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Effects of two different thinning methods on the diameter and basal area increments of silver lime (*Tilia tomentosa* Moench) target trees in Fruška Gora (Serbia)

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Abstract This paper analyses the cumulative effects of selective thinning and thinning from below on diameter and basal area increments of target trees after 25/26 years in 52, 69- and 86-year-old silver lime (*Tilia tomentosa* Moench) stands. Two target tree collectives were analysed: (1) elite trees selected between 1993–1994 from permanent sampling plots (selective thinning method), and (2) a 'comparable collective' of target trees selected in 2019 (25/26 years later) according to the same criteria as the elite trees, in the same stands thinned from below. Elite trees that were selectively thinned had: higher diameter, basal area and volume per tree, higher diameter and basal area increment for a given time period, and lower slenderness coefficients compared to the target trees that were thinned from below at 52 and 69 yr. While diameter increment decreases with age, and differences between elite trees of different ages are clearly delineated, diameter increments of trees thinned from below are not significantly different at 52 and 69 yr. In addition, basal area increment of trees is highest at 69 yr with selective thinning. When thinning from below, there were no significant differences in basal area increments between trees at 69 and 86 yr. Silver lime shows a strong growth response after selective thinning at ages 25/26 and 44 yr. However, our results show that this response is less pronounced when selective thinning begins at 61 yr.

Keywords: silviculture; selective thinning; thinning from below; diameter increment; basal area increment

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Introduction

Most of the range of the silver lime (*Tilia tomentosa* Moench) is in the Balkans, but the species is also native to Hungary, Slovakia, Moldova, Ukraine and Asia Minor (Turkey) (EUFORGEN 2021). In general, the dominant form of management is coppice (Eaton et al. 2016). In natural forest communities of different oak species and beech, lime trees are found as admixture species but may dominate if the natural forests are degraded. Of the total area of Fruška Gora National Park (26,672 ha), 80% are coppice stands, of which 37% are covered with lime due to clearcutting and insufficient stand regeneration (Medarević et al. 2001). In recent years, interest in lime silviculture has increased in Europe. The potentials of lime species in Europe are nowadays being recognized in various studies related to stand productivity and silviculture (Radoglou et al. 2009, Gill & Zajackwoski 2017, De Jaegere et al. 2016).

Considering climate change issues, silver lime has been investigated for its potential for future silviculture in Central Europe, especially as admixed tree species (Heinrichs et al. 2021). In this context, *Tilia platyphyllos* (Scop.) is also considered for future admixture forests in southern Germany (Walentowski et al., 2017). In north-western Europe, *Tilia cordata* (Mill.) has potential for sites where beech is threatened by climate change (Latte et al. 2020). In the warming climate, *T. tomentosa* stands may not be able to acquire same levels of carbon storage as beech stands in present conditions (Kasper et al. 2021) and the growth response to drought of dominant *T. tomentosa* trees under light thinning regime shows that the species may be vulnerable (Kasper et al. 2022). However, silver lime currently has no alternative in forest management at Fruška Gora where our research was conducted. Lime is considered a noble hardwood (Turok et al. 1996), and their wood has good technical and aesthetic properties and can be used in the veneer industry (Coello et al. 2013). In addition, silver lime has been shown to be fire resistant and is suitable on shallow, sandy soils with little humus (Bobinac 2005, 2015) and large-leaved lime (*Tilia platyphyllos* Scop.) is very productive on beech sites (Aleksić et al. 2014).

Stand-oriented silviculture is seen as more traditional (Oosterbaan et al. 2009, Manetti et al. 2016, Marchi et al. 2018, Pelleri et al. 2021), while tree-oriented silviculture is considered a ‘new’ (Oosterbaan et al. 2009) and ‘innovative’ approach (Manetti et al. 2016), although the concept has been known for a long time (Nicolescu 2001). Tree-oriented silviculture is used in stands of seed origin (high stands) where the most valuable stems are produced (Nicolescu 2001, Manetti et al. 2016), but it can also be used in coppice (low) stands (Manetti et al. 2016). The concept of elite trees introduced by Schädelin (1942) and later substantiated by Leibundgut (1966) is based on the permanent selection of trees throughout the development of the stand. A gradual final selection is made from the initial large base of tending candidates. Another approach targets trees selected at the first thinning and tended until the end of the rotation (Nicolescu 2001).

