Comparative Characterization of the Effects of the Climate–Tree–Growth Relationship in Anatolian Black Pine (*Pinus nigra* Arnold subsp. *pallasiana* (Lamb.) Holmboe) on Wood Treatability

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Abstract: The effects of the climate–tree–growth relationship on treatability were investigated in the Anatolian black pine (*Pinus nigra* Arnold subsp. *pallasiana* (Lamb.) Holmboe) based on the altitudinal locations at approximately 960 m (B1) and 1010 m (B2) in the former coniferous afforestation area in Beytepe, Ankara, Turkey. This was achieved by analysis of the 1° branches at 1, 2, and 3 m tree heights above ground level for the periods 82/98 (March 1982 to February 1998) and 98/04 (March 1998 to February 2004). It appeared that the climatic changes during the period 98/04 had a greater effect on the growth of the trees in both locations, where the differences became more noticeable from base to apex. The trees had more taper but had a larger diameter in B1 than in B2 during 98/04, and this directly affected wood density. Consequently, the faster growing B1 trees had a greater preservative uptake than in the slower growing B2 trees along the trunk. Therefore, to produce wood of adequate density and better permeability, it may be suggested that this species should be planted at Beytepe around the elevation of 950-1000 m with regard to the wider planting space of 2 m.

Key Words: Anatolian black pine, environmental factors, tree growth, wood treatability

İklim–Ağaç–Yetişme Karakteristik İlişkisinin Anadolu Karaçamı (*Pinus nigra* Arnold subsp. *pallasiana* (Lamb.) Holmboe) Türünün Emprenye Edilebilirliğine Etkisinin Karşılaştırılması

Özet: İklim–ağaç–yetişme ilişkisinin emprenye üzerine etkisi, Ankara Beytepe'deki ilk ağaçlandırma alanında yetişen Anadolu karaçamı (*Pinus nigra* Arnold subsp. *pallasiana* (Lamb.) Holmboe) için araştırıldı. Bu bağlamda, ağaçların büyüme özellikleri (boy, çap, budaklılık formasyonu) 960 m (B1) ve 1010 m (B2) yükseltisindeki yetişme muhitlerinden seçilen ağaçlar dahilinde, 82/98 peryodu (Mart-1982/Şubat-1998) ile 98/04 peryodu (Mart-1998/Şubat-2004) kapsamında incelendi. Bunun için; büyüme karakteristiği denek ağaçlarının boy ve göğüs yüksekliği çapı ile, emprenye edilebilirlik durumu ise bunların 1, 2 ve 3 m yüksekliklerinden kesilen 1° ana dalları ile belirlendi. Elde edilen sonuçlara göre, 98/04 peryodunda meydana gelen iklimsel değişikliklerin her iki yetişme bölgesinde de ağaçların yetişmesi (çap ve boy artımı) bakımından oldukça etkili ve önemli olduğu belirlendi. Buna göre, B1 bölgesinde yetişen ağaçların B2 bölgesindekilere nazaran 98/04 peryodunda daha geniş çapta fakat konikleşmiş bir biçimde büyüdükleri ve özgül ağırlığın buna bağlı olarak önemli ölçüde etkilendiği tespit edildi. Dolayısıyla, B1 bölgesinde yetişen ağaçların B2 bölgesindekilere göre daha hızlı yetişmeleri neticesinde, bunlardan elde edilecek ağaç malzemenin emprenye edilmesi halinde koruyucu sıvı içerilmesi miktarının (her üç yükseltideki 1° ana dallarından alınan numuneler bağlamında) yüksek bir düzeyde gerçekleşebileceği öngörülmüştür. Bu nedenle, uygun özgül ağırlık değerine sahip ve iyi emprenye olabilme özelliği gösteren nicelikte bir Anadolu karaçamı'nın Beytepe'de yetiştirilmek istenilmesi halinde, ağaçlandırmanın (dikim aralığı en az 2 m olacak şekilde) özellikle 950-1000 m seviyelerinde gerçekleştirilmesinin daha uygun olacağı önerilebilir.

Anahtar Sözcükler: Anadolu karaçamı, yetişme muhiti, çevresel faktörler, emprenye edilebilirlik

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Introduction

Environment, mainly in the form of wind action, induces mechanical stimuli, which influence the structural characteristics of wood, such as cell-wall thickness (Larson, 1962). However, the environment includes a large diversity of factors, which act both below the ground (e.g., moisture, nutrients in the soil) and above the ground (e.g., light, temperature), affecting the structure of the wood of a tree in a number of other ways (Zahner, 1963). Kozlowski (1971) stated that these factors create the microenvironment in which each individual tree grows. This microenvironment is not static throughout the life of a tree but is subject to change, thus contributing to variation in wood structure within a growth ring and from ring to ring. According to Richardson (1964), environmental factors (climate, fertilization, irrigation, tree spacing) are also thought to influence the development of growth stresses, and they may be related to changes in cell-wall thickness and microfibrillar angle. Therefore, the effect of environment is basically expressed through changes in ring width and proportion of latewood, which both directly affect the density and the fractional void volume of wood (porosity).

