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GROWTH AND PRODUCTIVITY OF SYCAMORE (*ACER PSEUDOPLATANUS* L.) IN NATURAL STANDS AND FOREST PLANTATIONS IN BULGARIA

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Abstract

The sycamore (*Acer pseudoplatanus* L.) shows good adaptability to climate change and it could be used more widely in plantations in Europe and Bulgaria. The purpose of this study is to analyse and establish the condition, growth and productivity of plantations and natural stands under different habitat conditions in Bulgaria. All plantations and natural stands over 30 years of age, pure or dominated by sycamore, were evaluated on site. The volume of natural stands varies from 216 $m^3 \cdot ha^{-1}$ to 944 $m^3 \cdot ha^{-1}$. The plantations' growing stock at the age of 40 is 399 $m^3 \cdot ha^{-1}$, 70-year-old plantation has a stock of 810 $m^3 \cdot ha^{-1}$. At the age of 50–55, the Norway maple (*Acer platanoides* L.), the silver linden (*Tilia tomentosa* Moench.), the hornbeam (*Carpinus betulus* L.) and the European beech (*Fagus sylvatica* L.) reach and exceed the growth in height of sycamore, but not in diameter. Under optimal conditions, sycamore can produce amount of volume that meets the requirements for intensive crops.

Key words: diameter, height, increment, volume.

Introduction

In recent years, interest in the broad-leaved species used for afforestation has increased in Bulgaria. In order to conserve biodiversity, particular attention is paid to native species. In Bulgaria, a reserve in this regard are the species of genus *Acer*. The sycamore is one of the most important species of the genus in Bulgaria (Pandeva 2004). Spiecker et al. (2008) recommend that sycamore should be used more widely in forestry in Europe.

The sycamore habitat in Bulgaria covers most of the territory of the country and is naturally spread mostly in the northeast (Pasta et al. 2016) parts of the country. It occurs mainly in mixed deciduous forests, in smaller or larger groups in all mountains, in fresh sites with altitudes up to 1400 m a.s.l. (Pandeva 2004). It covers an area of 2324.4 ha (Varbeva 2019).

The regular and abundant fruiting, the high seed germination (El Kateb 1992), the wide range of tolerance to geographical and soil conditions and to altitude (Joyce et al. 1998) provide successful regeneration of sycamore in most forest areas (Ammer 1996a) and good competitiveness, as well (Skovsgaard and Jørgensen 2004, Skovsgaard and Henriksen 2006).

Traditionally, the sycamore in Bulgaria is included in the composition of mixed forest plantations, such as some oaks (*Qurcus cerris* L., *Q. robur* L.), European beech (*Fagus sylvatica* L.), Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.) and other. Row schemes with spacing 2.0–3.0 m between rows and 1.0–1.5 m within the row or 3500–5000 pcs·ha^{-1} shall be applied. The method of mixing is single trees in rows and row-belt, rarely belt mixing (Varbeva 2019).

There are some recommendations regarding the management of the sycamore in Europe (Hein and Spiecker 2007, Hein 2008, Hein and Spiecker 2008a,b, Spiecker et al. 2008). Most of them are based on expertise and professional experience. Although very often these recommendations produce good results in local forestry practices, they are based on claims and hypotheses without being objectively examined. Therefore, their successful application in a wider geographical area should be verified (Hein et al. 2009).

Studies on the growth and productivity of sycamore show that the species grows intensively both in height and diameter at a young age up to 30 years (Kjølby 1958, Nagel 1985, Hamilton and Christie 1971, Spiecker 1991, Joyce et al. 1998, Hein et al. 2009). Some studies show that genetic origin influences height growth. Cundall et al. (1998), for example, found a significant difference in growth at a young age between British and continental origin. However, no significant difference in height growth was observed in the eight origins from Germany until the 31st year (Weiser 1971, 1981, 1996).

In Bulgaria the determination of the sycamore plantations' stock is carried out according to the European beech stemwood volume tables (respectively for high-stem and low-stem) by Nedyalkov (1960), Duhovnikov et al. (1963). Such a recommendation was made by Marschall (1975) for Austria. In Germany, the use of mountain ash volume tables is recommended (Hein et al. 2009). Hamilton and Christie (1971) propose to use general tables for calculating the stock of plantations of sycamore, ash (*Fraxinus excelsior* L., F. *angustifolia* Vahl) and silver birch (*Betula pendula* L.) for the conditions of Great Britain. Hein et al. (2009) emphasize that there are significant regional variations in growth rates and productivity of sycamore plantations.

