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Growth and yield for scots pine and oriental beech mixed stands in different mixture ratios

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Abstract

Mixed forest ecosystems are important to human life. In general, there are many positive aspects of mixed stands compared to pure stands biologically and ecologically. In forestry, the importance of mixed stands has increased in recent decades due to the potential benefits which can be gained, such as increased production, greater diversity, improved nutrient cycling or reduced risk of biotic and abiotic damage. Scots pine (*Pinus sylvestris* L.) and Oriental beech (*Fagus orientalis* Lipsky) are two of the most important tree species in Turkey. Mixed Oriental beech and Scots pine stands with different forest structures and biodiversity are widespread in Black Sea Region, Turkey. The management of mixed stands of these species is of increasing importance to foresters in Turkey, and a crucial factor is knowledge of the growth and yield relationship for the sound management of these stands.

This study aimed to determination of the growth and yield relationship for Scots pine and Oriental beech mixed stands in different mixture ratios in Black Sea Region. The data were obtained from 162 temporary sample plots with ranging stand ages, site index, density and mixture percentages. The diameter at breast height of all trees, height and age of a sufficient number of trees for each sample plots were measured and the average age, site index, density and mixture percentage were estimated by these data. The sample plots have 31-150 years for Scots pine and 33-117 years for Oriental beech of stand age range, 16.2-34.9 m Scots pine and 14.7-32.3 m for Oriental beech of site index range, 0.10-0.76 of Scots pine mixture ratio range, 2.9-10.0 of stand density range.

With the generated equation systems, stand age, site index, density and mixture ratio of the four such as age, site index, density and mixture percentage main factors in Oriental beech - Scots pine mixed stands, including the effects on the stands were determined numerically. Volume of main stand and mean annual volume growth show irregular depending on the mixture ratio for the same average age, site index, density and mixture percentage. The number of Oriental beech trees are increasing, while number of Scots pine trees and total number of trees are decreasing depending on the mixture ratio for the same average age, site index, density and mixture percentage. Average height for both species is increasing when mixture ratio is increased to 0.4 to 0.8 for the same average age, site index, density and mixture percentage. The results were in arrangement with the acknowledged growth rules.

Key words: mixed stands, yield, mixture percentage, oriental beech, scots pine, black sea region in Turkey

1. Introduction

For the last about 35 years the growth and yield of monocultures vs. mixed-species forests has been the subject of studies by forest managers and ecologists. In the last few years, mixed stands dynamics returned into the focus of forest science (Forrester et al., 2006; Pretzsch et al., 2013). In forestry, the importance of mixed stands has increased in recent decades due to the potential benefits which can be gained, such as increased production, greater diversity, improved nutrient cycling or reduced risk of biotic and abiotic damage (Cannell et al., 1992; Man and Lieffers, 1999; Río M., and Sterba, 2009).

Mixed stand definition is as follows; forests including a second tree species with a basal area of at least 10 per cent, in addition to the most abundant species, were defined as mixed forests (Bravo-Oviedo et al., 2014). The advantages of mixed stands are as follows: are more resistant to biotic and abiotic damage, show a maximum total volume production that does not decrease with stand density approaching the maximum but remains constant (Pretzsch, 2002), are more stable due to their sub-dominant and co-dominant trees (Pretzsch, 2002), are able to compensate for impacts on the stand density (windthrow, heavy thinnings) much better than pure stands through an accelerated increment of the residual stand (Pretzsch, 2002), provide a wider range of size classes and timber products, contribute to a greater diversity and therefore provide more habitats, are more

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appealing to visitors (Jensen, 2000), help to reduce risks in the case of climate change. In addition, mixed stands reduce the risk of insect and disease outbreaks, support a more diverse habitat for flora and fauna, and are considered to have more visual appeal to the general public than monocultures (Steinbeck and Kuers, 1996).

The mixture percentage and the mixture percentage of the essential items such as volume, basal area varies by country. In order to speak of mixed stands, the species mixture must be represented in a certain mixture percentage. Although there is no value has been adopted as a general on this mixture percentage in the world, a species participate in mixture in different proportions is sufficient. The mixture percentage limits as basal area ratio are taken as 30% in Switzerland, as 10% in Germany, as 10% in Central America and as 25% Southeast Europe (Linden and Agestam, 2003). In Central Europe the limit is usually 10% of either basal area or volume (Burkhart and Tham, 1992). According to the forest management regulations in Turkey, 10% mixture percentage by volume is sufficient to be considered as a mixed stand (General Directorate of Forestry, 2008).

Mixtures of conifers and broadleaves are developing on many sites in upland forests and are favoured by current policies designed to diversify conifer plantations. The mixed stands of Oriental beech and Scotch pine have many biologically and ecologically positive features compared to pure Oriental beech and Scotch pine stands. These mixed stands provide proper conditions for the production of higher-quality, longer, and more well-formed stems; enable an increase in harvest due to having different species; provide mull humus soil composition by accelerating decomposition of soil litter; supply an optimal utilization of soil potential and habitat via different root systems; and are more resistant to wind, snow, and ice damage owing to their diversity, structure, and species combinations (Atay, 1990; Duchiron, 2000).

Oriental beech (*Fagus orientalis Lipsky*) and Scots pine (*Pinus sylvestris L.*) are two of the most economically and ecologically important forest tree species for Turkey (Ertekin et.al., 2015), with a wide range of commercial uses. Oriental beech grows naturally in Turkey and is located in the Black Sea, Marmara, Aegean, and East Mediterranean regions, as well as in many other regions of the world (Davis 1982; Ertekin et. al., 2015). Oriental beech forests in Turkey cover 1,899,929 ha and compose nearly 8.5 % of the country’s total forest area (General Directorate of Forestry, 2015). Scots pine grows in Turkey (38°34′ N to 41°48′ N and 28°00′ E to 43°05′ E), from Eskişehir in the west to the country’s border in the east, occupying the northern part of the country (Anşin and Özkan, 2006). Scots pine occupies about 1,518,929 ha (6.8 %) in Turkey, growing mainly in the Black Sea coastal mountains (General Directorate of Forestry, 2015). Scots pine grows from sea level up to 2700 m (mainly 1000–2500 m) in Turkey.

The mixtures of these tree species, resulting in diverse forest structure and biodiversity, are widespread in the north of Turkey. Based on a 2015 inventory by the General Directorate of Forestry, the total forest area of Turkey is 22,342,935 ha, of which 8,394,788 ha (38.0%) is mixed stands and 4,367,251 ha (52.02%) of the mixed stand is coniferous and deciduous mixed stand, of which 32,927 ha (1.40%) is mixed stand of Oriental beech and Scotch pine (General Directorate of Forestry, 2015).