All of these above explanations show that variation between trees of the same species is influenced by environmental conditions and heredity. However, it is difficult to assess individually all the factors of such microenvironments, and to relate quantitatively their influence on the structure of wood (Hildebrandt, 1960).

The Anatolian black pine (*Pinus nigra* Arnold subsp. *pallasiana* (Lamb.) Holmboe) is one of the most indigenous species grown in Turkey (Kaya and Temerit, 1994). According to Yücel (2000), the total forest area in Turkey is 20.2 million hectares, and the Anatolian black pine is native to 2.2 million hectares of this area. Alptekin (1986) and Yaltirik (1988) described that its main distribution area is around the Mediterranean, Aegean and Marmara regions, whereas in the Black Sea region it is found in the Mediterranean enclave and is usually widespread at 350-800 m along the stream valleys in the inner parts of the west and central Black Sea regions. In central Turkey, however, it is found in some protected areas of the Central Anatolian Plateau only in small concentrations of coniferous forest. According to Ata (1995), since the Anatolian black pine grows contentedly in a various range of provenances in the prevailing climatic conditions, this species is mainly introduced to the plantations even in the continental regions at the steppes. The aim was to study, therefore, how the physical properties (including the treatability) of Anatolian black pine trees were affected by the environmental conditions in central Turkey, when established in the same site—but on different elevations—by analyzing individual branches.

Investigations were performed in the former coniferous afforestation area (along the Maslak Valley) in Beytepe Campus of Hacettepe University, Beytepe, Ankara, Turkey. The experimental area was previously used as uncultivated hill pastureland in the early 1970s, and was then gradually planted with the Anatolian black pine (*Pinus nigra* Arnold subsp. *pallasiana* (Lamb.) Holmboe). The Anatolian black pine trees planted at this site have grown in some contrasting ecological conditions; such situations close to species' distribution boundaries are of great interest in the investigation of tree response to climate. This site was therefore selected for our study based on its age and lack of recent disturbance. In earlier studies regarding Beytepe Campus, although considerable efforts were devoted to investigations of the flora (Erik, 1994) and the atmospheric pollens (Dogan and Erik, 1995), the wood properties including growth increment (on the base of crown development) of the planted trees of Anatolian black pine in the former coniferous afforestation area along the Maslak Valley have not been studied. Hence, the findings of this study are the first to come out on the behavior of tree development for the initial plantations of Anatolian black pine at this particular site.

Materials and Methods

Study site: The study site is situated in the Maslak Valley in Beytepe Campus, which is located on the Central Anatolian Plateau, approximately 17 km west of the city of Ankara at 39º 51' N and 32º 44' E (http://www.fallingrain.com/world/TU/68/Beytepe.html). The campus area, which covers an altitudinal range between approximately 900 and 1100 m extending from the north to the south, formerly had the appearance of the protected Central Anatolian steppe in the early 1970s but in the following years more than half of the total campus area changed into forest land due to afforestation, which was established gradually using various species (Erik,

1994, 2000). The location belongs to the arid climatic region of the continental Mediterranean area, which is characterized by great temperature differences between day and night, and dry summers with high light intensities and cold winters with slight precipitation (M.L., 1992). The area is geologically in the Central Anatolian Crystalline Complex (Goncuoglu et al, 1994), within the Ankara mélange belt (Bailey and McCallien, 1950), which represents the cretaceous ophiolitic mélange (Triassic complex) with Mesozoic carbonate blocks (Royaj et al., 2001). Furthermore, the region considered is phytogeographically in the Irano-Turanian zone, and is situated in square B4 (Davis, 1988).

Sample collection: As there were no such investigations previously, the altitudinal level of the trial locations was determined using a 1:25,000 scale geological map of Ankara I29–a2/a3, prepared by the Mining Research and Exploration Institute. In this context, this study was carried out at 2 locations (from the plantation established in 1982) in the western and eastern escarpments of the Maslak Brook in the mid-upper part of the Maslak Valley (based on the land that shows the stratigraphy of Pliocene aged sedimentary units), namely at approximately 960 m a.s.l. in B1 and somewhat higher in B2 at approximately 1010 m a.s.l. It was measured from the geological map that these locations were about 600 m from each other on a bird's-eye-view basis. The terrain has a western exposure in B1 and an eastern exposure in B2, and the steepness of its slope is about 20% in B1 and 30% in B2.

As these locations were introduced as an area of study for the afforestation of the Anatolian black pine in Beytepe, they were labeled as B1 and B2 for further possible research. For the study, 45 trees were selected in both locations, giving a total of 90 sample trees. To ensure that the complete range of tree sizes was represented in the samples, dbh (diameter at breast height; 1.3 m above ground (Philip, 1994)) of every selected tree in each location was measured with great care. The chosen trees were free from growth defects and were of good form as far as possible. Field data were also taken for planting space for both B1 and B2 to compare the spacing situation of the selected trees in these trial stands.