For the calculation of the stem volume of plantations and stands of sycamore in Romania, Giurgiu (1974) proposes the equation (1):

$$v = a \cdot 10^{(b \cdot \log(D) + c \cdot \log(D)^2 + d \cdot \log(H) + e \cdot \log(H)^2}, \quad (1)$$

where: H is the average height, in m; D is the average diameter of the plantation, in cm; the values of the coefficients are respectively a = 0.00035375, b = 1.02, c = 0.3997, d = 0.666, e = 0.021.

According to Varbeva (2019), this equation shows the highest accuracy in calculating the stock of plantations.

The volume of the stands is affected by the intensity of thinning. Unfortunately, the results for the sycamore are few (Bryndum and Henriksen 1988, Henriksen and Bryndum 1989, Stern 1989, Jorgenensen 1992, Plauborg et al. 2004, Hein et al. 2009). The growth response of the sycamore to thinning is most rapid at a young age, but then slows significantly. There are three approaches of thinning plantations given in the literature. They differ in their assumptions and advantages (Hein et al. 2009). Hein et al. (2009) conclude that although the sycamore is an attractive species for forestry, there is a lack of evidence-based research on its management.

The aim of this study is to determine the growth parameters of natural stands and plantations of sycamore in Bulgaria. Therefore, we outlined the following main tasks:

1. Creation and analysis of a database on the distribution of the species in Bulgaria.

2. Establishment of the condition, growth and productivity of plantations and natural stands under different habitat conditions.

Object and Methods

An analysis of the natural stands and forest plantations of the sycamore in Bulgaria was made. Six natural stands and sixteen plantations were selected as sample plots (Table 1).

Sample plots were identified by analysis of a sycamore source database, derived from the national database of the Executive Forest Agency (EFA). The selection of sites to set the sample plots is based on the analysis of the database.

All plantations and natural stands over 30 years of age, pure or with predominant participation of the sycamore, in good condition and homogenous structure were selected as sample plots.

The information on the habitat conditions (Table 1) in the studied sites was obtained from the forest management plans of the state forest enterprises.

The study conducted by Varbeva (2019) proved that there is no statistically significant difference between the growth parameters of natural stands and plantations, therefore the present study does not differentiate them according to their origin.

Data on the age of the stands were based on the current forest management plans of the forest enterprises, updated at the time of the survey. The size of the sample plots was determined based on the area, the condition of the stand and the configuration of the terrain. The diameters of all trees were measured by 2 cm diameter classes and the basal area (G) was calculated.

The species participation in the composition was calculated based on the total basal area of the plot. The density ($N \cdot ha^{-1}$) is calculated, and the average diameter (D_{cp}) is derived from the mean basal area. The dominant diameter was calculated as the average diameter of the hundred thickest trees per 1 ha.

The mean breast height diameter increment (Z_d) and the mean height increment (Z_h) were also calculated. Relative stocking is determined based on the actual stock of each species in the composition divided by the stock of the yield table of the species. For the sycamore, the Norway maple and the hornbeam, the tables for high-stem European beech stands were used (Poryazov et al. 2004). For plantations where the original afforestation scheme is clear, the survival rate is calculated.

The site index of the studied stands is determined according to a table for high-stem European beech stands (Poryazov et al. 2004).

The volume (V) per 1 ha is calculated using the equation (2):

$$V = a \cdot 10^{(b \cdot \log(D) + c \cdot \log(D)^2 + d \cdot \log(H) + e \cdot \log(H)^2)}, \quad (2)$$

where: H is the mean height, in m; D is the average diameter of the stand, in cm; the values of the coefficients are respectively: a = 0.00035375, b = 1.02, c = 0.3997, d = 0.666, e = 0.021 (Giurgiu 1974).

Table 1. Characteristics of the sample plots.