There is no universally optimal number of elite trees. Although there have been efforts to define the required number of trees at the end of the rotation period (Abetz & Klädtke 2002), selection remains a largely subjective category (Pommerening et al. 2015), as there are different recommendations for different tree species and site conditions in terms of the total number of trees that should be at the end of the rotation period. According to different authors, this number can vary and is usually between 40 and 200 trees per hectare (Oosterbaan et al. 2009, Štefančík 2013). Determining the optimal number of trees is important for the application of selective thinning and for evaluating its effects; if the number of trees is too large, the effects may be reduced (Bončina et al. 2007).

The aim of this work is to determine the structural characteristics and cumulative growth response of two target tree collectives after 25-

26 years of thinning treatments established in three different silver lime stands ages. The target tree collectives are elite trees tended under selective thinning method and the comparable collective of trees tended under thinning from below treatment.

Materials and Methods

Sample plots and tree selection

The subject of the study is coppice stands of silver lime in the area of Fruška Gora Mountain (Serbia), located on a site of pedunculate oak, hornbeam, and Turkey oak with limes (*Carpino betuli-Quercetum roboris* (Anić 59) Rauš 1971. var. geograf. *Tilia argentea* + *Tilia cordata* B. Jovanović (1980) 1997. subass. *typicum* (Tomić 2013)). The investigated stands originated from clearcuts of stands of the mentioned forest community that were already in a regressive succession phase. The stands were mostly managed by a system of 'high coppice stands' in longer rotation periods, where thicker assortments of trees can be produced as in the high forests of seed origin (Marković & Petrović 1956). Coppice forests with this structure are considered to be in the process of conversion to high forests (Stajić et al. 2009), and are located on plateaus at 165-180 m above sea level. In addition, the subsoil is loess and the soil type is Cambisol. From 1993 to 2019, the mean annual precipitation was 620.7 mm and the mean annual air temperature was 11.8°C. Data were collected from the nearest meteorological station of the Republic Hydrometeorological Institute of Serbia (2021) in Sremska Mitrovica, located 18.7-21.5 km from the sample plots and 82 m above sea level.

The study is based on six sample plots ranging in size from 0.19-0.27 ha (Table 1). Three permanent research plots were established in 1993 an 1994 - one in each of the three investigated stands (stand ages 26, 44 and 61 years). Each plot was established in a homogeneous part of the stand in terms of species composition, canopy closure and age.

During their establishment, it was noted that the immediate vicinity was also homogeneous and could serve for later comparisons. In the following 25-26 years, selective thinning was regularly carried out in the three permanent plots (S treatment). The remaining area of the stand was thinned from below. In the fall of 2019, comparative 0.25 ha sample plots were established in the immediate vicinity of the permanent plots with a buffer zone 10 m wide (Treatment B). There were three age periods - 1st age period (stand age 26-52 years), 2nd age period (stand age 44-69 years), and 3rd age period (stand age 61-86 years) - and two treatment types - S (selective thinning) and B (thinning from below). Selective thinning in the 25- or 26-year period aimed to tending

Table 1 Stand structure characteristics on the sample plots (N - number of trees; G - stand basal area; V - stand volume; dg - mean quadratic diameter; D100 - mean quadratic diameter of the 100 thickest trees (dominant diameter); hL - Lorey's mean height; H100 - mean height of the 100 thickest trees (dominant height)); R-index - Clark & Evans (1954) aggregation index.

Sample plot	Plot area [m²]	Coordinates	Age [yr]	N [trees·ha⁻¹]	G [m²·ha⁻¹]	V [m³·ha⁻¹]	dg [cm]	D100 [cm]	hL [m]	H100 [m]	R-index
1S	1930.3	N45° 8' 30.444'	52	399 (202/5/192)*	20.7	219.20	25.7	36.9	22.9	23.9	1.03
1B	2542.6	E19° 24' 21.0378'	52	892 (684/90/118)	41.5	500.60	24.4	34.4	24.8	25.5	1.14
2S	2667.6	N45° 8' 12.411'	69	289 (195/8/86)	25.4	282.03	33.5	43.7	25.9	26.7	1.25
2B	2586.4	E19° 22' 31.263'	69	449 (414/8/27)	33.9	396.98	31.0	38.8	26.2	27.0	1.30
3S	2540.9	N45° 8' 47.666'	86	189 (189/0/0)	24.9	281.89	40.9	44.8	27.7	28.2	1.49
3B	2524.7	E19° 20' 47.767'	86	392 (356/28/8)	38.7	465.87	35.4	43.3	28.3	28.5	1.25

Note: Number of trees per hectare from crown classes 1, 2 and 3 are shown in brackets (upperstory /midstory /understory trees).

about 150 elite trees per hectare. Elite trees were defined in the way described by Schädelin (1942), Nicolescu (2001) and Pretzsch (2009).