For the experimental analysis, the 1° branch of all trees was sampled directly after felling of the branches at the bottom of the stem (1 m) and at 2 locations in the upper parts of the stem (2 and 3 m heights). In this case, the number of the 1° branch on each tree was counted, and the transverse sectional area was measured at the midpoint. Since the research was carried out in 2 different experimental periods, the total number of the branches at the same location was separated into 2 groups to study the branches in equal numbers for both periods. Harvesting was performed at the end of February in 1998 and 2004, before the vegetative season, thereby preventing current growth. From each 1° branch, an experimental sample, referred to as "plug", was taken in 13 cm longitudinal length from the proximal first-order axis (Figure 1).
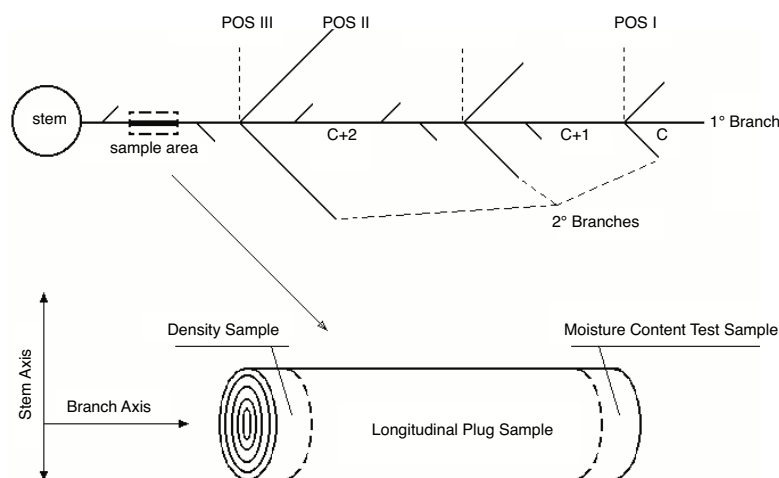

Figure 1. Collection and preparation of the experimental samples from the proximal first-order axis (1° branch), illustrating the structure up to order 2° branches (Modified from Roberntz, 1999).

After removal of the bark, small samples 1 cm thick were cut from the ends of each plug. The remainder of each plug was then cut to 10 cm in length. Small samples were identified to use either for determinations of density (used here synonymously with specific gravity) or of the green (free) moisture content of wood. In this case, one of the small samples was referred to as the "density sample" whereas the other was referred to as the "moisture content test sample". The longer sample, referred to as the "longitudinal plug sample", was used in the treatment experiment after being kiln dried to 12% moisture content.

Determination of wood density: The maximum moisture content method was used to determine wood density. The weight after drying until constant weight (at 103 ± 2 ℃) divided by the green volume (measured by the water displacement method (Oleson, 1971)) gives wood density. To obtain the green volume, experimental samples were firstly saturated with distilled water by pulling a vacuum of –80 kPa (600 mmHg) for 12 h, and soaking for 10 days. The volume of a body is then determined most accurately by determining the amount of liquid that it displaces. After having performed this procedure, wood density (d, kg m^{-3}) was calculated by using the following equation: $d = [Mo/(Mo/G) + (Ms - Mo)] \times 1000$, where Mo is oven dry mass (g), Ms is saturated mass (g), and G is specific gravity of cell wall substance (G is taken to be 1.53 g cm^{-3} (Kollman and Cote, 1968)).

The 1° branches of various trees of the same species growing at different elevations vary in the fractional void volume of wood (porosity), which is an important factor influencing the amount of liquid that can be absorbed in a given block volume and influences the way preservative retention is expressed. Therefore, a further assessment was made in relation to the maximum theoretical possible uptake of each plug based on porosity (P, %). This takes into account the density. The amount of space available in each plug was calculated as an estimation of the maximum volume of preservative that could be absorbed by wood (McQuire, 1970). This was calculated from the following equation: $P = [1 - (d/1530)] \times 100$.

Determination of Green Moisture Content (MC): The oven-drying method was performed for determination of MC. In this case, the green mass of each sample was weighed and was oven dried at 105 °C for 24 h. After cooling in a desiccator charged with silica gel, the dry mass was weighed, and moisture content (MC, %) of the plug samples was determined by MC = [(green mass/oven dry mass) – 1] x 100. The plug samples were then kiln-dried to nominal 12% moisture content by a mild drying schedule (schedule L: 60 °C dry bulb, 57 °C wet bulb (Pratt, 1986)).

Determination of longitudinal fluid uptake as the percentage of void volume filled (LVVF%): After the plugs were conditioned to an equilibrium moisture content of about 12% at 20 ℃ and 65% relative humidity, they were weighed and sealed with ABS (polymer dissolved in methyl ethyl ketone, Durapipe) leaving only one end open, so that penetration was restricted to one face. After reconditioning, the plugs were reweighed, and treated with a water-borne preservative, 2% CCA (Commercial Tanalith-C, Hicksons) (BS 4072, 1987 part 1), by a mild full-cell treatment schedule of 15 min vacuum (–0.84 bar) followed by pressure (3 bar) for 6 min. No final vacuum was applied. Treated masses were weighed and the fluid uptake (as the percentage of void volume filled in the longitudinal flow direction, LVVF%) was determined on a whole-block basis (McQuire, 1975) by LVVF% = [((Treated mass, g – Sealed mass, g)/Block volume, m^{3})/100]/P, where Block volume is calculated by the equation [p $(r)^{2}$ l], in which r is the radius of the sample (m) and l is its length (m).