Forestry enterprise	Geographic coordinates	Area, ha	Altitude, m	Exposure	Relief	Slope, °	Soil characteristics				
							Soil type	Texture	Bulk density	Depth, cm	Humidity
Berkovitsa*	43°08'13.3" 23°17'03.4"	0.4	950	W	slope lower part	28	Dystric Cambisols	Loamy sand	loose	61–120	fresh to moist
Lesidren*	42°54'20.9" 24°27'23.6"	0.2	1400	E	hollow	11	Eutric Cambisols	Sandy clay	compacted	31–60	fresh
Kotel*	42°54'52.3" 26°20'49.0"	0.9	900	N	slope upper part	29	Eutric Cambisols	Loamy sand	loose	31–60	fresh
Gurkovo 1*	42°46'48.7" 25°39'26.2"	1.4	800	E	slope upper part	23	Dystric Cambisols	Loamy sand	loose	61–120	fresh to moist
Gurkovo 2*	42°46'41.0" 25°39'25.2"	0.3	750	E	slope upper part	30	Dystric Cambisols	Loamy sand	loose	61–120	fresh to moist
Preslav*	43°04'36.2" 26°51'28.2"	5.5	550	NE	ridge	12	Grey Luvisols	Sandy clay	loose	> 120	fresh to moist
Simitli	41°46'04.2" 23°01'44.5"	2.3	1300	N	slope lower part	21	Dystric Cambisols	Loamy sand	loose	61–120	fresh to moist
Karnobat 1	42°56'00.6" 26°55'40.1"	0.9	400	SE	hollow	9	Haplic Chromic Luvisols	Loamy sand	loose	61–120	fresh
Karnobat 2	42°56'04.8" 26°55'35.2"	0.2	400	SE	slope lower part	9	Haplic Chromic Luvisols	Loamy sand	loose	61–120	fresh
Varna	43°17'25.7" 27°54'53.4"	0.4	250	E	slope upper part	2	Grey Luvisols	Sandy clay	compacted	61–120	fresh to moist
Tsonevo	42°56'54.6" 27°27'29.7"	0.6	200	N	slope upper part	9	Grey Luvisols	Loamy sand	loose	61–120	fresh
Gabrovo 1	42°47'05.5" 25°19'38.9"	0.5	950	N	slope lower part	7	Dystric Cambisols	Loamy sand	loose	61–120	fresh to moist
Gabrovo 2	42°46'44.8" 25°20'04.5"	0.2	900	E	slope lower part	13	Dystric Cambisols	Sandy clay	loose	61–120	fresh to moist
Sofia	42°46'42.5" 23°18'47.9"	0.9	500	N	Riverside to 3 m.	2	Alluvial Fluvisols	Loamy sand	loose	> 120	fresh to moist

Pirdop	42°45’59.3” 23°55’06.5”	0.2	1200	SW	slope upper part	8	Eutric Cambisols	Loamy sand	loose	31–60	fresh
Kazanlak	42°43’55.6” 25°28’23.9”	5.4	1050	W	slope lower part	31	Dystric Cambisols	Loamy sand	loose	61–120	fresh
Varbitsa	42°55’58.6” 26°40’38.0”	4.5	850	NE	slope upper part	12	Dystric Cambisols	Loamy sand	loose	61–120	fresh to moist
Preslav	43°04’45.2” 26°51’06.5”	2.7	550	NE	ridge	12	Grey Luvisols	Sandy clay	loose	> 120	fresh to moist
Targovishte 1	43°10’07.0” 26°39’07.1”	0.7	400	N	slope lower part	6	Grey Luvisols	Sandy clay	loose	> 120	fresh to moist
Targovishte 2	43°08’30.1” 26°39’59.8”	1.6	600	N	hollow	2	Grey Luvisols	Sandy clay	compacted	61–120	fresh to moist
Cherni lom	43°24’47.8” 26°05’19.7”	0.5	400	NE	plateau	14	Chernozem	Sandy clay	loose	> 120	fresh
Shumen	43°14’50.1” 26°53’18.5”	0.3	450	NW	plateau	6	humus-carbonate	Sandy clay	loose	61–120	fresh

Note. The sample plots marked with asterisk (*) are natural stands.

The mean annual increment in volume is calculated in two variants – non-normalized, expressing the growth of the mixed plantation and normalized, calculated for pure full stocked sycamore stands with the specific height and diameter and area of 1 ha.

A one-way ANOVA test was used to determine if there are statistically significant differences between values of the mean annual increment (MAI) of four groups of sub-zones: I-2 (sub-zone of oak stands); II-3 (sub-zone of mixed deciduous stands; II-1 (sub-zone of sessile oak, European beech and silver fir) and II-2 (sub-zone of European beech, silver fir and Norway spruce). The results from ANOVA test showed that there is no statistical difference between the values of the groups.

Results and Discussion

The sycamore forms pure or with predominant participation in the composition of the plantations, which are small in area – from 0.2 to 5.5 ha (Table 2). They range from 550 to 1400 m a.s.l. The small areas of the sites give reason to assume that the emergence of pure stands or dominated by the sycamore occur in open spaces, in areas where clear cuttings of European beech stands were done or in small areas affected by natural disturbances.

Table 2. Characteristics of sample plots.