Early studies about mixed stands of Oriental beech and Scotch pine, which are a mix of coniferous and deciduous trees and intolerant and tolerant trees, were carried out in Germany from Bonnemann (1939) (Pretzsch, 2009). In this study by Bonnemann (1939), it is stated that the number of stems per hectare for Beech is much greater in comparison with pine and that pine trees are taller at every age in comparison with beech. Whereas beech falls behind in growing in height during its youth, it later reaches pine and stays in the upper layer. Mean diameter of beech is thinner in comparison with pine; however, this difference decreases with increasing age. It was determined that the basal area of beeches is equal to those of pines at the age of 140 – 150. In addition, the total volume efficiency of Pine-Beech stand per hectare is greater in comparison with that of pure Scots Pine stand. Weck (1955) determined that the total stand volume of pine-beech mixed stand is greater in comparison with those of pure pine and beech stands. Wiedemann (1949) determined that the increment is greater in equal age Scots Pine – Beech mixed stands both during the youth and the old periods in comparison with pure stands. In addition, Erteld and Hengst (1966) have determined that the mean volume increment for old pure beech stands is greater in comparison with those of pine-beech mixed stands (Fırat, 1972).

In recent years, studies about the planning of mixed stands have become popular, resulting in an increasing trend in these studies worldwide. Changes in silvicultural planning approaches from pure stands to mixed stands increase the need for growth models to determine the effects of silvicultural activities applied in mixed stands. The management of mixed stands of these species is increasingly important for foresters in Turkey. A crucial factor for the sound management of these stands is knowledge of the growth at the individual tree level of each different species. The objective of this study is to develop a site conversion equation for mixed stands of Scots pine and Oriental beech in the Black Sea Region in the north of Turkey.

This study aimed to determination of the growth and yield relationship for Scots pine and Oriental beech mixed stands in different mixture ratios in Black Sea Region.

2. Materials and methods

The study area is in the Black Sea Region, the North of Turkey. The study area covers the Forest Districts of Zonguldak, Kastamonu, Sinop, Ankara and Amasya. This study area ranges in latitude (North) from 40º15'28" to 41º46'15" and in longitude (East) from 32º28'02" to 37º32'56" (Figure 1). These sampled mixed stands were naturally regenerated and uniformly stocked stands (55-97% tree layer cover), without any evidence of historical damage such as fire or storms. Located between 750 m and 1750 m altitude, the study area is characterized geomorphological by high mountainous land, with moderate steep slopes ranging between 5% and 60% (30 % of the whole area). The mean annual temperature is between -5.8 Cº and 14.6 Cº, and minimum and maximum temperatures are -8.4 Cº and 22.67 Cº, respectively. The climatic regime is of typical Black Sea climate characterized by a mild winter, a cool summer and relatively homogeneous precipitation as high as 1000 and 1250 mm.

In this study, the data were obtained from 162 temporary sample plots with ranging stand age, site index, density and mixture percentage in mixed stands Scots pine (*Pinus sylvestris* L.) and Oriental beech (*Fagus orientalis* Lipsky). The 162 regional-level sample plots obtained by Kahriman (2011) were used in this study. These studied beech/pine mixed stands were selected to have uniform stratification when both two species have been in the upper stratum, such that there are site trees of both species in the plot. The size of circular plots ranged from 600 to 1200 m^2, depending on stand density in order to achieve a minimum of 30-40 trees per these species in sample plots. Within each plot, tree species and the diameter at breast height (d.b.h.) of trees ≥ 6 cm were recorded in the inventory. The diameters at breast height, stump diameter, total height, crown height, crown diameter, age, diameter increment and spatial coordinate were measured in trees of sample plots. In each plot altitude, aspect and slope were also measured.

Figure 1. Map showing the locations of the regional administrative forest districts in which mixed Scots pine-Oriental beech were studied in the north of Turkey.

Descriptive statistics including mean, minimum, maximum and standard deviation of the plot characteristics such as stand age, site index, quadratic mean diameter, mean height weighted by basal area, stand basal area, stand volume, number of trees per hectare, stand density and mixture percentage are listed below (Table 2).

Table 1. Minimum, maximum, mean and standard deviation (SD) of main characteristics of the study material.

Species	Variable	Mean	Min.	Max.	SD
Scots pine	A (year)	84.2	31.4	150.1	27.4
	SI (m)	25.9	16.2	34.9	4.3
	$\bar{d}_g$ (cm)	34.9	16.6	51.1	8.3
	$\bar{h}_g$ (m)	22.5	8.2	35.1	6.7
	G (m^2/ha)	20.1	6.1	42.9	8.3
	V (m^3/ha)	218.0	32.0	535.3	120.6
	N (number/ha)	230.8	62.5	600.0	117.9
Oriental beech	A (year)	71.9	33.2	117.0	19.5
	SI (m)	24.3	14.7	32.3	3.6
	$\bar{d}_g$ (cm)	20.1	8.8	39.7	5.7
	$\bar{h}_g$ (m)	18.3	9.2	28.7	5.0
	G (m^2/ha)	13.0	1.8	33.6	6.2
	V (m^3/ha)	116.8	6.5	335.8	76.7
	N (number/ha)	436.7	60.0	1025.0	200.0
Sum	G (m^2/ha)	33.1	12.7	55.9	10.9
	V (m^3/ha)	334.8	52.3	717.9	169.0
	N (number/ha)	667.6	180.0	1520.0	241.8
	RD	6.5	2.9	10.0	1.8
	P_{Pine}	0.61	0.24	0.90	0.14

A age, SI site index, $\bar{d}_g$ quadratic mean diameter, $\bar{h}_g$ mean height weighted by basal area, G basal area, V stand volume, N number of stems per hectare, RD relative density (stand density according to Curtis, 1982), P_{Pine} mixture percentage according to Scots pine tree.

When analyzing the effect of interspecific interaction on stand growth in mixed species forests, the definition of species proportions plays an important role. Mixture is expressed as percentage and shown with the numbers between 10 %- 90 %. Species proportions can be defined in many different ways, by crown cover, stem number, basal area, volume, or biomass; depending on the objective of the study (Bravo-Oviedo et al., 2014). For a given mixed stand, the species proportion may differ considerably depending on species proportion definition, and, consequently, different net effects on stand growth were reported (Pretzsch, 2009). The most common way to define species proportion is by basal area (Légaré et al., 2004; Perot and Picard, 2012; Groot et al., 2014). Besides, participation rate of the species to the canopy cover is based on the determination of the mixture ratio on the aerial photo.