Meteorological data: Mean air temperature (T, ℃) and total precipitation (P, mm) were collected from the meteorological station in Ankara and plotted based on months for the periods 82/98 and 98/04. The climatic characteristics of the area were also estimated according to data on the relative humidity (RH, %), and average maximum and minimum temperatures (Tmax, Tmin, ℃).

Results

Seasonal patterns: The seasonal patterns of the experimental area based on the mean monthly temperature and precipitation are illustrated in Figure 2 for the periods 82/98 (from March 1982 to February 1998) and 98/04 (from March 1998 to February 2004). The other comparative characterization of the climatic performance is shown in Figure 3.

In a manner in conformance with the continental climate, cold winters and hot summers characterize the climate in Beytepe (Ankara). For instance, a snow cover is often established in December and usually remains until
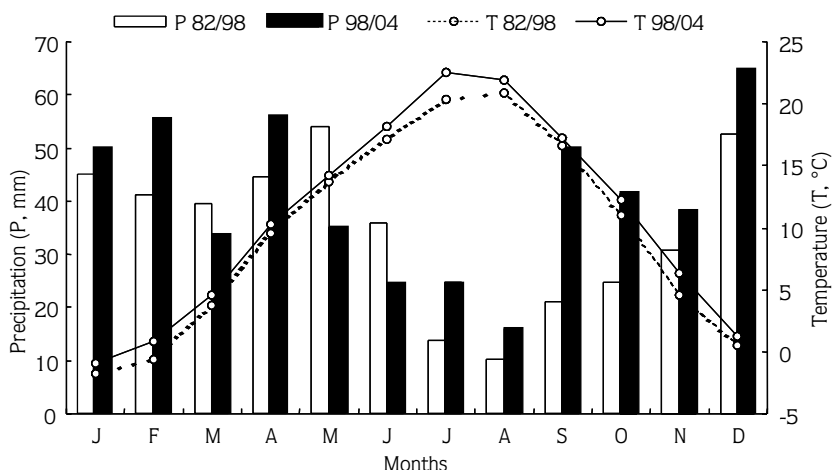
Figure 2. Mean monthly air temperature (T, ℃) and precipitation (P, mm) of the trial area during the study periods 82/98 (March 1982-February 1998) and 98/04 (March 1998-February 2004).
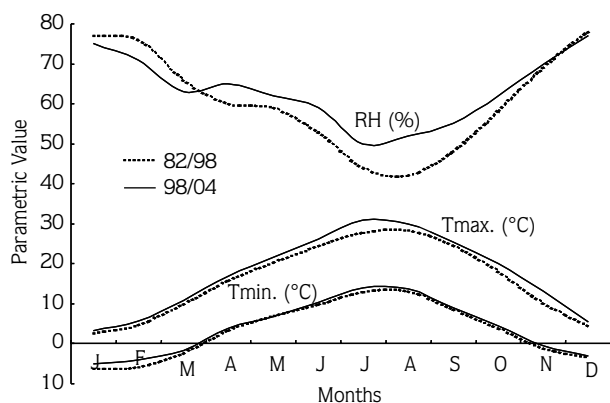

Figure 3. Changes in the relative humidity (RH, %), maximum average temperature (Tmax, ℃) and minimum average temperature (Tmin, ℃) in the experimental area during the study periods.

February, and the dry season extends from June to August. As shown in Figures 2 and 3, mean temperature during the period of 82/98 was 9.6 °C, and absolute relative humidity for the same period was about 61% with great variation during the year. These values were found to be increase to 10.7 °C and 63%, respectively, for the period 98/04. The hottest months were July (average of 20.3 °C for 82/98 and of 22.5 °C for 98/04) and August (20.8 °C, 21.9 °C), while the coldest months were January (–1.8 °C, –1.0 °C) and February (–1.6 °C, –0.8 °C). According to the forecast information, the period 98/04 had noticeably higher temperatures than 82/98 (Tmax: 17.5 °C, 15.9 °C; Tmin: 4.0 °C, 3.3 °C).

It was also noted that the sampled site almost always received slight precipitation in both periods due to its ravine nature. The main rainy season in the area extends from mid-March to May and rainfall is the greatest in April. It was, therefore, noted that the total precipitation of the area was distributed unequally over the considered periods, showing high intra-annual variation, i.e. 415 mm (82/98), and 470 mm (98/04). From May until September, the precipitation in the study area was significantly reduced compared to other months of the year in either period.

Growing Patterns: It was observed that the planting space varied between and within the trial locations due to the establishment of the plantation with random tree spacing. The field data showed that mean planting space was 1.8 m in B1 and 1.5 m in B2 (extending from 1.6 to 2.0 m in B1 and from 1.3 to 1.7 m in B2), and hence it was noted that B1 represented the widest spacing and B2 the narrowest. The mean spacing of the selected trees at 1.8 m in B1 was 86% and at 1.5 m in B2 was almost 78%. As both trial stands were unthinned from the time of the establishment of the considered plantation, it was also seen that there was heavy self-thinning in B2, where there were almost twice the number of feeble trees with small stem diameter in comparison to B1.