Forestry enterprise	Composition*	Afforestation scheme, m	Density, trees·ha^{-1}	Survival, %	Age, years	Mean height, m	Dominant height, m	Mean height increment, m·yr^{-1}	Site index	Average diameter, cm	Dominant diameter, cm	Mean diameter increment, cm·yr^{-1}	Basal area, m^2·ha^{-1}	Stand volume, m^3·ha^{-1}	Mean volume increment, m^3·ha^{-1} ·yr^{-1}	Mean volume normalized increment, m^3·ha^{-1}·yr^{-1}	Relative stocking
	AP 9		680			20.6	24.0	0.52	1	24.5		0.63	38.81	365	9.12	10.13	
Sofia	TT 1	2.0×2.0	70	30	40	20.0	23.0	0.50	1	20.0	28.5	0.50	2.99	34	0.86	-	1.13
	Total		750			-	-	-	-	-		-	41.80	399	9.98	-	
Pirdop	AP 10	1.0×1.5	1257	19	45	24.5	2.07	0.54	1	23.8	34.6	0.53	55.93	596	13.25	13.25	1.9
Kazanlak	AP 10	1.0×2.0	744	15	50	20.0	24.0	0.40	1	24.4	33	0.49	34.75	321	6.42	6.42	1.1
	AP 6	1.0×1.5	333	5		21.0	24.0	0.42	1	28.8		0.57	21.53	211	4.22	7.03	
	CB 3	-	144	-		20.0	22.0	0.40	1	20.0		0.40	4.85	56	1.12	-	
Varbitsa					50						38.6						0.95
	FS 1		89	-		21.0	23.0	0.42	1	30.0		0.60	6.65	78	1.57	-	
	Total		566	-		-	-	-	-	-		-	33.03	345	6.91	-	
Simitli	AP 10	1.0×2.0	1214	24	50	22.0	24.0	0.55	1	18.1	29.4	0.45	31.19	301	7.54	7.54	1

Forestry enterprise	Composition*	Afforestation scheme, m	Density, trees·ha^{-1}	Survival, %	Age, years	Mean height, m	Dominant height, m	Mean height increment, m·yr^{-1}	Site index	Average diameter, cm	Dominant diameter, cm	Mean diameter increment, cm·yr^{-1}	Basal area, m^2·ha^{-1}	Stand volume, m^3·ha^{-1}	Mean volume increment, m^3·ha^{-1} ·yr^{-1}	Mean volume normalized increment, m^3·ha^{-1}·yr^{-1}	Relative stocking
Karnobat 1	AP 6	unknown	483	-	50	22.0	23.0	0.44	1	22.2	29.7	0.44	18.74	189	3.79	5.34	0.71
	APt 3	-	233			23.0	24.0	0.46	1	20.0		0.40	6.77	83	1.67	-	
	TT 1		117			23.0	24.0	0.46	1	20.0		0.40	4.56	56	1.12	-	
	Total		833			-	-	-	-	-		-	30.07	329	6.58	-	
Karnobat 2	AP 5	unknown	583	-	50	22.0	24.0	0.44	1	20.0	30.8	0.40	18.32	178	3.56	7.12	0.84
	APt 3	-	333			23.0	25.0	0.46	1	22.0		0.44	12.07	149	2.97	-	
	FS 1		83			23.0	25.0	0.46	1	20.0		0.40	2.17	27	0.53	-	
	CB 1		133			23.0	24.0	0.46	1	16.0		0.32	2.37	29	0.58	-	
	Total		1132			-	-	-	-	-		-	34.93	383	7.64	-	
Preslav	AP 7	1.0×1.5	783	12	55	23.0	25.0	0.42	1	27.2	37.5	0.49	45.57	473	8.60	12.29	1.19
	CB 2		233				24.0	0.42	1	18.0		0.33	6.44	79	1.44	-	
	FS 1		83				23.0	0.42	1	24.0		0.44	3.23	40	0.72	-	
	Total		1099				-	-	-	-		-	55.24	592	10.76	-	
Shumen	AP 10	1.0×1.5	786	12	55	21.0	22.0	0.38	1	23.9	32.2	0.43	35.32	337	6.13	6.13	1.1
Tsonevo	AP 10	1.0×1.5	1417	21	60	20.0	23.0	0.40	1	21.7	30.8	0.43	52.79	479	9.59	9.59	1.7

