2003 (4)		2004 (5)		2005 (6)		2006 (7)		2007 (8)		2009 (10)		2011 (12)		2013 (14)		Total DBH inside bark, cm
	Treatments	Mean, mm	Sub groups	Mean, mm	Sub groups	Mean, mm	Sub groups	Mean, mm	Sub groups	Mean, mm	Sub groups	Mean, mm	Sub groups	Mean, mm	Sub groups	Mean, mm	Sub groups	Mean, mm	Sub groups	Mean, mm	Sub groups	Mean, mm	Sub groups	
»Bük«	Control	4.34	a	2.49	a	3.21	a	5.86	a	4.26	a	5.21	a	3.99	a	2.72	a	1.07	a	1.46	a	0.91	a	11.56
	25% pruned	4.07	a	2.61	a	3.41	a	5.53	a	4.35	a	5.08	a	3.90	a	2.39	a	0.83	a	1.34	a	0.75	a	11.46
	50% pruned	4.29	a	2.62	a	3.40	a	5.58	a	4.33	a	5.21	a	4.31	a	2.78	a	1.06	a	1.49	a	0.82	a	11.61
	75% pruned	4.15	a	1.65	b	1.71	b	2.79	b	2.88	b	3.82	b	3.25	b	2.30	a	1.01	a	1.32	a	0.83	a	10.52
»Nebiler«	Control	9.19	a	5.17	a	8.04	a	7.75	a	5.65	a	5.53	a	4.81	a	4.89	a	3.52	a	2.82	a	3.48	a	15.40
	25% pruned	9.17	a	5.11	a	8.04	a	7.88	a	5.57	a	5.65	a	4.72	a	4.94	a	3.01	a	2.77	a	3.36	a	15.29
	50% pruned	8.96	a	4.07	b	6.00	b	6.70	b	5.30	a	5.75	a	4.87	a	5.15	a	3.65	a	3.09	a	3.69	a	15.11
	75% pruned	9.55	a	3.08	c	3.70	c	4.69	c	4.49	b	5.08	a	4.28	a	4.88	a	3.52	a	3.16	a	3.75	a	14.39
»Kursunlu«	Control	7.71	a	7.07	a	8.52	a	8.32	a	7.51	a	6.27	a	5.00	a	4.60	a	3.14	a	2.41	a	2.29	a	16.25
	25% pruned	7.60	a	7.12	a	8.75	a	8.19	a	7.75	a	6.62	a	5.54	a	5.28	a	3.26	a	2.47	a	2.47	a	16.57
	50% pruned	7.14	a	6.01	a	7.20	b	7.30	a	7.26	a b	6.13	a	5.42	a	5.00	a	3.69	a	2.29	a	2.34	a	15.99
	75% pruned	7.48	a	3.56	b	4.16	c	5.50	b	6.28	b	6.10	a	5.90	a	4.56	a	3.47	a	2.66	a	2.19	a	15.15

* Observation years and number of years passed since pruning (in parenthesis)

photosynthesize. Therefore, these branches contribute little to the growth and may even be a burden to the tree resources (Savill et al. 1997, Kozlowski and Pallardy 1990, Montagu et al. 2003). Moreover, Savill et al. (1997), citing research conducted in *Chryptomeria japonica* by Wang et al. (1980), inform that removing 10% or slightly more of the live crown actually improved the growth. Savill et al. (1997), referring to research done in Europe and North America, also indicate that pruning more than 1/3 of canopy will reduce diameter growth. Uotila and Mustonen (1994), in a study on Scots pine (*Pinus sylvestris* L.), found that growth reduction was statistically significant (up to 33% decrease in diameter growth compared to the control) when 40% or more of the live crown was removed by pruning.