After selection of the trees in the specified size, both tree height and stem diameter at 1.3 m (dbh) was measured sequentially at the end of February in 1998 and 2004 for both trial locations. In this case, mean tree

height and mean stem diameter based on the dbh (in parentheses) in 1998 were 8.5 m (15.3 cm) in B1 and 7.4 m (13.9 cm) in B2. These values were observed to be change to 9.6 m (16.7 cm) and 8.1 m (15.0 cm), respectively, in 2004.

The growing patterns during the 2 periods for both locations are shown in Table 1 based on the stem and branch diameters, including with the proportion of heartwood in the collected branches. As expected, all the considered patterns declined with increasing tree height. Moreover, it was found that the selected trees were individually slower growing on one experimental location than another. In this case, the trees of B1 grew almost vigorously, whereas the trees of B2 showed slow-growing characteristics. The reason for the slower tree growth in B2 could be related to its higher elevation and to its narrower planting space. This situation was therefore reflected in the proportion of heartwood, which was the greatest in B2. This finding is in agreement with the report by Bamber (1976). However, considering between-tree variations within each location, there were no significant differences in the proportion of heartwood between the 2 study periods.

Furthermore, it appears that the climatic changes (i.e. based on the increasing precipitation) during the period 98/04 had a greater effect on the growth of the trees in both locations, where the differences became noticeable from the base to the apex of the selected trees. Comparison of the trial locations suggests that the trees had more taper but had a larger diameter in B1 than in B2 at the end of the period 98/04 and this directly affected tree volume (i.e. based on the stem diameter at 1 and 3 m heights). Larson (1969) explained that the differences in tree volume between the trial trees grown in the same area are dependent on the site conditions that control the growth rate of the trees as a result of the properties of the soil (fertility, depth, moisture retention) and the climate (temperature, photoperiod, light intensity, rainfall), which are both significantly affected by altitude. It is therefore not surprising that significant differences were observed in the growing patterns, which were greater at B1 than at B2 as a result of lower elevation and greater light intensity.

Physical properties: Descriptive statistics of the experimental results for moisture content (MC), wood density, porosity (P), and the preservative uptake in the longitudinal flow direction (as the percentage of void

Table 1. Growing patterns of the selected trees in the trial locations during the 2 study periods. Each item of data is the mean values ± SD obtained for all measurements.

Height (m)	82/98			98/04		
	Stem (cm)	Branch (mm)	Heartwood (%)	Stem (cm)	Branch (mm)	Heartwood (%)
Location B2						
3	11.8 ± 1.05	16.2 ± 0.47	56.5 ± 1.2	13.5 ± 1.18	17.4 ± 0.75	57.1 ± 1.5
2	14.2 ± 0.62	18.0 ± 0.54	59.6 ± 1.5	15.2 ± 1.15	19.0 ± 0.82	60.0 ± 1.3
1	15.4 ± 0.82	19.6 ± 0.63	62.8 ± 1.4	16.7 ± 0.94	20.2 ± 0.81	63.4 ± 1.1
Mean	13.8 ± 0.82	17.9 ± 0.55	59.6 ± 1.4	15.1 ± 1.09	18.8 ± 0.82	60.2 ± 1.3
Location B1						
3	13.4 ± 1.13	18.0 ± 0.74	52.8 ± 1.1	14.6 ± 0.86	19.1 ± 0.66	53.0 ± 1.6
2	15.0 ± 1.07	19.7 ± 0.60	55.0 ± 1.3	16.5 ± 1.60	20.8 ± 0.81	55.7 ± 1.2
1	17.3 ± 0.95	21.3 ± 0.39	56.5 ± 1.2	18.4 ± 1.01	22.5 ± 0.57	57.0 ± 1.3
Mean	15.2 ± 1.05	19.6 ± 0.58	54.8 ± 1.2	16.5 ± 1.20	20.8 ± 0.68	55.2 ± 1.4

The values shown for the stem and branch are the diameter figures. The values in 98/04 are the cumulative score based on the period 82/98.

volume filled, LVVF%) are given in Table 2. Examination of the means given in Table 2 reveals that the porosity tends to increase with increases in tree height in either location, whereas wood density seems to be almost the mirror image of the porosity from the base to the apex of the tree. In the cases of MC and LVVF%, it also shows an increasing trend among the tree heights in both B1 and B2.

Discussion

Wood density, Porosity, Moisture content: Mean density of the B2 trees—based on the branches at 1, 2, and 3 m heights—were significantly lower than that of the B1 trees, whereas the trees of both experimental locations were less dense in the period 82/98 than they were in 98/04 (Table 2). Consequently, for comparable parameters, the slower growing B2 trees had a higher porosity than the faster growing B1 trees. Furthermore, both locations showed the lowest porosity values at 1 m above ground level, where the MC was also the lowest value relating to the fractional void volume of wood. In this case, the high MC was associated with a greater porosity, which was accompanied by lower density. Thus, the faster growing B1 trees had less MC than did the slower growing B2 trees.