Forestry enterprise	Composition*	Afforestation scheme, m	Density, trees·ha^{-1}	Survival, %	Age, years	Mean height, m	Dominant height, m	Mean height increment, m·yr^{-1}	Site index	Average diameter, cm	Dominant diameter, cm	Mean diameter increment, cm·yr^{-1}	Basal area, m^2·ha^{-1}	Stand volume, m^3·ha^{-1}	Mean volume increment, m^3·ha^{-1} ·yr^{-1}	Mean volume normalized increment, m^3·ha^{-1}·yr^{-1}	Relative stocking
Gabrovo 1	AP 10	1.0×1.5	1140	17	60	23.0	25.0	0.38	1	25.7	36.4	0.43	59.02	607	10.12	10.12	1.8
Gabrovo 2	AP 10	1.0×1.5	1020	15	60	21.0	23.0	0.35	2	25.8	34.3	0.43	53.40	515	8.58	8.58	1.6
Targovishte 1	AP 10	1.0×1.5	533	8	60	25.0	27.0	0.42	1	27.4	35.1	0.46	31.43	346	5.78	5.78	0.9
Targovishte 2	AP 10	1.0×1.5	1011	15	60	22.0	25.0	0.37	1	23.3	30	0.39	43.18	425	7.08	7.08	1.3
Cherni lom	AP 10	1.0×1.5	821	18	60	20.0	23.0	0.33	2	22.8	34.9	0.38	33.49	307	5.12	5.12	1
Varna	AP 10	unknown	650	-	70	27.5	29.0	0.39	1	34.7	48.8	0.50	61.52	765	10.93	10.93	1.8
Kotel	AP 8	-	622	-	45	20.0	23.0	0.44	1	22.6	35.5	0.50	24.89	228	5.06	6.41	0.79
	FS 2	-	344	-	45	17.0	19.0	0.38	1	16.0		0.36	8.67	92	2.04	-	
	Total	-	966	-	-	-	-	-	-	-		-	33.56	320	7.10	-	
Gurkovo 1	AP 9	-	592	-	45	20.0	22.0	0.44	1	20.8	30.0	0.46	20.07	182	4.05	4.5	0.54
	CB 1	-	85	-	45	17.0	19.0	0.38	1	22.0		0.49	3.2	34	0.75	-	
	Total	-	677	-	-	-	-	-	-	-		-	23.27	216	4.80	-	
Gurkovo 2	AP 5	-	1333	-	45	20.0	22.0	0.44	1	20.1	38.1	0.51	55.97	513	11.48	22.96	2.41
	CB 4	-	1300	-	45	17.0	19.0	0.38	1	14.0		0.31	21.02	222	4.94	-	
	APt 1	-	333	-	45	15.0	17.0	0.33	2	30.0		0.67	21.17	209	4.64	-	
	Total	-	2966	-	-	-	-	-	-	-		-	98.16	944	21.06	-	

Forestry enterprise	Composition*	Afforestation scheme, m	Density, trees·ha^{-1}	Survival, %	Age, years	Mean height, m	Dominant height, m	Mean height increment, m·yr^{-1}	Site index	Average diameter, cm	Dominant diameter, cm	Mean diameter increment, cm·yr^{-1}	Basal area, m^2·ha^{-1}	Stand volume, m^3·ha^{-1}	Mean volume increment, m^3·ha^{-1}·yr^{-1}	Mean volume normalized increment, m^3·ha^{-1}·yr^{-1}	Relative stocking
Preslav	AP 6	-	500	-	45	22.0	24.0	0.49	1	24.5	29.1	0.54	23.48	232	5.16	6.00	0.86
	CB 2	-	167	-	45	22.0	23.0	0.49	1	18.0		0.40	4.26	51	1.14	-	
	AC 2	-	150	-	45	22.0	23.0	0.49	1	20.0		0.44	4.77	58	1.28	-	
	Total	-	817	-	-	-	-	-	-	-		-	32.51	341	7.58	-	
Berkovitsa	AP 10	-	344	-	55	24.0	25.0	0.44	1	24.5	30.6	0.45	16.20	171	3.10	3.1	0.5
Lesidren	AP 10	-	2317	-	60	23.5	26.0	0.39	1	21.0	24.1	0.35	80.31	821	13.68	13.68	2.4

Note: *AP – *Acer pseudoplatanus* L.; CB – *Carpinus betulus* L.; TT – *Tilia tomentosa* Moench; FS – *Fagus sylvatica* L.; APt – *Acer platanoides* L.; AC – *Acer campestre* L.

The sycamore prefers shady exposure, with the only exception being the stand in the Berkovitsa State Forest Enterprise (SFE) located on a sunny exposure. It is noticeable that at lower altitudes (550–900 m) the plantations are located on convex relief forms – the upper portion of the slope and the hilly. At higher altitudes, they are in concave relief – a depression or a lower portion of the slope. The sycamore grows on slopes, as well as on steep terrains. The main soil types are Cambisols (Dystrict and Eutric) in the Middle Mountain Range of European beech and coniferous forests and grey forest soils (Gray Luvisols) in the lower plain-hilly and hilly-mountain ranges of oak forests. The texture of soil is sandy-clay in all sample plots. The maple prefers friable soils, with the exception of the plantation in Lesidren SFE growing on compacted soil. The demand of the maple is evident to the depth of the soil, which is at least medium deep (31–60 cm), most often deep (31–60 cm), and very deep (61–120 cm). In terms of soil moisture, the habitats are fresh and fresh to humid.