According to the data reported by Bobinac (1996), the stand represented by the 1S and 1B plots originated after a clearcut of an oak-silver lime stand. Before the 1S sample plot was established (1993), there had been one silvicultural intervention (cleaning). The stand consisted of 2368-2952 trees per hectare, with a mean diameter at breast height of 13.6-13.8 cm, and with the share of silver lime in the species composition being 85-90% in terms of number of trees and over 90-95% in terms of basal area and volume. The stand that was represented by the 2S and 2B plots originated from a clearcut logging of a stand that was already dominated by silver lime. After the clearcut, the stumps were removed manually and the stand regenerated from root suckers. Before the establishment of the permanent 2S sample plot (1994), one cleaning had been carried out. After two further thinnings from below, the residual number of trees was 916 per hectare, with a mean diameter of 22.1-22.8 cm at the time of establishment of the experimental plot S2. The stand represented by plots 3S and 3B also originates from root suckers after stump removal. The stand was also dominated by silver lime prior to clearcutting. Prior to the establishment of the 3S sample plot (1994), one cleaning and three thinnings from below were carried out, after which 532 trees per hectare were left, with a mean diameter of 27.5 cm. In the total stand structure, the share of silver lime was 94% in terms of the number of trees and over 96% in terms of total basal area and volume.

On the permanent sample plots-1S, 2S and 3S-in the period from 1993 (1994) to 2010, four selective thinnings were carried out, while in the other part of the stands, the forest engineers performed two thinnings from below.

The selection of elite trees under Treatment S was based on the qualitative evaluation of the stand structure (Bobinac 1996), with the selection criteria being similar to those used in other works (e.g. Bončina et al. 2007, Štefančík 2013, Manetti et al. 2016, Pelleri et al. 2021, Skovsgaard et al. 2021). This meant that the trees had to belong to the dominant crown class and possess high quality stems, suitable dimensions, and healthy and evenly developed crowns in a uniform spatial arrangement. For the B treatment, a collective of trees comparable to elite trees was selected in the fall of 2019. These trees also numbered about 150 per hectare, and the selection criteria were the same as for elite tree selection, but 25-26 years later. The comparison with the selective thinning experiment was based on the best trees ('comparable collective of trees') at the end of the research period in the B treatment with the treatment carried out by the forest engineers in the given stands. We considered these trees to be those most comparable with the elite trees in the selective thinning treatment. When it came to thinning from below, the objective comparison with the elite trees under the S treatment was possible mainly at the end of the experiment. The reason for this is that, in long time-series, there may be changes in crown class structure-that is, the loss of the initial rank of certain trees. In this way, we chose the best trees (with highest quality) so the difference between the comparable collectives of trees should reflect the effects of treatments. The basis for comparing the best collectives tended under different thinning methods was similar in other works (e.g. Bobinac & Andrašev 2009, Manetti et al. 2016, Pelleri et al. 2021).

Field measurements and growth characteristics

At the end of 2019, the cross diameters of all trees (N) were measured in the east-west (d1) and north-south (d2) directions using a manual calliper. Crown classes were determined based on Assmann's (1970) modified classification (CC_1: upperstory, categories 1 and 2 according to Kraft (1884); CC_2: midstory, category 3 according to Kraft (1884); and CC_3: understory, categories 4 and 5 according to Kraft (1884)). Total height was measured using a Vertex III (Haglöf, Sweden) hypsometer. Height curve fitting was performed using the Michailoff function (Michailoff 1943) and tree volume calculated according to yield tables of Banković et al. (1989). Basal area (G), stand volume (V), mean quadratic (d_g) and mean quadratic diameter of 100 thickest trees (dominant diameter, D_{100}), mean Lorey's height (h_L), and the mean height of 100 thickest trees (dominant tree height, H_{100}), as the mean of 100 tallest trees in the stand) were also calculated at the stand level using the formulas presented in Laar & Van Akca (2007) and Pretzsch (2009). The main structural characteristics of the analyzed stands are given in Table 1. To determine spatial structure all the trees were mapped in a local coordinate system using a compass and the distance between each tree was measured using a hypsometer. Based on the coordinates of the trees, R-index was calculated (Clark & Evans 1954) showing how the trees are spatially arranged. The arrangement may be random ($R = 1$), have a tendency to clump ($R < 1$), or be uniformly distributed ($R > 1$). Deviations from the random spatial distribution of the trees were checked using a c-test presented by the authors in the same paper (significant results indicate whether such a deviation exists).