Although mixture percentage can be identified by taking into account of various stand parameters such as the number of trees, basal area and volume, it can be determined generally depending on basal area values of species. Because basal area can be determined easily and is in relation with a high level of stand volume. The mixture percentage is calculated depending on basal area of pine – beech species in this study. Mixture percentage of mixed stands of Oriental beech and Scotch pine is calculated by the proportion of the total basal area of Scots pine trees in stands to the total basal area of the stands.

$$P_{Pine} = \frac{G_{Pine}}{G_{Total}}$$

where P_{Pine} is mixture percentage of Scots pine in stands, G_{Pine} is total basal area of Scots pine trees in stands and G_{Total} is the total basal area of the stands.

The data evaluated within the scope of this study were obtained from the study by Kahriman (2011). In the study carried out by Kahriman (2011), stand models related to Scots pine-Oriental breech mixed stands was developed as density-variable yield tables. The mean diameter ($\bar{d}_g$), mean height ($\bar{h}_g$), tree density (N), basal area (G) and stand volume (V) of main stand were calculated in density-variable yield tables as functions of stand age (A), site index (SI), stand density (RD) and mixture ratio (P_{Pine}) via regression equations. Afterwards, the change in the main and removed stand elements of the density-variable yield tables as well as the other elements of the yield table were calculated for both Scots pine and Oriental breech separately on the basis of stands. Growth values of Scots pine-Oriental breech mixed stands were put forth in this study for different mixture percentages using the data acquired from the study carried out by Kahriman (2011).

3. Results

162 samples were taken in this study that will reflect the variety in age, site index, stand densities and mixture percentages. The distributions of sample areas according to age, site index, stand density and mixture percentages was given in Figure 2.

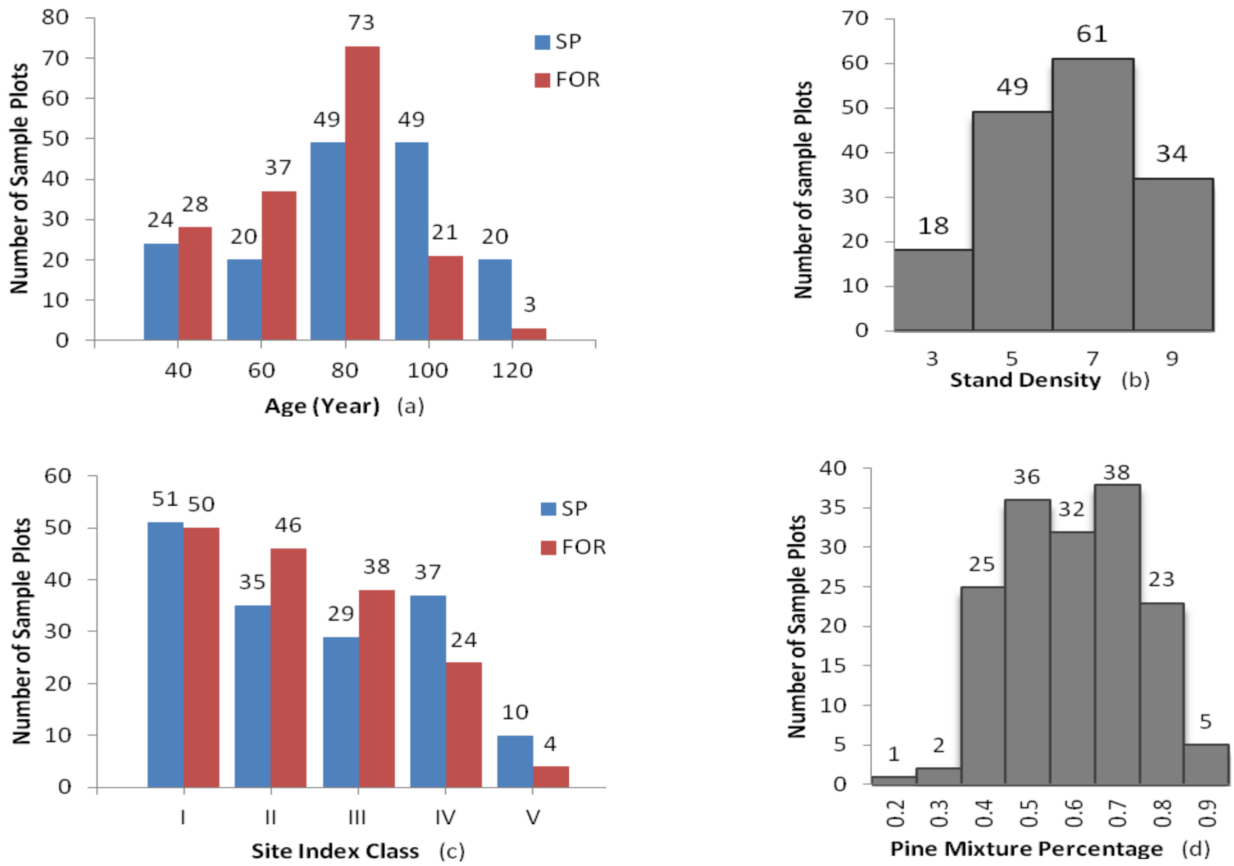

Figure 2. Distribution of sample plots by age (a), stand density (b), site index class (c) and mixture percentage (d) (SP: Scots pine, FOR: Oriental beech)

The sample plots distribution for Scots pine according to the age classes of 40, 60, 80, 100 and 120 were respectively 24, 20, 49, 49 and 20 whereas for Oriental Breech it was 28, 37, 73, 21 and 3 (Figure 2a). 18 of the sample plots are in the stand density of 3, 49 are in the stand density of 5, 61 are in the stand density of 7 and 34 are in the stand density of 9 (Figure 2b). The distribution of sample plots according to site index for Scots pine from good site index to bad site index was 51, 35, 29, 37 and 10 respectively whereas for Oriental Breech it was 50 46, 38, 24 and 4 (Figure 2c). When the distributions of sample plots according to the mixture percentages of Scots pine are examined, it was observed that of the 162 sample sites, the mixture percentages were 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 for 1, 2, 25, 36, 32, 38 and 28 respectively (Figure 2d).