Sycamore plantations were created in the Moesian and Thracian forest areas (except the plantation at the Simitli SFE). They are situated in two forest zones – the plain-hilly and hilly-mountainous zone of oak forests at 200 m a.s.l. and the middle mountain zone of European beech and coniferous forests up to 1300 m a.s.l. (Table 2). The relief forms are varied – convex and concave, and the slope of the terrain varies from flat to steep. The soils are medium in mechanical composition, usually light, mostly deep and very deep. Soil moisture is good (fresh and fresh to moist soil).

The analysis of the stand characteristics of the natural stands shows that the sycamore can form stands pure in composition or with a predominant participation in the composition. Under natural conditions, the species may be mixed with the European beech, common hornbeam, Norway maple or field maple. The plantations are pure or mixed with European beech, hornbeam, silver linden, Norway maple, with a participation of 1/10 to 3/10 of the stand volume. For most plantations, the afforestation scheme applied is 1.0×1.5 m. Another scheme of afforestation is 1.0×2.0 m and the rarest scheme of afforestation is 2.0×2.0 m.

The density of 40-50-year-old plantations ranges from 677 (Gurkovo 1) to 2966 (Gurkovo 2) trees per ha. At the age of 55–60 the density is from 344 to 2317 trees per ha and 650 trees per ha at the age of 70. Self-thinning of the plantations was intense, survival was greatly reduced and ranged from 5 to 24 %. Intense self-thinning is an indicator of the great light-demanding nature of the species.

The density is lower than this in the normal yield table values (Poryazov et al. 2004) at the stands in Berkovitsa, Kotel and Gurkovo 1 and is an indicator of the relatively greater demand for light of the sycamore compared to the European beech. The density of the stands at the sites in Gurkovo 2 and Lesidren significantly exceeds the normal table values from 1.54 to 2 times, respectively. Hence it is an indicator of the species' biological potential in this regard.

The average height of the mean sample tree at the age of 40–50 is in the range of 20–22 m. At the age of 55–60 the height ranges from 20 to 25 m. In the 70-year-old plantation in Varna SFE, an average height of 27.5 m was calculated. The height of the average dominant tree at the age of 45–50 is from 22 to 24 m. At 55–60 years of age it is 22–26 to 29 m at the age of 70. According to Joyce et al. (1998), sycamore shows excellent height growth during the first 30 years on appropriate site conditions. Significant decrease of its height growth occurs after 50 years of age. According to the growth models developed in Germany (Nagel 1986), sycamore plantations reach over 30 m in I yield class.

In the conditions of the middle mountain zone of European beech and coniferous forests, the sycamore outstrips in height the European beech, the hornbeam and the Norway maple, and in the lower plain-hilly and hilly-mountainous zone of the oak forests its growth is equalized with the common hornbeam. For the first 30 years, the Hamilton and Christie (1971) and Nagel (1986) growth models show better sycamore growth than the European beech, with European beech outgrows sycamore after 60, according to the Hamilton and Christie model (1971) and after 100 in the Nagel model (1986).

The height growth rate was characterized by the values of mean height increment. The increment ranges from 0.33 to 0.55 m per year. The most intensive growth is over 0.50 m / year and it is observed between 40 and 49 years of age. In general, there is a linear relationship between altitude and mean growth. The plantation in Simitli State Forest Enterprise is at altitude 1300 m a.s.l. and the increment is 0.55 m per year, and in Varna SFE it is at 250 m a.s.l. and the average increase in height is 0.39 m per year. Over the age of 60, the average height increment decreases. Hein et al. (2009) indicate that all height growth curves for the sycamore have one common feature – rapid growth at a young age (up to 20–25 years), which then slows down. In the best habitats, the species reaches 19.5 m by the age of 20 (Claessens et al. 1999).

The average diameter varies from 18.1 to 28.8 cm at the age of 40–50. At the age of 55–60, values range from 21.0 to 27.4 cm.

The studied objects showed the following relationship between density and mean diameter: at the age of 45–50 the average diameter is inversely related to the density. It reaches its maximum value (28.8 cm) for densities of 566 trees per ha and decreases to 18.1–20.1 for densities of 1214–2966 trees per ha. An exception to this trend are the plantations in Pirdop SFE.

At the age of 55–60 at densities from 344 to 1140 trees per ha there is no clear relationship between the average diameter and the density and it varies from 22.8 to 27.4 cm. A smaller average diameter was calculated at densities of 1417 trees per ha (21.7 cm) and 744 trees per ha (21.0 cm).

The relationship between size and density has been a topic of intense research for decades (Pretzsch 2005). However, for the time being, the exact correlations for the sycamore have not been established. Conditional results have been obtained in France comparing the self-thinning curves of the sycamore, the European beech, the mountain ash, the sessile oak and the common oak: the data on the sycamore is limited, but the relationship between size and density seems to have a steeper curve than this in the European beech (Le Goff and Ottorini 1999) and mountain ash, but close to that of the oaks. Therefore, a pure, even-aged stand of a sycamore would have a lower density than the same pure stand of a European beech or mountain ash, and the same density of the plantation of the sessile oak or common oak.