We analysed the following growth characteristics of the target trees (elite trees in the S treatment and the comparable collective of trees in the B treatment) in 2019: g_a (basal area), v_a (volume), d_a (arithmetic mean diameter), h_a (arithmetic mean height), and h/d (slenderness coefficient), all expressed per tree.

Basal area and diameter increments

To collect increment data, two opposite increment cores (north-south direction) were taken using an increment borer. After preparing the surface with progressively finer grits (Orvis & Grissino-Mayer 2002)-P120, P240, P320, P500 and P1000-the cores were scanned using a HP Photosmart 4040 scanner with a resolution of 1200 dpi. All measurements on the cores were performed using ImageJ software (Schneider et al. 2012). Cross-dating of cores was performed using the method of Yamaguchi (1991) in order to determine the years 1993 and 1994-onset of selective thinning-and to avoid possible errors due to the presence of micro-rings and false rings (Speer 2009). Diameter and basal area increments were calculated based on width measurements of 25-26 rings as periodic annual increments (PAId and PAIg) for the given period (Pretzsch 2009).

The initial values (1993-1994) of diameter at breat height of elite trees and the trees from the comparable collectives of trees were obtained by subtracting 25-26-years of diameter increment using the increment cores (Table S1).

The diameters of the trees from 1993-1994 were reconstructed in the following way: first, we calculated the ratio of the 2019 cross diameters (d_1: d_2). Then, diameter d2, which was measured from north to south, was reduced by a 25-26-year diameter increment in the manner described above. The 1993-1994 diameter d_1 was calculated by multiplying the reconstructed d_2 by the 2019 d_1: d_2 ratio.

Statistical analysis

Comparison of tree-level growth characteristics was conducted using two-way crossed ANOVA (or full two factors ANOVA) to compare the two treatments (selective thinning and thinning from below) across all three age periods (26-52; 44-69 and 61-86 years) (Quinn & Keough 2002, Montgomery 2017).

All the target trees were measured, and data from each of the six plots were used to calculate the above growth characteristics d_a, g_a, h_a, and v_a per tree. The same sample of trees was bored to obtain increment cores for the diameter and basal area increment measurements. Thus, 221 target trees were measured and cored. To compare the diameter and basal area increments over the 25-26 year period, a covariance method (two-way ANCOVA) was introduced to account for the original dimensions of the trees (diameter at breast height $d_{1993\text{-}1994}$ for diameter increment and basal area for basal area increment).

Data processing was performed in the R environment (R Core Team 2021). We used the function 'Anova' from the car package to express significant differences (Fox & Weisberg 2019). The separation of mean values was accomplished with Least Significance Difference (LSD) test using the agricolae package (de Mendiburu 2021). All values at $p < 0.05$ were considered significant. The assumptions of the two-way ANOVA and two-way ANCOVA were checked analytically and graphically by controlling for homoscedasticity using Levene's test and normality of the residuals using the Shapiro-Wilk test (See Tables S3, S4 and Figures S1-S4). When these conditions were not met, different data transformations were used (Tables S3 and S4). For the data visualisation the ggplot2 (Wickham 2016) and the gridExtra packages were used (Auguie & Antonov 2017). Finally, throughout the article, the following abbreviations were used for the combination of treatments (S and B) and age periods (1, 2, and 3): 1S, 1B, 2S, 2B, 3S, and 3B.

Results

The structure of the two target tree collectives

The number of trees, in both collectives, ranges from 145 to 155 trees per hectare and the R-index confirms that they are uniformly distributed (Table S2). At the end of the observed period, the target trees from S treatment amounted 74.9-79.4% out of total number of all upperstory trees in respective stands while the target trees from the B treatment amounted between 21.2 (1B) and 43.3% (3B) out the total number of upperstory trees in the respective stands (Table S2).