The photosynthetic surface of a tree crown, which is directly related to growth, is reduced at least for a certain period after pruning. However, in the remaining foliage, which generally functions below its maximum photosynthetic capacity, photosynthetic activity is enhanced during the years after pruning (Lovett Doust 1989). Alcorn et al. (2008) reported that in most artificial defoliation studies photosynthetic activity remained unchanged initially, and then increased following leaf-area recovery to levels even above those of plants that had not been defoliated. It, therefore, appears that a pruned tree, by increasing photosynthetic activities in its remaining foliage, allocates its energy to rapidly restore crown loss, which consequently leads to reduction of diameter growth. In short, trees recover leaf-area loss and consequently growth loss by increasing their photosynthetic activity following defoliation.

Each observation tree was surrounded by unpruned buffer trees to avoid any unequal competition and border effects. In this way it was expected that observation trees would be exposed to more or less equal competition, the only difference being the differential pruning effect on the trees.

It was observed that the duration of the recovery period from disturbance due to pruning varied at different experimental sites depending on site quality (Fig. 1). For example, recovery from pruning effects at »Bük« experimental site, which has the lowest site quality among the three test sites, lasted longer than the other two sites (6 years vs. 4 years). This implies that on good sites, trees perform better in producing new needles and branches in order to compensate for growth reduction caused by removed foliage and branches. It appears that any intervention on stands, including pruning, influences crown dynamics depending on species, site quality and age at which the intervention is applied (Forrester et al. 2010). Additionally, 50% pruning had no significant effect on DBH increment at »Bük« as opposed to »Nebiler« and »Kursunlu«. This can be explained by a higher response to silvicultural treatments on better sites compared to poor sites, which means that trees on less productive sites suffer from nutrients and water deficits more than they do from solar radiation.

At »Bük« test site, annual DBH increment under 75% pruning intensity was significantly lower than those under three other intensities (control, 25% and 50% pruning) during the first six years after pruning (2001–2006). However, this difference disappeared in the 7^{th} year (in 2007). At those test sites with higher site quality, »Nebiler« and »Kursunlu«, annual DBH increments both under 50% and 75% pruning intensities were statistically lower than those under control and 25% pruning intensities (Fig. 1, Table 2 and 3). The results show that the growth rate of *Pinus brutia* is higher on good sites, and that tree canopy can recover faster than that on poor sites, reaching the growth rate of the control group. Indeed, Endo and Mesa (1992) suggested heavier pruning, based on prior studies, on sites with higher site quality because faster recovery is possible on such sites.

Obviously, reduction in annual DBH increment would result in reduction of cumulative DBH and volume growth collectively. The results showed that pruning up to 75% of tree height reduced overall DBH growth by 9.0%, 6.5% and 6.7% in »Bük«, »Nebiler« and »Kursunlu«, respectively, some 14 years after pruning (Fig. 2). Estimates of stem volume production over 14 years suggested that 75% pruning would reduce standing volume (m^3/ha) by 18%, 19% and 21% for the three sites, respectively. Endo and Mesa (1992) conducted a study in Colombia on 3.5 year old *Pinus patula* plantations, pruned to an intensity of 30, 50 and 70% of total canopy. Based on analyses conducted 4.5 years after pruning, they also found that the 70% pruning treatment caused statistically significant reductions in volume increment per ha, and thus suggested a lower level of pruning for the species.

Pruning is targeted for providing cleartrunks in the final crop for more than 20 cm in mean stand diameter, which provide higher grade lumber. *P. brutia* can reach this diameter at approximately 40 to 70 years depending on site quality (Erkan 1996). Erkan et al. (2010) made an economical evaluation of pruning for *P. brutia* and showed that the internal rate of revenue (IRR) can reach up to 10% for 40 years rotation period for good sites. Longer rotation periods have less IRR due to the discount rate of money spent as pruning cost.

It should also be noted that there was no negative effect of pruning on DBH increment in the first growing season following pruning. This result implies that a tree stores nutrition in its different parts so that it compensates for the loss resulting from crown reduction during the first growing season after pruning. Kukpa (2007) found similar results in a study conducted on cherry trees.

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