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The effect of different tending on stand structure and quantitative production of European beech (*Fagus sylvatica* L.) stand in a selected region of East Slovakia

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ABSTRACT: The paper deals with assessment of a long-term experiment (45 and/or 53 years of investigation) in the 90-years-old European beech (*Fagus sylvatica* L.) stand in a selected region of East Slovakia. The research was performed from 1960 to 2013 on subplots managed by four different methods: (*i*) plot with heavy thinning from below (C grade according to the German forest research institutes from 1902), (*ii*) plot with free crown thinning (thinning interval of 5 years), (*iii*) plot with free crown thinning (thinning interval of 10 years) and (*iv*) control plot (with no thinning). The diameter and height structure was calculated by structural indices according to Füldner (1995). Additionally, the following quantitative parameters were analysed: number of trees (tree density), basal area, standing volume, total yield production, total annual volume increment, total tree number decrease including thinning, self-thinning and abiotic injurious factors. The most suitable structure documented by the above-mentioned indices was found on the plots managed by free crown thinning. Similarly, from the quantitative aspect, the highest values (total production according to basal area) were reached on the plot tended by free crown thinning (thinning interval of 5 years). As for the total production according to merchantable volume, the highest values were obtained from the plot treated with heavy thinning from below.

Keywords: quantitative production; free crown thinning

A forest stand is undergoing various external as well as internal changes during its development. In most cases, it is characterized by quantitative parameters (number of trees, diameter at breast height, tree height and volume) and/or derived values (basal area, standing volume, increments, etc.). The dynamics of the above-mentioned quantitative characteristics is influenced by numerous factors, such as tree species and its age, site and climatic conditions, etc. (Assmann 1968; Vyskot et al. 1971; Šebík, Polák 1990; Vacek et al. 1996; Pretzsch 2005), as well as interspecific or intraspecific competition (Freise, Spiecker 1999; Pretzsch et al. 2010). However, from the management aspect the methods of tending based on the type of thinning and its intensity are considered to belong among the most important factors (Schober 1972; Kató, Mülder 1992; Klädtke 1997).

A lot of articles have been published on the above-mentioned subject, concerning the methods of tending in beech stands and its effect on both quantitative and yield production parameters due to different thinning treatments (Réh 1968, 1969; Šebík 1971, 1983; Štefančík 1968, 1974, 1984; Korpeľ 1988; Šebík, Polák 1990; Štefančík 2013a,b). Similar development could also be seen abroad, mainly in Germany and France (Assmann 1968; Kennel 1972; Pardé 1981; Polge 1981; LeGoff, Ottorini 1993; Dhôte 1997; Pretzsch 2005).

Apart from the facts mentioned above the time when the first thinning has to be done is also very im-

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portant. Most of the authors recommended to start with the tending of a stand in a very early growth phase of thicket (Réh 1968, 1969; Jurča, Chroust 1973; Lüpke 1986; Korpeľ et al. 1991) and/or in small pole stage stands at the very latest (Štefančík 1974). There are some experiments when tending started only in a pole stage stand (Štefančík 1974, 2013a; Pretzsch 2005). Results from long-term investigations showed that in the case of late, but systematic and intensive tending in beech stands it is possible to achieve satisfactory quantitative production. However, this is dependent on tending methods and/or thinning type (Štefančík 2013a). Additionally, on the basis of synthesis of thinning experiments carried out in beech stands in the past, mainly abroad, Šebík and Polák (1990) stated that volume production in stands treated with crown thinning is approximately the same as in stands with moderate or heavy thinning from below. This was also more or less confirmed by the latest results from assessments of long-term experiments established in Slovakia (Štefančík 2013a,b).

The aim of this paper is to compare changes in selected parameters of quantitative production in beech stands tended by different thinning methods for a long period of time (45 and 53 years of investigation).

MATERIAL AND METHODS

The research was carried out on a series of permanent research plots (PRPs) Kalša, established in the stand located in East Slovakia, Sobrance forest enterprise, Slanec forest district, compartment 284. The beech stand originated from natural regeneration under the large-area shelterwood cutting. The stand age on the PRPs at their establishment was 37 years.

The above-mentioned series of PRPs consists of four subplots (C, H, H2, 0) with the area of each plot of 0.25 hectares. The basic mensurational characteristics are presented in Table 1.

The analysis of different management regimes was performed on each subplot for a long period of time (45 and 53 years, respectively). On the plot marked as C, a heavy thinning from below (C grade according to German forest research institutes from 1902) was realized. On plots marked as H and H2, the method of free crown thinning according to Štefančík (1974) principles was applied. Thinning interval on plot H is 5 years, and on plot H2 10 years. This method focuses on the individual tending of trees of selective quality (promising and target trees). The plot marked as 0 is the control plot (with no thinning).