Mean diameters are significantly higher in the S treatment at the end of all three studied age periods, and diameter values increase with age in both treatments. This increase is not significant in the S treatment between the ages of 68 and 86 years which may indicate the age limit of responsiveness of silver lime trees. The significance of the age × treatment interaction shows that the increase in mean diameter at stand age of 69 is higher in the S treatment than in the B treatment. In addition, the mean values of basal area per tree are significantly higher in the S treatment at all stand ages, while volume per tree is significantly higher in the S treatment only at ages 52 and 69. There are no differences between the target trees in the 2S and 3S treatments which may be attributed to the strong response of basal area of silver lime during the 2nd age period. In the B treatment, basal areas in the 2B and 3B treatments are significantly different and significantly lower than those in the 2S and 3S treatments. In addition, mean heights are significantly different between treatments at ages 52 and 86, but not at age 69 years. The slenderness coefficient of the two target tree collectives is lower in the S treatment and decreases with age in the B treatment. However, in the S treatment, the slenderness coefficient tends to be low (below 70) at all ages, which is confirmed by age × treatments interaction (Figure 1, Table 2).

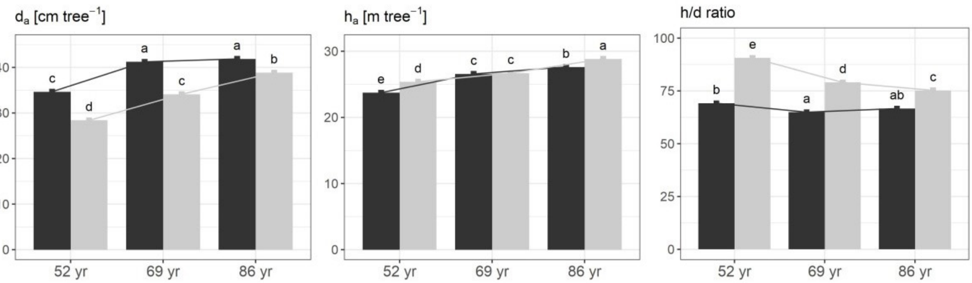
Table 2 Results of the two-way ANOVA for the mean values of the growth characteristics of two target tree collectives.

GC	Age		Treatment		Age × Treatment	
	F	*p*	*F*	*p*	*F*	*p*
d_a	93.04	< 0.01	76.33	< 0.01	5.65	0.0041
h_a	198.28	< 0.01	34.09	< 0.01	9.99	0.0001
g_a	76.32	< 0.01	93.01	< 0.01	5.65	0.0041
v_a	100.15	< 0.01	67.20	< 0.01	5.32	0.0056
h/d	33.12	< 0.01	265.85	< 0.01	10.99	< 0.01

Note: GC = growth characteristics; d_a = arithmetic mean diameter; h_a = arithmetic mean height; g_a = arithmetic mean basal area; v_a = arithmetic mean volume; h/d = slenderness coefficient.

Increments of the two target tree collectives

The response of the trees in terms of increments is different at all ages and depends on the thinning method. While diameter increments of trees did not differ in the 52- and 69-year-old stands when thinned from below, they did differ when thinned selectively. A very strong growth response in selective thinning is illustrated by the fact that there were no significant differences in basal area increments between the trees from



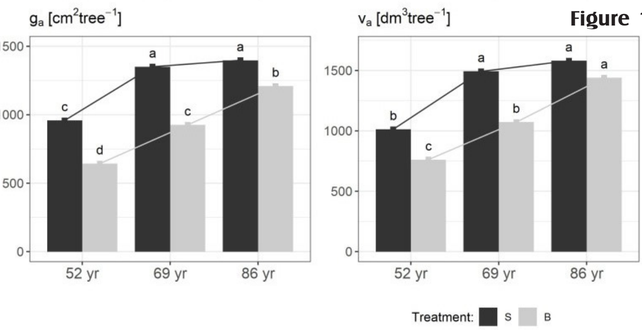


Figure 1 Growth characteristics of the two target tree collectives of trees subjected to different thinning treatments (different letters indicate significant differences based on the LSD test at the p < 0.05 level). Abbreviations: d_a-arithmetic mean diameter; h_a-arithmetic mean height; h/d ratio-slenderness coefficient; g_a-arithmetic mean basal area; v_a-arithmetic mean volume per tree.