Although it appears that there were similar trends in both locations during the 2 periods considered, each location showed different characteristics based on the variation of wood density within trees (Figure 4). In this case, the greatest differences were noted in B1. For instance, wood density slightly decreased from the base (1 m) to 2 m height of the tree but then dramatically decreased from 2 m to 3 m in B1, whereas there was always a smooth decreasing trend along the tree trunk in B2. This relationship was the reverse in the cases of

Table 2. Means of green moisture content (MC), wood density, porosity (P, the fractional void volume of wood), and the longitudinal fluid uptake (in terms of the percentage of void volume filled, LVVF%). Figures in parentheses are standard deviations.

Height (m)	82/98				98/04			
	MC (%)	Density (kg m^{-3})	P (%)	Uptake (LVVF%)	MC (%)	Density (kg m^{-3})	P (%)	Uptake (LVVF%)
Location B2								
3	158	517	65.5	57.9	156	520	65.4	57.7
	(1.7)	(1.1)	(0.13)	(0.15)	(1.8)	(1.5)	(0.10)	(0.19)
2	148	544	63.8	56.9	136	579	61.4	53.5
	(1.7)	(1.6)	(0.11)	(0.20)	(1.2)	(1.5)	(0.15)	(0.24)
1	138	573	61.8	55.1	113	669	55.4	47.2
	(1.9)	(1.7)	(0.19)	(0.16)	(1.8)	(1.8)	(0.18)	(0.16)
Mean	147	545	63.7	56.7	135	589	60.7	52.8
	(1.8)	(1.5)	(0.14)	(0.17)	(1.6)	(1.5)	(0.14)	(0.20)
Location B1								
3	119	642	57.2	67.1	143	556	62.9	77.4
	(1.1)	(1.1)	(0.18)	(0.11)	(1.1)	(1.4)	(0.17)	(0.16)
2	115	658	56.1	65.4	108	690	53.9	62.3
	(1.3)	(1.9)	(0.12)	(0.19)	(1.2)	(1.3)	(0.19)	(0.22)
1	113	668	55.5	63.5	99	738	50.8	57.5
	(1.0)	(1.1)	(0.17)	(0.13)	(1.8)	(1.0)	(0.21)	(0.15)
Mean	116	656	56.3	65.3	117	662	55.9	65.7
	(1.1)	(1.4)	(0.16)	(0.14)	(1.4)	(1.2)	(0.19)	(0.18)

MC, density, P and LVVF% are significantly different from each other at $P < 0.05$ level in a given column according to the Tukey comparison test, which was performed by one-way analysis of variance.
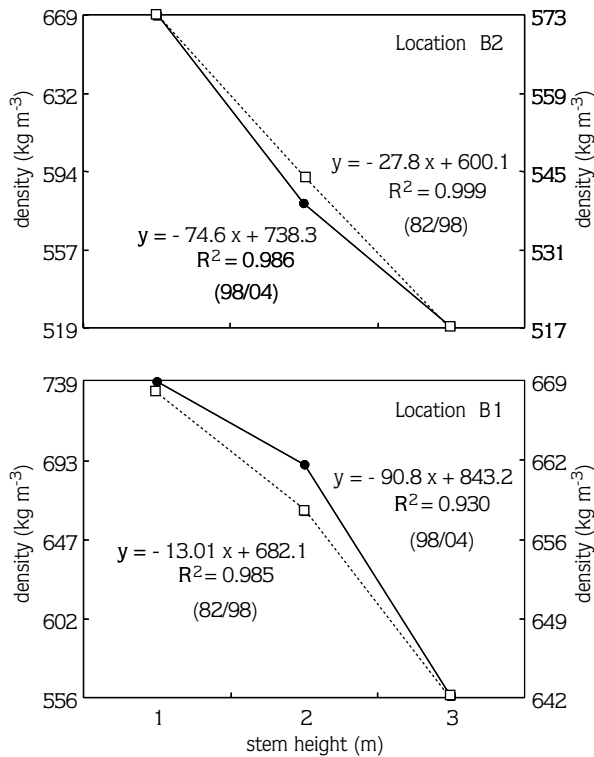
Figure 4. Variability of wood density along the heights in B1 and B2 during the study periods (dashed line indicates the period 82/98; solid line indicates the period 98/04).

porosity and MC values (Table 2). It could be therefore pointed out that all of these results were consistent with the findings reported by Eckstein et al. (1989) for the correlation of growth of coniferous trees with precipitation.

The experimental results also showed that, although a negative correlation was noted from the base to the apex of the tree, the overall pattern of wood density was not associated effectively with the proportion of heartwood in either location. The changes in wood density between the 2 periods were higher in each tree height, whereas the proportion of heartwood accounted for very little variation. In this case, the total amount of latewood (which was not assessed in this study) would be a direct influence on density values in comparison with the proportion of heartwood. On the other hand, branches of the trees grown in both B1 and B2, which both had the highest amounts of heartwood in the period 98/04, also had the highest wood densities in comparison to those for the period 82/98. The trend of the proportion of

heartwood from the base to the apex of the tree paralleled that for density in both locations. This observation, however, was sustained with the tree heights only, and has to be investigated and confirmed by further evidence in future studies.