Growth in the average diameter of the sycamore is more intense than the European beech and the field maple, but lags behind at the age of 45 compared to the

Norway maple, which reaches an average diameter of 30 cm. In two of the plots with the participation of the hornbeam, the growth in diameter of the maple is more intense, and in Gurkovo 1 the growth in diameter of the two species is even. However, the experimental plots do not give basis for claiming that under these conditions the sycamore has a more intensive growth in diameter than the European beech and hornbeam because it is not known whether these co-occurrences are of the same age or settled in the stand at a later stage.

According to Nagel (1985), the sycamore reaches its maximum increment in diameter at the age less than 10 when open grown outdoors without competition. These results are in line with studies of its height growth: the species reaches maximum growth indicators both in height and diameter at an early age. Growth in diameter in the sycamore is most intense until the age of 20–25, after which it slows down (Spiecker 1991).

The diameter of the average dominant tree at the age of 40–50 ranges from 28.5 cm to 38.6 cm. At 55–60 years of age it is between 24.1 and 37.5 cm. Logically it does not show a relationship with the density of the stands, because dominant trees are less competing for growing space with other tree categories.

At the age of 40–45, the sycamore plantations exceed the growth in height and diameter of the natural European beech, silver linden, hornbeam and Norway maple stands. At the age of 50–55, Norway maple, silver linden, hornbeam, European beech reach and exceed the growth in the height of Sycamore, but not yet in diameter.

The average diameter increments at different ages were determined as follows: 40 years – 0.63 cm per year; 45 years – 0.44–0.53 cm per year; 50 years – from 0.40 cm per year up to 0.57 cm per year; 55 years – from 0.43 cm per year up to 0.47 cm per year; 60 years – from 0.35 cm per year up to 0.46 cm per year. The average growth in diameter of the 70-year-old plantation also has a high value of 0.49 cm per year.

A significant increase in the average diameter increment is observed for plantations with densities from 333 to 750 trees per ha, respectively 0.64 and 0.63 cm per year. After the age of 50, the mean diameter increment decreased from 0.43 to 0.37 cm per year. With respect to the average diameter increment, it can be summarized that the intensive diameter increment is up to 50–60 years of age, after which it slows down. Maximum height and diameter growth was observed at 40-45 years of age. When comparing the growth parameters of the studied stands with the normal table values (Poryazov et al. 2004), it is seen that the sycamore shows more intensive growth in height and diameter than the European beech at the age between 45 and 60.

The analysis of the basal area shows that at the age of 40–55 there is no correlation between density of up to 1214 trees per ha and the basal area as it varies from 23.26 to 41.8 $m^2 \cdot ha^{-1}$. At a density of 1257 and 2966 trees per ha the basal area increases to 55.93 and 98.16 $m^2 \cdot ha^{-1}$ respectively. At the age of 55–60 there is a linear relationship between the basal area and the density, which varies from 16.2 $m^2 \cdot ha^{-1}$ to 80.31 $m^2 \cdot ha^{-1}$.

The values of the stand volume vary from 171 $m^3 \cdot ha^{-1}$ (Berkovitsa density 344 trees per ha) to 944 $m^3 \cdot ha^{-1}$ (Gurkovo 2 density 2966 trees per ha). The total productivity of sycamore varies between 800 and 1000 $m^3 \cdot ha^{-1}$ at the age of 80 according to Germany and Denmark growth models, while in the UK, productivity reaches 766 $m^3 \cdot ha^{-1}$ at the same age (Joyce et al. 1998).

The productivity of the sycamore (~1050 $m^3 \cdot ha^{-1}$) is significantly higher than that of the European beech, which reaches only 546 $m^3 \cdot ha^{-1}$ at the age of 80 in first yield class (Schober 1995).

Henriksen and Bryndum (1989) indicate that for Danish sample plots on similar habitats where thinning of sycamore and beech stands has been made, the sycamore has a higher stock than European beech only until 40 years of age. The mean and current volume increment culminates earlier than in European beech. Although the height growth of mountain ash and sycamore is similar, the productivity of mountain ash is significantly lower (555 $m^3 \cdot ha^{-1}$) at the age of 80 at first site index class (Volquardts 1958). A comparison by Lockow (2004) of the influence of dominant heights on the volume increment of the sycamore, mountain ash and European beech in northern Germany reveals another model for the first site index class plantations of the three species: at a dominant height of 30 m the volume of plantations of the sycamore exceeds that of ash trees by 180 $m^3 \cdot ha^{-1}$ in terms of overall productivity, whereas European beech is superior to sycamore only at heights greater than 30 m, provided that they were equal in height at the last cultivation.