52- and 86-year-old stands although the base affecting the basal area increment (tree diameter) was much larger in 86-year-old stands than in 52-year-old stands.

Compared to the B treatment, diameter and basal area increments are higher under the S treatment in all age categories. As the age of the stands increases, the diameter increment decreases, and there is a clear separation between age periods in the S treatment. However, for the B treatment, there are no significant differences between diameter increments in 52- and 69-year-old stands, as confirmed by the significant age × treatment interaction. While basal area increment of trees in selective thinning is highest at stand age 69 years there were no significant differences between stands aged 69 and 86 years after thinning from below. The F-ratio of the treatment factor is 6-8 times higher than the F-ratio of the age factor for both the diameter and basal area increment of the two target tree collectives, which means that the thinning treatment has a greater influence on diameter and basal area increment than age (Figure 2, Table 3).

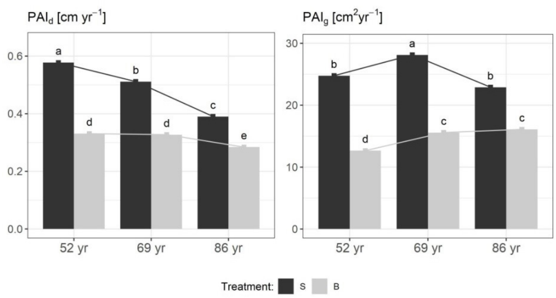


Figure 2 Diameter and basal area increments of the two target tree collectives (different letters indicate significant differences based on the LSD test at the $p < 0.05$ level). Abbreviations: PAId-periodic annual diameter increment PAIg-periodic annual basal area increment.

Table 3 The ANCOVA comparison of the increment of diameter and basal area of the two target tree collectives.

Source of variability	PAId [cm·yr^{-1}]		PAIg [cm^2·yr^{-1}]	
	F	*p*	*F*	*p*
Initial growth characteristics (diameter or basal area)	12.32	**< 0.01**	61.72	**< 0.01**
Age (1, 2, and 3)	27.20	**< 0.01**	26.80	**< 0.01**
Treatment (S and B)	210.56	**< 0.01**	189.30	**< 0.01**
Age × Treatment	11.45	**< 0.01**	5.34	**< 0.01**

Note: PAId: Periodic annual diameter increment;
PAIg: Periodic annual basal area increment.

Discussion

Due to an unfavourable qualitative stand structure-that is, a low number of good quality trees in the studied silver lime forests on Fruška Gora at the age of 26, 44, and 61 years- early tree selection and the application of selective thinning were suggested (Bobinac 1996). Regular application of selective thinning (S treatment) caused more divergent effects at the target tree collectives level in the indicated age periods 26-52, 44-69, and 61-86 years than thinning from below (B treatment), applied in the same stands.

In stands tended by selective thinning, the crop trees are considered to be the 'stand skeleton' in terms of stability (Štefančík 2013). The effects of different thinning methods in silver lime stands at Fruška Gora were observed in the two target trees collectives. Over a period of 25-26 years, there were significant differences between two target tree collectives in terms of basal area, mean diameter, slenderness coefficient, and increments in the studied stand ages.

In the results collected by Štefančik (2013), the diameter increment of beech crop trees were higher in free crown thinning than in heavy thinning from below. Moreover, silver lime responded differently in individual age periods. In the age periods 26-52 and 44-69 years, better effects were obtained than in the age periods 61-86 years. From 46 to 56 years of age, silver lime also showed a positive response to thinning under other site conditions (Bobinac 2015).

Regarding basal area increment, the response is higher under the influence of selective thinning than thinning from below; the response is 92% higher at stand age period 26-52 years, 75% higher at stand age period 44-69 years, and 44% higher at stand age period 61-86 years. In addition, the effects of selective thinning on target tree diameter increment are present at all age periods, but are less pronounced the later in a tree's life that thinning is applied. When selective thinning began at age 61 years, diameter increment was 33% less than in the stand where thinning was implemented at age 26 and 23% less in the stand where it began at age 44. In the stand where selective thinning had been carried out since the age of 26 years, the effects resulted in high values for diameter and basal area increment and low values of slenderness coefficient. This confirms the need for early selection and selective thinning in silver lime forests as proposed by Bobinac (1996), and is consistent with the results of similar studies on other tree species (Kerr 1996, Rytter & Werner 2007, Novák et al. 2017, Štefančík et al. 2018).