The change of total stand volume based on mixture percentage for the same age, site index class and stand density were given in Table 2 and Figure 3. Total stand volume shows an irregularity based on the mixture percentage for the same age, site index class and stand density (Table 2, Figure 3). Namely; the total yield shows a general decrease in stands that are younger than 40 years for the same stand density and site index from a mixture percentage of 0.8 to 0.6 and 0.4. Total stand volume increases towards 0.6, 0.4, 0.8 mixture percentage for the low densities of I. SI stands aged 40-60 and towards 0.4, 0.6, 0.8 for the stands in the II. III. IV. and V. SI and the moderate and high densities of the I. SI stands. Total stand volume increase is observed in the I. SI and II. SI low density stands at the age of 60-80 towards a mixture percentage of 0.6, 0.4, 0.8 respectively; whereas the mean stand volume increases towards the 0.4, 0.6, 0.8 mixture percentage respectively for III., IV., V. SI and the moderate and high density stands of the II. SI. An increase in the total stand volume is observed towards 0.6, 0.4, 0.8 mixture percentages respectively for the I., II. SI of stands older than 80 and the lower stand density of the III. SI; whereas an increase in the total stand density is observed towards 0.4, 0.6, 0.8 mixture percentages respectively for the IV., V. SI and the moderate and higher density stands of the III. SI.

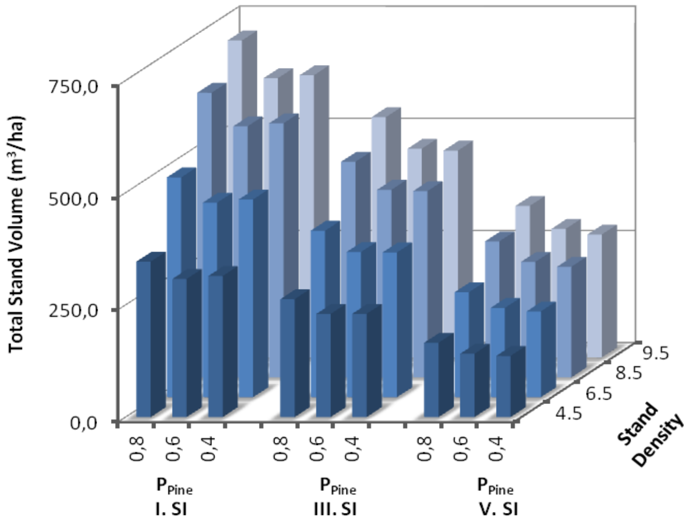

Figure 1. The change of Total Stand Volume according to index site class, stand density and mixture percentage (stand age=80 year)

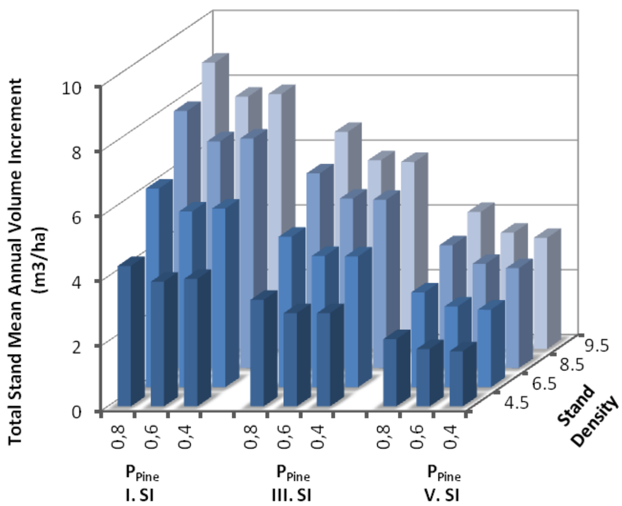

Figure 2. The change of Mean Annual Volume Increment for Total Stand according to site index class, stand density and mixture percentage (Stand age=80 year)

Whereas total stand volume is 634.1, 566.3 and 559.4 m^3/ha for the 8.5 stand density I. SI stands aged 80 with respective mixture percentages of 0.8, 0.4 and 0.6 respectively; it is 480.5, 415.0 and 418.0 m^3/ha for the III. SI and 303.0, 246.4 and 257.3 m^3/ha for the V. SI. Whereas total stand volume is 229.7, 193.6 and 185.9 m^3/ha for the 8.5 stand density III. SI stands aged 40 with respective mixture percentages of 0.8, 0.6 and 0.4; it is 480.5, 418.0 and 415.0 m^3/ha for 80 year stands with respective mixture percentages of 0.8, 0.6 and 0.4 and 554.4, 485.0 and 483.8 m^3/ha for 120 year old stands with respective mixture percentages of 0.8, 0.6 and 0.4 (Table 2).

Table 2. The change of Total Stand Volume and Mean Annual Volume Increment for Total Stand (m^3/ha) according to stand ages, site index, density and mixture percentage