No planned silvicultural interventions were carried out until the establishment of PRPs. However, plot H2 was established later (in 1968) compared to the other three plots. Consequently, only 10 biometrical measurements were performed on plot H2 since its establishment in 1968 as opposed to 12 measurements that were performed on the remaining three plots (C, H and 0). On all subplots, the standard biometrical measurements were carried out. In the framework of the measurements, the quantitative parameters (breast height diameter, both height of tree and base of tree crown, crown width) were measured, and selected traits were assessed according to silvicultural and commercial classification.

Table 1. The basic characteristics of the given series of permanent research plots (PRPs) Kalša

Characteristic	Kalša PRP
Establishment of PRP	1960
Age of stand (yr)	37
Site index	26 (34 at stand age of 90 years)
Geomorphologic unit	Slanské vrchy Mts.
Exposition	east
Altitude (m)	520
Inclination (degrees)	15
Parent rock	Andesite
Soil unit	Eutric, pseudogleyic Cambisol
Forest altitudinal zone	3th oak-beech
Ecological rank	B (fertile)
Management complex of forest types	311 – fertile oak beech woods
Forest type group	*Fagetum pauper* (Fp) lower tier
Forest type	3314 woodruff beech woods (lower tier)
Average annual temperature (°C)	6.0
Sum of average annual precipitation (mm·yr^{-1})	790

Silvicultural classification consists of biosociological position of trees according to growth (tree) classes (Štefančík 1974): (*i*) dominant tree, (*ii*) co-dominant tree, (*iii*) intermediate tree, (*iv*) suppressed tree – decreased, (*v*) suppressed tree – dying out.

The parameters of quantitative production were calculated according to generally known formulas used in forest management planning (Priesol, Polák 1991).

The calculation of the results was performed by standard methods for tending evaluation and production-silviculture relations, using the QC Expert software package (Kupka 2008). To find out the statistical significance of the differences between subplots (representing different tending regimes) according to diameter at breast height (DBH) and tree height, the single-factor analysis of variance ANOVA (SPSS, Tulsa, USA) was used. The diameter and height structure was found by structural indices according to Füldner (1995). For the calculation of selected structural indices the growth simulator Sibyla (Fabrika 2005) was used.

RESULTS AND DISCUSSION

Stand structure. The diameter and height development of investigated subplots is characterized by the values of mean diameter (d_g) and height (h_g) presented in Table 2.

In the initial stage of research, the values were almost the same, as well as the course of curves of diameter frequency distribution was found similar for three subplots (H, C and 0). It is a type of left-hand asymmetric distribution, typical of stands, which were not managed until then (Fig. 1). Additionally, subplot H2 showed the same course, although it was established later (in 1968).

Table 2. Development of stand characteristics

Plot	Stand	Age (yr)	N (trees·ha^{-1})	G (m^2·ha^{-1})	V_{7b} (m^3·ha^{-1})	Mean	
						diameter $d_{1.3}$ (cm) (d_g)	height (m) (h_g)
0	total	37	3,760	28.9	151	9.9	12.6
	main	45	2,496	32.4	253	12.9	16.6
		55	1,524	36.2	380	17.4	21.4
		65	816	36.3	470	23.8	26.2
		75	656	39.7	607	27.8	30.6
		85	556	42.1	676	31.0	32.1
		90	528	44.8	727	32.9[a]	32.9[ac]
H	total	37	3,780	29.6	155	10.0	12.6
	main	45	1,832	21.4	153	12.2	15.3
		55	1,332	24.2	233	15.2	19.3
		65	892	26.2	314	19.4	22.7
		75	732	30.6	453	23.1	27.6
		85	612	34.1	493	26.6	28.8
		90	564	36.9	593	28.9[a]	29.4[c]
H2	total	37	–	–	–	–	–
	main	45	1,692	28.6	262	14.7	20.5
		55	1,124	29.1	329	18.2	22.8
		65	580	24.7	326	23.3	25.7
		75	512	30.8	473	27.7	29.7
		85	424	32.6	558	31.3	32.1
		90	364	32.5	561	33.7[a]	31.6[ac]
C	total	37	3,784	29.4	156	10.0	12.6
	main	45	736	19.5	169	18.4	18.6
		55	568	26.4	307	24.3	24.4
		65	436	30.0	412	29.6	28.4
		75	376	34.3	556	34.1	33.2
		85	368	39.2	667	36.8	34.7
		90	364	41.9	713	38.3[b]	34.5[ab]