Our results are also in line with the technical silvicultural recommendations for *T. tomentosa* in Romania (MAPMM/1 2000, MAPMM/2 2000, cited in the work of Radoglou et al. 2009) which recommended the first thinning for crop trees at stand age 20-25 years. Furthermore, the production of veneer logs is projected in a rotation cycle of 80-100 years with moderate thinning intensity, and with the last thinning is scheduled to occur between 60 and 70 years of age.

The results of thinning show that silver lime is a very responsive tree species, which makes it more useful at different stand ages than some other species, where thinning after 20 or 25 years of age give inadequate results (Hibbs & DeBell 2006, Leak & Solomon 1997). If there is a strong growth response of residual trees after thinning this indicates that they may have a high light compensation point as they are able to utilize the available amount of sun light (Yoshida & Kamitani, 1998). Therefore, we believe that silver lime can be seen as very responsive species to the light conditions created by thinning. At the same time, silver lime is moderately shade tolerant (Radoglou et al. 2009), which leads to the fact that it can be characterised as an ecologically plastic species. Beech, for example, still responds to thinning even at an age of 70 or 90 years (van der Maartern 2013, Bončina et al. 2007). The results of the study by Bončina et al. (2007)

showed that crop trees between 70 and 81 years had an average basal area increment of 18.9-19.1 cm^2, and trees aged 81 to 91 years old had an average increment of 18.2-20.4 cm^2 in selective thinning, both slightly lower than the 3S treatment in this study (23 cm^2). The response of beech in eastern Serbia at stand age 30-35 years under a more intensive selective thinning regime gave an average basal area increment of 22 cm^2 (Bobinac 2004), which means that silver lime also gave slightly better results in this case (25 cm^2 in 1S treatment and 28 cm^2 in 2S treatment). Compared to traditional approach, tree-oriented silviculture gave positive effects in diameter increment in thinning trials in 45-50 years old beech stands in Italy (Pelleri et al. 2021), and there are growing evidence that the tree-oriented silviculture may enhance ecosystem service provisions in general (Marchi et al. 2018).

The obtained results allow considering many aspects of practical value in the management of silver lime coppice forests, including the important issue of shortening the rotation cycle. Currently, the rotation age in the coppice forests of Fruška Gora is 80 years. If the management objective is target diameter, the rotation cycle can be shortened by early-onset selective thinning (Kerr 1996).

The current trend of climate change and the potential trend of degradation of natural stands due to the invasion of woody neophytes in the regeneration phase on Fruška Gora, such as the already present *Ailanthus altissima* (Mill.) Swingle and *Robinia pseudoacacia* L., draws attention to the possibilities of further human intervention in the tending approach of young lime forests and stopping the spread of the neophytes (Bobinac 2013, Bobinac et al. 2016).

The trial plots established and the results obtained can be used in the future to address other important aspects of selective thinning related to its potential use as an adaptation measure in the context of climate change and tree devitalization. This has already been confirmed in other trials with other tree species (Bobinac & Andrašev 2009, Sohn et al. 2016, Diaconu et al. 2015, Diaconu et al. 2017, van der Maarten 2013) and is significant considering the fact that silver lime has been assessed as suitable mixed tree species for future use in Central Europe as an admixed species (Heinrichs et al. 2021).

Conclusions

Target trees that were selectively thinned responded differently than the trees thinned from below. In terms of diameter and basal area growth response, the thinning effects were stronger for trees that were selectively thinned. The cumulative effects of selective thinning in the analysed period (25-26 years) were visible in all age periods, but were more pronounced in the 26-52 age period (diameter increment) and in the 44-69 age period (basal area increment).

Diameter increment decreases with age, and values differed significantly between age periods in relation to selective thinning. For thinning from below, there are no differences between increments at ages 52 and 69. While the increase in basal area peaks at age 69 for selective thinning, there were no differences between ages 69 and 86 years for thinning from below. The results indicate that the limits of silver lime response are somewhere between 44 to 61 years of age. Selective thinning should therefore be started as early as possible, as the response to thinning decreases with age, even if visible effects can still be achieved later.

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