Total Stand Volume						Mean Annual Volume Increment for Total Stand					
SD	P_{Pine}	A	I. SI	III. SI	V. SI	SD	P_{Pine}	A	I. SI	III. SI	V. SI
4.5	0.4	40	140.9	102.3	59.6	4.5	0.4	40	3.52	2.56	1.49
4.5	0.4	80	314.3	229.9	136.1	4.5	0.4	80	3.93	2.87	1.70
4.5	0.4	120	366.5	268.4	159.2	4.5	0.4	120	3.05	2.24	1.33
4.5	0.6	40	142.3	105.2	63.3	4.5	0.6	40	3.56	2.63	1.58
4.5	0.6	80	307.7	229.8	141.2	4.5	0.6	80	3.85	2.87	1.77
4.5	0.6	120	356.8	266.9	164.6	4.5	0.6	120	2.97	2.22	1.37
4.5	0.8	40	165.1	123.6	76.2	4.5	0.8	40	4.13	3.09	1.90
4.5	0.8	80	346.4	262.6	165.7	4.5	0.8	80	4.33	3.28	2.07
4.5	0.8	120	399.5	303.5	192.3	4.5	0.8	120	3.33	2.53	1.60
6.5	0.4	40	198.7	144.5	84.2	6.5	0.4	40	4.97	3.61	2.11
6.5	0.4	80	440.7	322.6	191.2	6.5	0.4	80	5.51	4.03	2.39
6.5	0.4	120	513.4	376.1	223.4	6.5	0.4	120	4.28	3.13	1.86
6.5	0.6	40	202.3	149.7	90.2	6.5	0.6	40	5.06	3.74	2.25
6.5	0.6	80	433.4	323.7	199.0	6.5	0.6	80	5.42	4.05	2.49
6.5	0.6	120	501.9	375.5	231.6	6.5	0.6	120	4.18	3.13	1.93
6.5	0.8	40	236.1	176.9	109.1	6.5	0.8	40	5.90	4.42	2.73
6.5	0.8	80	489.8	371.1	233.9	6.5	0.8	80	6.12	4.64	2.92
6.5	0.8	120	563.9	428.2	271.0	6.5	0.8	120	4.70	3.57	2.26
8.5	0.4	40	255.5	185.9	108.5	8.5	0.4	40	6.39	4.65	2.71
8.5	0.4	80	566.3	415.0	246.4	8.5	0.4	80	7.08	5.19	3.08
8.5	0.4	120	659.7	483.8	288.0	8.5	0.4	120	5.50	4.03	2.40
8.5	0.6	40	261.6	193.6	116.8	8.5	0.6	40	6.54	4.84	2.92
8.5	0.6	80	559.4	418.0	257.3	8.5	0.6	80	6.99	5.23	3.22
8.5	0.6	120	647.8	485.0	299.5	8.5	0.6	120	5.40	4.04	2.50
8.5	0.8	40	306.5	229.7	141.8	8.5	0.8	40	7.66	5.74	3.54
8.5	0.8	80	634.1	480.5	303.0	8.5	0.8	80	7.93	6.01	3.79
8.5	0.8	120	730.1	554.4	351.1	8.5	0.8	120	6.08	4.62	2.93
9.5	0.4	40	283.6	206.4	120.6	9.5	0.4	40	7.09	5.16	3.01
9.5	0.4	80	629.0	461.1	274.1	9.5	0.4	80	7.86	5.76	3.43
9.5	0.4	120	732.8	537.8	320.5	9.5	0.4	120	6.11	4.48	2.67
9.5	0.6	40	291.0	215.4	130.0	9.5	0.6	40	7.27	5.39	3.25
9.5	0.6	80	622.5	465.4	286.7	9.5	0.6	80	7.78	5.82	3.58
9.5	0.6	120	721.1	540.0	333.9	9.5	0.6	120	6.01	4.50	2.78
9.5	0.8	40	341.6	256.0	158.0	9.5	0.8	40	8.54	6.40	3.95
9.5	0.8	80	706.6	535.5	337.8	9.5	0.8	80	8.83	6.69	4.22
9.5	0.8	120	813.7	618.2	391.7	9.5	0.8	120	6.78	5.15	3.26

A age, SI site index, RD relative density (stand density according to Curtis, 1982), P_{Pine} mixture percentage according to Scots pine tree.

Mean annual volume increment for total stand is irregular based on the mixture percentage of the same age, site index and stand density (Table 2, Figure 4). The mean annual volume increment values for stand in the 8.5 stand density aged 80 in the I. SI are 7.93, 7.08 and 6.99 m^3/ha for respective mixture percentages of 0.8, 0.4 and 0.6; whereas the values are 6.01, 5.19 and 5.23 m^3/ha for the III. SI and 3.79, 3.08 and 3.22 m^3/ha for V. SI. Whereas the mean annual volume increment values for total stand are 5.74, 4.84 and 4.65 m^3/ha respectively for III. SI 8.5 stand density stands aged 40 with respective mixture percentages of 0.8, 0.6 and 0.4; for those aged 80 with mixture percentage values of 0.8, 0.6 and 0.4 they are 6.01, 5.23 and 5.19 m^3/ha respectively and 4.62, 4.04 and 4.03 m^3/ha for mixture percentage values of 0.8, 0.6 and 0.4 aged 120 (Table 2).

Volume and volume increments for the same stand density and site index have the highest values for the 0.8 mixture percentage in the density-variable yield tables for Scots pine-Oriental beech mixed stands. Whereas volume and volume increments decrease from a mixture percentage of 0.8 to 0.6 and 0.4 for young stands, it generally decreases from 0.8 mixture percentage to 0.4 and 0.6 for the fine site indexes of old stands. The total volume of the stand increases in good site index in which the growing energy of the beech trees with wolf tree feature is given to stem growth instead of branching. This is observed in old stands with good site index. Mixture percentage of 0.6 in stands where Oriental beech individuals are generally overgrown and 0.4 mixture percentage in stands with shapelier stems which are not overgrown are ranked second. The fact that volume is greatest in the 0.8 mixture percentage can be explained by the facts that the Scots pine which is a light tree has higher volume since it is located at the upper layer and has greater diameter. The fact that volume is smaller when the mixture percentage is % 40-60 can be explained by the facts that the diameter and heights of Scots pine individuals are % 80 lower in comparison with the mixture and that the number of beech per unit area is smaller. That is, the diameters of Scots pine trees decrease depending on their diameter and height when the ratio of both species in the stand is equal while the total volume decreases since the number of beech trees is smaller. It can be concluded that the change in the volume and volume increase depending on the mixture percentage is natural for the Scots pine and Oriental beech mixed stands. The fact that volume and volume increase values are greater in stands with greater ratio of Scots pine in Scots pine-Oriental beech mixed stands shows that the volume and volume increase values are greater is greater as we move towards pure Scots pine stands. Çalışkan (1989) has determined that the stand volume and basal area is greater in stands with greater number of Scots pines in the Karabük Büyükdüz research forest with Scots pine, fir and beech mixed stands.

The change of stand volume with mixture percentage is given in Figure 5. When Figure 5 is examined, it is observed that there is no data related negativity that might cause the low values of the observed actual volume values in the sample areas for the mixture percentage.

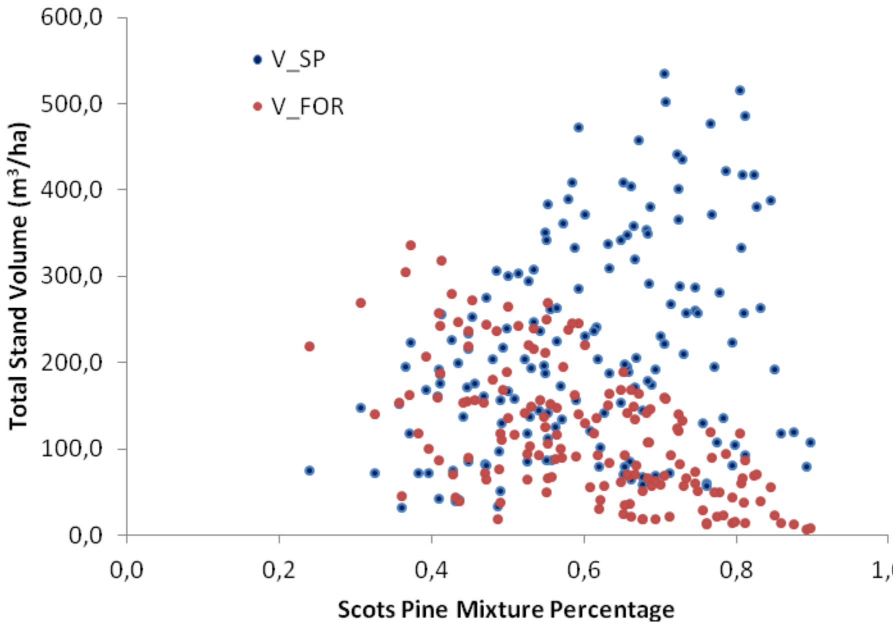

Figure 5. The change of Scots pine and Oriental beech Stand Volume according to Scots pine mixture percentage

The quadratic mean diameter (Figure 6a), mean height weighted by basal area (Figure 6b), total stand volume (Figure 7a), mean annual volume increment for total stand (Figure 7b), tree density (Figure 8a) and mean annual increment (Figure 8b) values related with the density-variable yield tables prepared for Scots pine-Oriental beech mixed stands for both species were compared at a stand density of 8.5 and the site indexes in all mixture percentages.