According to Kjølby (1958), the current annual increment in volume in Denmark is highest at 21 years of age – 19.5 $m^3 \cdot ha^{-1}$, and the mean annual increment in volume at 27 years of age is 15 $m^3 \cdot ha^{-1}$ for stands with I site index. The growing stock at 80 years of age ranges from 700 $m^3 \cdot ha^{-1}$ (for the fifth yield class) to 1050 $m^3 \cdot ha^{-1}$ (for the site index class V). The current annual increment in volume for the conditions of Germany is highest at the age of 20 (about 20 $m^3 \cdot ha^{-1}$) and the average growth at the age of 30 (15 $m^3 \cdot ha^{-1}$) (Spiecker 1991).

The average non-normalized volume increment increases from 3.10 (Berkovitsa) to 21.06 $m^3 \cdot ha^{-1}$ year (Gurkovo 2). The average normalized volume increment is from 3.10 (Berkovitsa) to 22.96 $m^3 \cdot ha^{-1}$ (Gurkovo 2) annually. According to Joyce et al. (1998), the maximum value of mean annual increment reaches about 20 $m^3 \cdot ha^{-1}$ per year for I yield class, and the age of biological maturity of maximum volume production for different yield classes varies between 20 and 30 years.

The results of Dunn's post hoc test for average normalized volume increment showed statistical significant difference between sub-zones II-1 and II-2. The boxplot of MAI by sub-zones is given of Figure 1.

The minimum and maximum values of the mean non-normalized and normalized increment in volume are observed in pure plantations and are respectively from 5.12 $m^3 \cdot ha^{-1}$ to 13.25 $m^3 \cdot ha^{-1}$ annually. Of the 22 sample stands and plantations, in 6 the mean normalized increment in volume exceeds 10 $m^3 \cdot ha^{-1}$ per year, which is considered sufficient to create intensive wood production crops.

When setting a production goal – sawtimber and special assortments – veneer, Joyce et al. (1998) recommend rotation period of 60–80 years on the best site conditions and 100 on less suitable sites.

The growing stock of the stands and plantations is high, despite of the intense self-thinning and low survival rate, and ranges from 0.5 to 1.9.

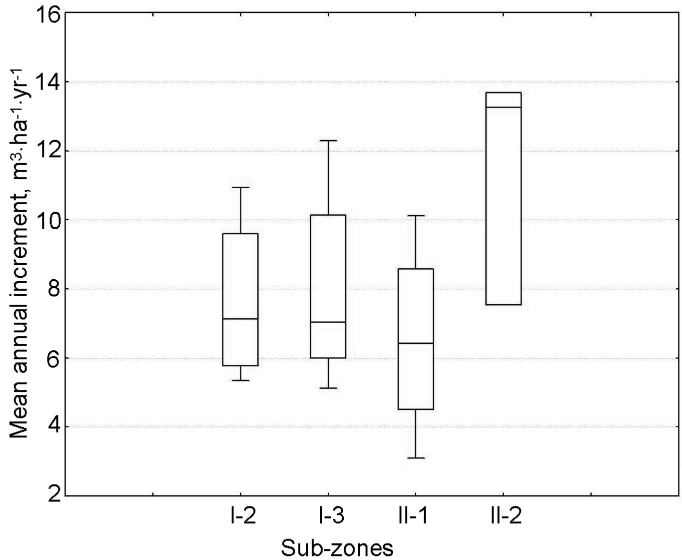

Fig. 1. Box-plot of mean annual increment for four groups of sub-zones.

Conclusions

The described above give the ground to draw the following important conclusions:

The highest values of stem volume are observed in the objects at altitudes between 550 and 1400 m a.s.l. on shade exposure.

Under optimal habitat conditions, sycamore can achieve productivity that meets the requirements for intensive plantations. It shows values from 13.25 to 21.96 $m^3 \cdot ha^{-1}$ at the age of 45; 13.68 $m^3 \cdot ha^{-1}$ at 60 years of age and 10.93 $m^3 \cdot ha^{-1}$ at the age of 70.

The studies carried out and the conclusions reached justify the following recommendations:

Areas located in the Middle Mountain zone of Beech and Coniferous Forests, Sub-zone of Low-altitude forests of Durmast oak, Common beech and fir (600–1000 m a.s.l.) and sub-zone of middle-mountain forests of beech, fir and spruce up to 1400 m a.s.l. Shady exposures and diverse habitats with fresh and moist soils are suitable.

Sycamore plantations can be created both pure and mixed. Suitable mixing species are: beech, Norway maple, linden, field maple, common cherry, mountain ash.

The obtained results, drawn conclusions and recommendations can help to improve and expand the future work with sycamore in Bulgaria.

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