Permeability: The results showed that LVVF% had an inverse relationship to wood density, whereas it had a likewise trend with porosity (Table 2). The LVVF% was lower at 1 m height than higher in the tree in both locations during both periods. Examination of the means presented within Figure 5 reveals that, although its variation was much higher in 98/04 than in 82/98, both locations received higher changes in LVVF%. In this case, B1 trees showed the greater difference between the 2 periods. These differences did not appear to be consistent with height within the tree in 98/04. On the other hand, in B2, the changes were closer to each other at each height in both periods.

Relation of wood density and permeability: Wood with low density usually retains more preservative (Koch, 1972) due to a function of high void volume (Kollmann and Cote, 1968) or, as stated by Siau (1984), the
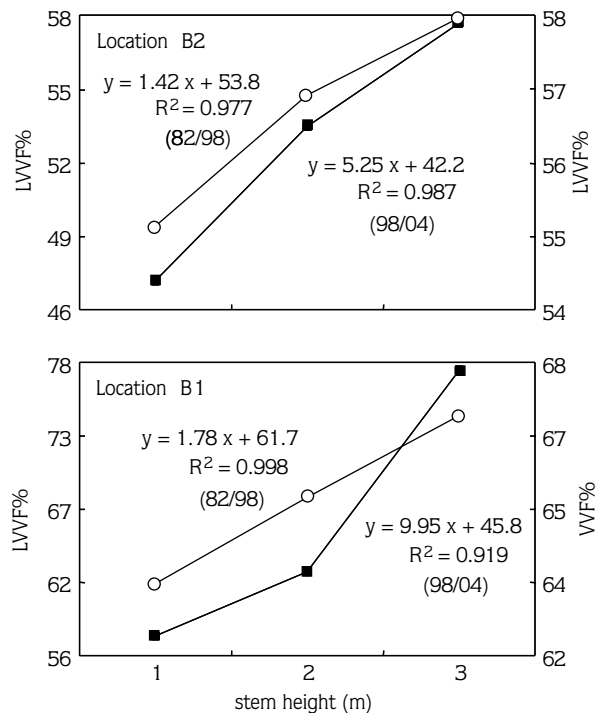

Figure 5. Variability of LVVF% along the heights in B1 and B2 during the study periods (dashed line indicates the period 82/98; solid line indicates the period 98/04).

fractional void volume (porosity) of wood determines the maximum amount of treating solution that can be injected into wood structure. Therefore, it was expected that the trend of LVVF% would approximately follow an inverse trend with density in correspondence with the increasing trend of porosity from the base to the apex of tree. However, the average results in the trees grown in B2, which had the higher porosity values in both periods, did not support this expectation. According to McQuire (1970), obviously some other factors such as the percentage of pits aspirated, or resistance of the bordered pit membranes to rupturing under pressure have an important effect on the relatively poor result of LVVF% based on the greater amount of porosity.

In contrast, LVVF% within trees—up to the stem—was significantly correlated with wood density, especially in B2 for either period. In B2, during 82/98 and 98/04 (in parentheses), an increase in LVVF% from 55.1 to 57.9 (and from 47.2 to 57.7) was paralleled by a corresponding decrease in density (kg m^{-3}) from 573 to 517 (and from 669 to 520). This pattern was also seen in B1, particularly during 82/98. However, the differences in wood density between the heights of the tree did result in greater variation in LVVF% in 98/04. In this context, the most important factor explaining higher longitudinal fluid uptake at 3 m height compared with lower in the tree may be related to the high porosity, which in turn influences the quality of treated wood, allowing better performance. This observation is presented in Figure 6 on a larger scale.