The quadratic mean diameter and mean height weighted by basal area values are greater for the Scots pine in comparison with the Oriental beech for stand density of 8.5 and III. SI (Figure 6a and 6b).Whereas Scots pine mean height increases as we move from mixture percentage of 0.4 to 0.6 and 0.8 until the age of 80, it increases from mixture percentage of 0.8 to 0.6 and 0.4 for ages above 80. Oriental beech quadratic mean diameter increases as we move from mixture percentage of 0.8 to 0.6 and 0.4 (Figure 6a). Mean height weighed by basal area values increase from mixture percentage of 0.8 to 0.6 and 0.4 for both species (Figure 6b). Total stand volume and mean annual volume increment for total stand values increase from mixture percentage of 0.4 to 0.6 and 0.8 for Scots pine, whereas for Oriental beech it increases from a mixture percentage of 0.8 to 0.6 and 0.4 (Figure 7a and 7b). Whereas volume and increment values for the 0.4 mixture percentage are greater in Scots pine until the age of 55, after the age of 55 these values are greater for Oriental beech. Whereas mean annual increment increases for Scots pine from a mixture percentage of 0.4 to 0.6 and 0.8, it increases from a mixture percentage of 0.8 to 0.6 and 0.4 for Oriental beech (Figure 8b). Mean annual increment at the mixture percentage of 0.4 is greater in Oriental beech in comparison with Scots pine. Whereas tree density increases for Scots pine from a mixture percentage of 0.4 to 0.6 and 0.8, it increases from a mixture percentage of 0.8 to 0.6 and 0.4 for Oriental beech (Figure 8a). The total tree density in the stand is greatest for the mixture percentage of 0.4, whereas it is smaller for the mixture percentage values of 0.6 and 0.8.

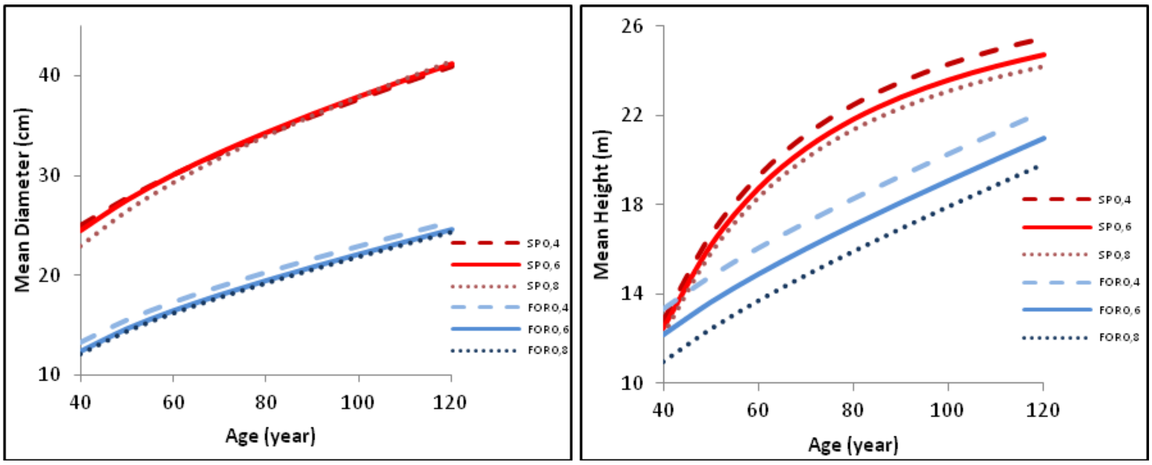

Figure 6. The compare of mean diameter (6a) and mean height (6b) based on mixture percentage for both species at a stand density of 8.5 and the III. SI

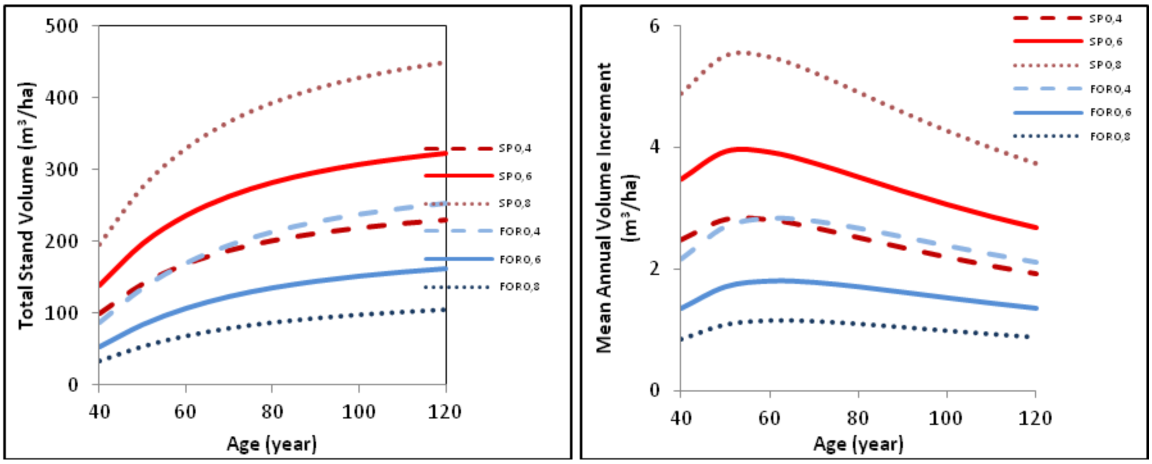

Figure 7. The compare of total stand volume (7a) and mean annual volume increment (7b) based on mixture percentage for both species at a stand density of 8.5 and the III. SI