N – number of trees; G – basal area; V_{7b} – volume of timber of 7 cm in diameter and more, C – plot with heavy thinning from below, H – plot with free crown thinning, thinning interval of 5 years, H2 – plot with free crown thinning, thinning interval 10 years, 0 – control plot (with no treatment), values with the same letter – not significantly different on the level $\alpha = 0.05$

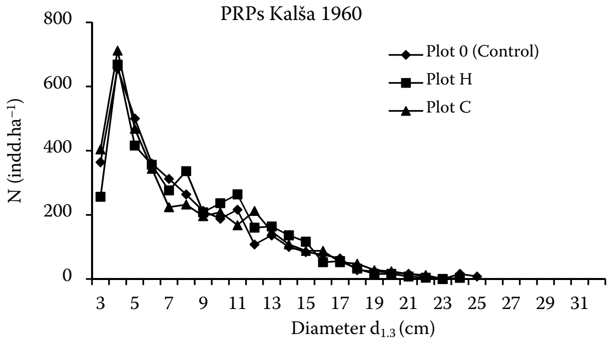

Fig. 1. Diameter frequency distribution in the initial stage of research

After 45 and/or 53 years under different thinning regimes, the differences between the plots increased (statistically significant differences in mean diameter at the level $\alpha = 0.05$ were found between plot C and all other plots). The highest values of d_g were found on the plot that was tended by heavy thinning from below from the initial stage of research (plot C), and the lowest on plot H (Table 2). The above-mentioned development reflects the tending methods, when on the plots managed by free crown thinning, the intervention was realised in the whole vertical profile of the stand. Moreover, individuals with large diameter values were also removed in favour of target trees. Contrary to plot H, different development was found on plot C, where the suppressed tree layer was removed by first interventions. Consequently, only dominant, co-dominant and intermediate trees remained in the stand and these are thicker in comparison with the other plots. The same results were also obtained on other PRPs in Slovakia (Štefančík 2013a–c) with similar research objective.

The most suitable diameter differentiation was observed on the plot managed by free crown thinning, where interventions were realised in the whole vertical profile. It was also confirmed by the values of diameter differentiation indices (TM_d) according to Füldner (1995), which were found the highest just on the plots treated with free crown thinning (for H = 0.635 and H2 = 0.533). The values above 0.500 represent the strong type of differentiation. For comparison, on the control plot it was 0.362 (medium type of differentiation) and the lowest values of indices were obtained on plot C (0.187 – low differentiation), where the total suppressed level of the stand was removed by the treatment. The above-mentioned values of indices were similar to those found in 105-years-old beech PRP Cigánka (Štefančík 2013a). Better development of diameter and height differentiation, found on plots managed by the free crown thinning method is not surprising. It is a consequence of systematic interventions realised at the crown level of the stand. By this treatment, more light is available for intermediate and suppressed trees. This is contrary to the control stand (without any treatment) where the suppressed trees are dying out in large numbers. The above-mentioned fact resulted in the "equalization" of stand canopy, which is very often observable in the beech stands.

The effect of different tending regimes was also observed according to the height structure, expressed by the relative number in the growth (tree) classes (Fig. 2). The proportion of trees at the crown level of the stand (1^{st} + 2^{nd} growth class) and at the suppressed level of the stand (3^{rd} to 5^{th} growth class) is very important from the silvicultural point of view. In the initial stage of research, the proportion of the suppressed level of the stand was found higher in comparison with the crown level of the stand on three plots (H, C and 0). The proportion of the crown level of the stand ranged from 39% (plot C) to 46% (plot H).

After 45 and/or 53 years of investigation, a decreased crown level of the stand was found only on plots with free crown thinning (plot H and H2). This could be considered a little surprising, although a 10% difference was observed only when compared

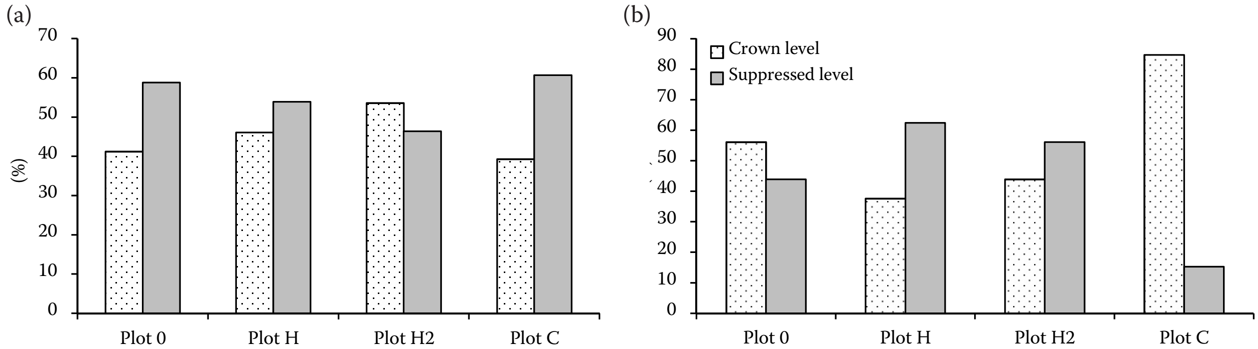

Fig. 2. Proportion of individuals at the crown level of the stand (1^{st} and 2^{nd} growth class) and at the suppressed level of the stand (3^{rd} to 5^{th} growth class) in the initial stage of research (a), after 45 (53) years of investigation (b)