Effects of the planting space on the properties of tree growth: According to Briggs et al. (1986), influencing crown size is one of the most important ways in which the forester can regulate the amount of wood and timber quality produced. In this context, it has been stated by Echols (1959) and Moltesen et al. (1985) that wide initial spacing and thinning both stimulate growth in the crown and delay the onset of competition between
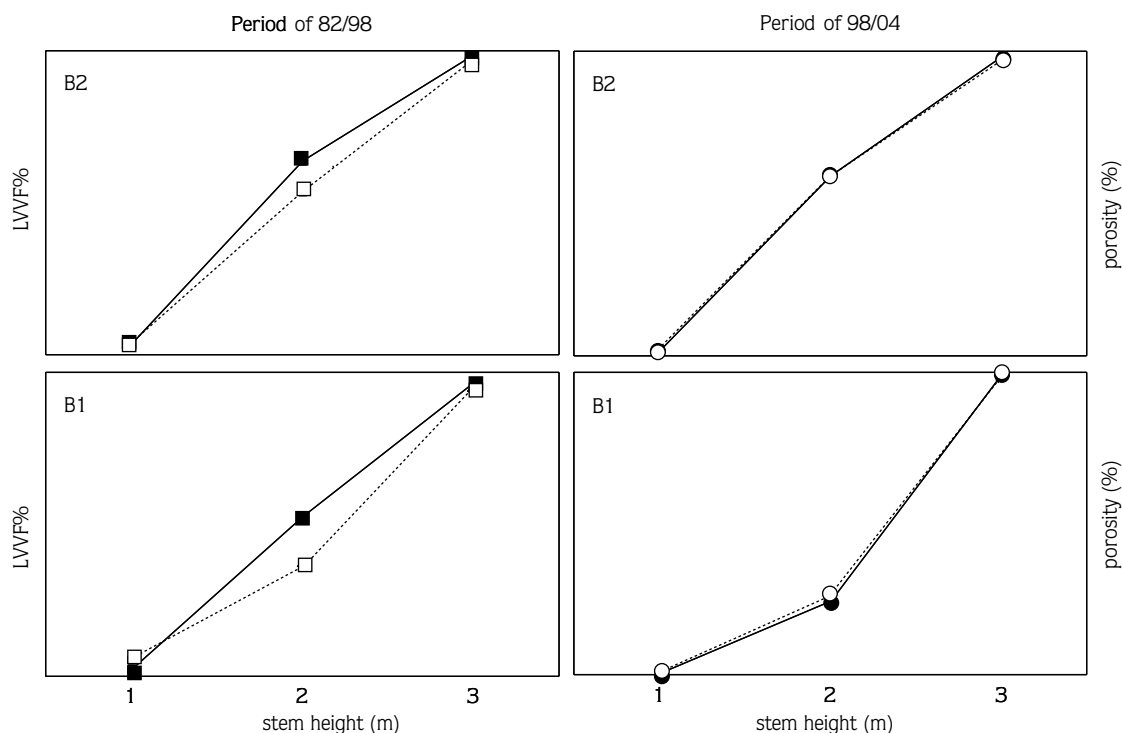

Figure 6. Comparison of changes in LVVF% (solid line) with porosity (dashed line) along the heights in either locations (B1 and B2) based on the study periods (82/98 and 98/04). Because the values are listed in Table 2, only the equations of linear relationships are shown here:
82/98 B2: (LVVF% = 53.8 + 1.43x R^2 = 0.977, porosity = 44.9 + 5.94x R^2 = 0.930)
82/98 B1: (LVVF% = 61.7 + 1.79x R^2 = 0.999, porosity = 55.4 + 0.85x R^2 = 0.985)
98/04 B2: (LVVF% = 42.3 + 5.25x R^2 = 0.987, porosity = 50.7 + 5.00x R^2 = 0.987)
98/04 B1: (LVVF% = 45.8 + 9.95x R^2 = 0.919, porosity = 43.8 + 6.05x R^2 = 0.927)

crowns for available light, whereas close spacing or pruning, especially if including the removal of live branches, reduces the amount of active crown. Therefore, the growth behavior of the selected trees of B1 and B2 could be related to planting space. As mentioned earlier, the trees grew vigorously in B1 in the wide planting space, whereas they grew slower in B2 at the base of close spacing. It was suggested by Denne (1976) that a restriction on crown development results in lower wood production, and the field data shown in Table 1 explain the overwhelming effect of planting space on tree development for both trial locations.

It is necessary to consider the implications of silvicultural practices on wood properties and the effect this has on the suitability of the resultant timber for particular end uses; for example, timber strength, drying properties and performance in service may all be affected (Dadswell, 1958; Fielding, 1967). In this case, specific gravity (used here synonymously with wood density) has been correlated with strength (Brazier, 1977), and it was observed in our study that wood density was higher in the selected trees of B1 grown at the widest spacing. Hence, for wider spaced trees, as the wood density increases the strength of timber also presumably increases and the rotation time of the crop becomes important. However, further work on the strength properties of the planted timber of the Anatolian black pine from various spacing stands (grown in the former coniferous afforestation area in Beytepe, Ankara) is required to clarify these points.

Conclusions

Generally, this study provides an opportunity to analyze the long-term and the short-term environmental effects on tree growth based on the branches at 1, 2, and 3 m heights. In this case, the results in terms of differences in longitudinal permeability related to wood density were correlated to the effect of the climatic changes during the study periods 82/98 and 98/04 in terms of the precipitation and the temperature. However, a number of other parameters need to be examined.

Data from this study indicated that the trees from wider spaced plots eventually came into less competition with each other than those at the narrower spacing and grew faster by succeeding with the western exposure. This has important consequences for timber producers and further work, especially incorporating strength testing, should be carried out on unthinned plots in the afforestation area in Beytepe to clarify these findings.

In conclusion, it may be suggested that to produce wood of adequate density and better permeability the future plantations of the Anatolian black pine (in a coniferous afforestation area in Beytepe, Ankara) should be provided for altitudes between 950 and 1000 m in accordance with tree spacing of 2 m. Moreover, further systematic research is also needed on the effects of spacing and crown size on wood properties, anatomical and gross timber features such as physical properties (i.e. fiber saturation point, swelling and shrinkage values), timber strength, drying characteristics, and performance in service (i.e. behavior of the natural durability against wood deterioration such as decay and termites).

Similar work has to be carried out in different locations among the plantation of Anatolian black pine (in the former coniferous afforestation area in Beytepe) to observe more comparable results on the basis of the effect of climate–tree–growth relationship on wood treatability.

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