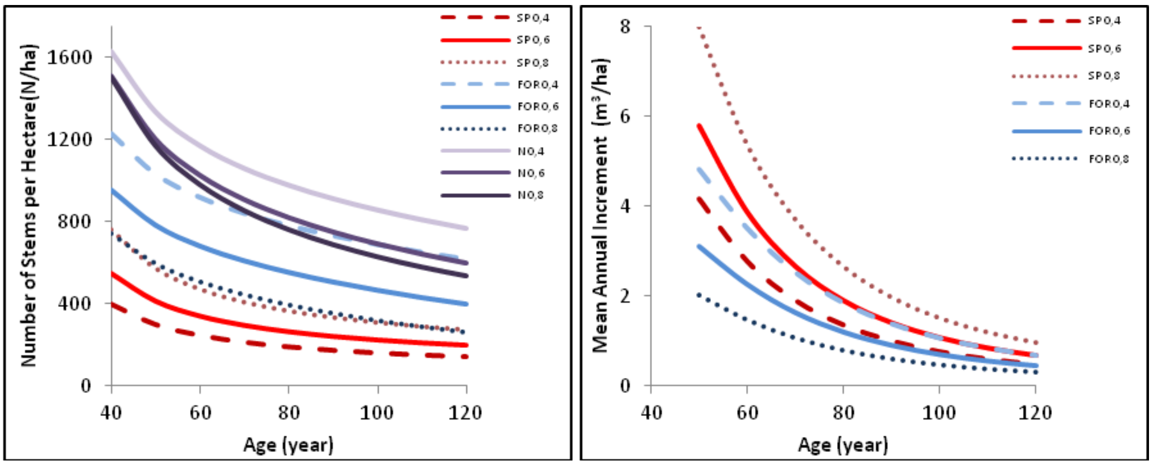

Figure 8. The compare of tree density (8a) and mean annual increment (8b) based on mixture percentage for both species at a stand density of 8.5 and the III. SI

The density-variable yield tables prepared as part of our study were compared with the normal yield tables prepared by Alemdağ (1967) and Batu (1971) for pure Scots pine and by Carus (1998) for pure Oriental Beech. The normal stand density value of Scots pine-Oriental beech mixed stands was taken as 8.5 considering the density of the areas where measurements were carried out. The comparison of yield tables were carried out using the volume and volume increment values at the stand density of 8.5 which is considered as normal in this study. In addition, values in the yield tables for stands of tree species grown under the best conditions, meaning the values for the stands in the first site index for all species were compared in order to get better results. The total stand volume, mean annual increment and mean increment values for total stand for Scots pine and Oriental beech as well as the Scots pine-Oriental beech stands in this study with good site index and normal density are given in Figure 9a, 9b and 10.

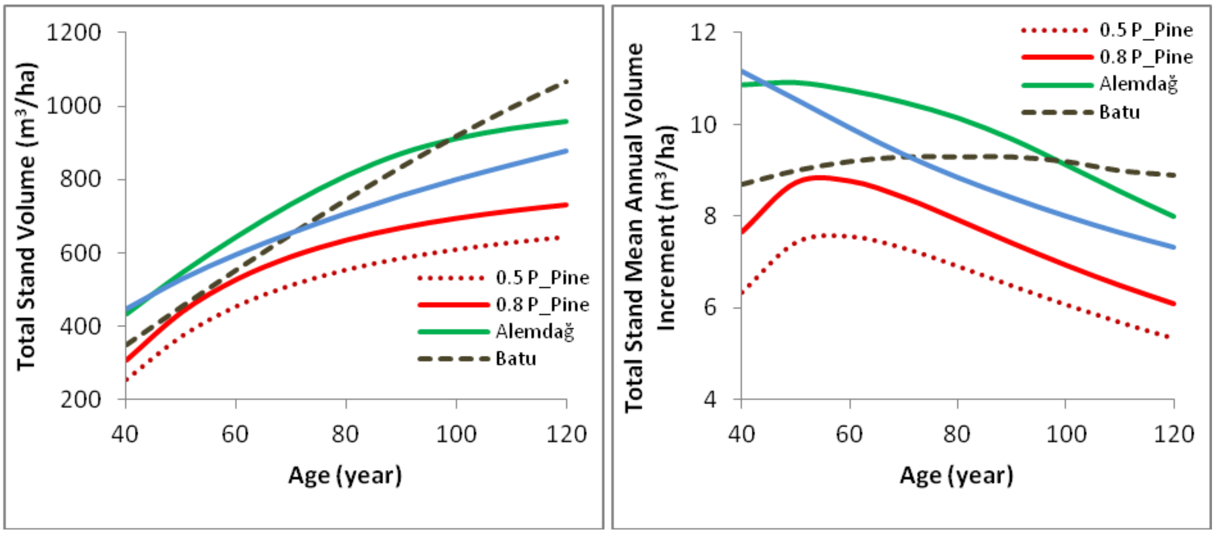

Figure 9. The change of Total Stand Volume (9a) and Total Stand Mean Annual Volume Increment (9b) of SP-FOR, Scots pine (Alemdağ, 1967 and Batu, 1971) stands at normal stand density value and good site index

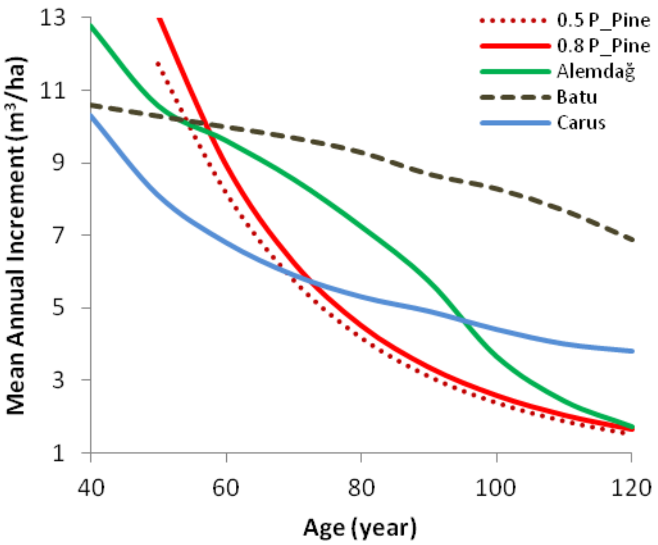

Figure 10. The change of Mean Annual Increment of SP-FOR, Scots pine (Alemdağ, 1967 and Batu, 1971) and Oriental beech (Carus, 1998) stands at normal stand density value and good site index

Total stand volume and mean annual volume increment values are ranked first for Oriental beech (Carus, 1988) until the age of 45, for Scots pine (Alemdağ, 1967) between the ages of 45-100 and for Scots pine (Batu, 1971) after 100 years of age (Figure 9a and 9b). Total stand volumes at 100 years are ranked as; 917.4 m^3/ha Scots pine (Batu, 1971), 912.2 m^3/ha Scots pine (Alemdağ, 1967), 800.0 m^3/ha Oriental beech (Carus, 1988), 693.4 m^3/ha SP-FOR stands (0.8 mixture percentage) and 607.5 m^3/ha SP-FOR stands (0.5 mixture percentage). Mean annual volume increment for total stand at 100 years of age are ranked as; 9.20 m^3/ha Scots pine (Batu, 1971), 9.12 m^3/ha Scots pine (Alemdağ, 1967), 8.0 m^3/ha Oriental beech (Carus, 1988), 6.93 m^3/ha SP-FOR (0.8 mixture percentage) and 6.07 m^3/ha SP-FOR stands (0.5 mixture percentage).

Mean annual increment is highest until the age of 60 in SP-FOR stands (0.8 mixture percentage stands) and in Scots pine stands (Batu, 1971) after the age of 60 (Figure 10). Stands at SP-FOR stands (0.8 mixture percentage) have higher mean annual increment than Scots pine stands (Batu, 1971), Scots pine (Alemdağ) and Oriental beech (Carus, 1988) until the age of 60 and higher than Oriental Beech (Carus, 1988) between 60-75 years of age. Stands at SP-FOR (0.8 mixture percentage) have higher mean annual increment than Scots pine (Batu, 1971), Scots pine (Alemdağ, 1967) and Oriental beech (Carus, 1988) until the age of 55 and higher than Oriental Beech (Carus, 1988) between the ages of 55-70. Mean annual increment at the age of 100 is ranked as; 8.30 m^3/ha Scots pine (Batu, 1971), 4.40 m^3/ha Oriental beech (Carus, 1988), 3.66 m^3/ha Scots pine (Alemdağ, 1967), 2.57 m^3/ha SP-FOR (0.8 mixture percentage) and 2.40 m^3/ha SP-FOR (0.5 mixture percentage).

4. Conclusions and discussion

Quadratic mean diameter in Scots pine decreases from 0.8 mixture percentage to 0.4 and 0.6 for I. SI at the same age and lower stand densities, whereas it decreases from 0.8 mixture percentage to 0.6 and 0.4 in moderate and high stand densities; from 0.4 mixture percentage to 0.6 and 0.8 in stands with low stand density in II. SI and from 0.8 mixture percentage to 0.6 and 0.4 in moderate and high stand densities. Quadratic mean diameter generally decreases from 0.8 mixture percentage to 0.4 and 0.6 for stands younger than 100 years of age at all stand densities in III., IV and V. SI and at all stand densities, whereas it decreases from 0.4 mixture percentage to 0.6 and 0.8 for stands older than 100 at all stand densities. Whereas quadratic mean diameter for Oriental beech, decreases from 0.6 mixture percentage to 0.4 and 0.8 in the same site index and same age as we move to lower stand densities and it decreases from 0.6 mixture percentage to 0.8 and 0.4 at moderate and high stand densities.

Total stand volume and increment is irregular for the same age, site index and stand density depending on the mixture percentage. Total yield and its increment decreases from 0.8 mixture percentage to 0.6 and 0.4 for stands younger than 40 years of age at the same stand density and site index. Total stand volume and its increment of aged 40-60 increases towards 0.6, 0.4, 0.8 mixture percentage for the low stand densities of stands in the I. SI and towards 0.4, 0.6, 0.8 mixture percentage in stands included in II., III., IV. and V. SI with moderate and high stand densities of I. SI. There is an increase in total stand volume of 60-80 years old in the low stand densities I. SI and II. SI stands respectively as we move towards 0.6, 0.4, 0.8 mixture percentage and towards 0.4, 0.6, 0.8 mixture percentage respectively for III., IV., V. SI and the moderate and high density stands of II. SI. There is an increase in total stand volume and increment that are over the age of 80 towards 0.6, 0.4, 0.8 mixture percentage for in the I., II. SI and the low stand densities of stands in the III. SI and towards 0.4, 0.6, 0.8 mixture percentage in stands included in IV. and V. SI with moderate and high stand densities of III. SI. he portion of cumulated removed stand based on mixture percentage increase from 0.8 mixture percentage to 0.4 and 0.6 same age, site index and stand density.

The density variable yield tables prepared as part of this study were compared by the normal yield tables prepared by Alemdağ (1967) and Batu (1971) for Scots pine and by Carus (1998) for pure Oriental beech. It was determined that the total stand volume and mean increment values of SP-FOR mixed stand with 0.8 mixture percentage, I. SI and normal stand density (8.5 stand density) were highest for Oriental beech (Carus, 1988) until the age of 45, for Scots pine (Alemdağ, 1967) during the ages of 45-100 and for Scots pine (Batu, 1971) after the age of 100. It was determined that the mean annual increment was highest in SP-FOR mixed stand with a mixture percentage of 0.8 until the age of 60 and for Scots pine (Batu, 1971) stand after the age of 60.

The volume and volume increment values related with the density variable yield tables prepared for Scots pine-Oriental beech mixed stands were compared for both species at 8.5 stand density and site indexes in all mixture percentages. It was determined that the volume and volume increment values increased from 0.4 mixture percentage to 0.6 and 0.8 for Scots pine and from 0.8 mixture percentage to 0.6 and 0.4 for Oriental beech. It was put forth that the volume and increment values at 0.4 mixture percentage were highest in Scots pine until the age of 55, whereas it was highest for Oriental beech after 55 years of age. It was determined that the mean annual increment value increased from 0.4 mixture percentage to 0.6 and 0.8 for Scots pine and from 0.8 mixture percentage to 0.6 and 0.4 for Oriental beech (Figure 8b).

It will be possible to continue the existence of Scots pine- Oriental beech mixed stands that are economically and biologically important for the Middle and Western Black Sea Regions only via the arrangement of forest management plans that take into consideration the growth relations of these forests as well as their stand structures. Hence, it is important for the development of forest management plans to have knowledge about the growth relations of species in Scots pine-Oriental beech mixed stands. This study will enable the development of growth models required for both management plans and civil culture applications by determining the production potentials related with Scots pine – Oriental beech mixed stands. The ecological, economic and social functions of Scots pine – Oriental beech mixed stands will be used most effectively by determining the growth legalities for both species separately and as a whole.

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