(a) (b)

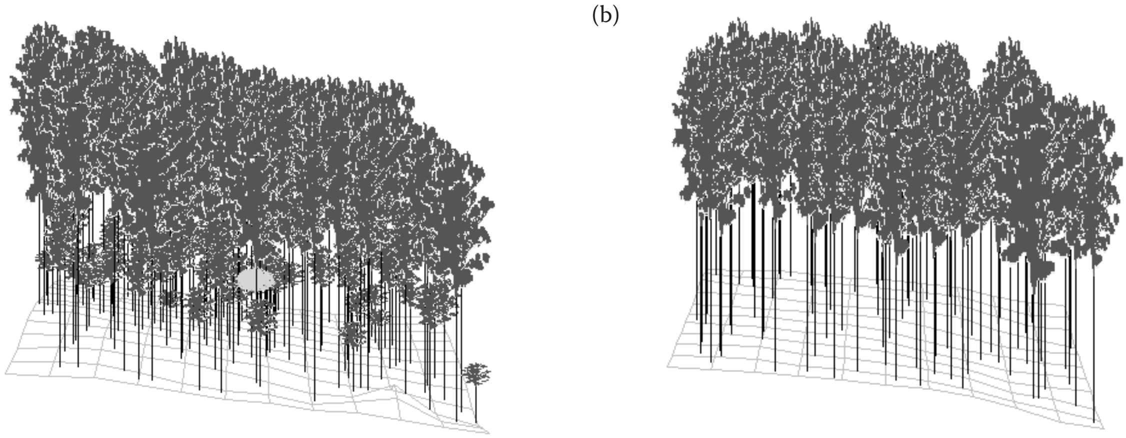

Fig. 3. Stand structure on plots managed by free crown thinning (a) and by heavy thinning from below (b) after the 53-year period of investigation

with the initial stage of research. Our explanation could be that on the above-mentioned two plots a lot of dominant and co-dominant individuals were removed by thinning in favour of the target trees. On the other hand, there was no intervention at the crown level of the stand on plots tended by heavy thinning from below and control plot (with no treatment). Moreover, the stands where the above-mentioned plots are located suffered very intensively from beech bark necrosis in the 60's and 70's of the last century. Consequently, many dominant and co-dominant trees died or were removed in consequence of the above-mentioned disease. According to the basal area it ranged from 77 to 84% out of all trees suffering from the mentioned disease (Štefančík, Leontovyč 1966; Štefančík 1974). Results found in Kalša PRP are not in accordance with the Šebík, Polák (1990) outcomes, who stated a shift of individuals to higher tree classes in beech stands tended by heavy thinning from above. However, on other PRPs of ours managed by the same thinning methods, the conclusion of these authors was fully confirmed (Štefančík 2013a,b). As for the proportion of the crown level of the stand during the period of investigation (45 and 53 years), the values ranged (except for plot C) from 38% to 56%. It is in accordance with the results published by Assmann (1968) for 102-years-old beech stand tended by moderate thinning from above, where the proportion of the crown level of the stand and the suppressed level of the stand was found to be 54% and 46%, respectively.

The greatest changes were registered on plot C (heavy thinning from below), where in consequence of the removed suppressed level of the stand the only remaining trees were dominant, co-dominant and/or intermediate individuals (the 3rd growth class) with a low proportion (15%). This stage also fully corresponds to indices characterizing the height differentiation (TM_h) according to Füldner (1995), which were found the highest for plots tended by free crown thinning (H = 0.554 and H2 = 0.443), contrary to the control plot (0.210) and plot C (0.039) (Fig. 3).

As for a comparison of the values of mean height (h_g) between subplots, after 45 and/or 53 years of investigation, the highest values were found on plot C, different from the other three subplots. Statistically significant differences (at the level α = 0.05) were found only between plot C and H.

Table 3. Development of quantitative production of the stand for 53 (45) years

Plot	Age range (yr)	Total decrease of trees						Total Production				
		N		G		V_{7b}		N	G		V_{7b}	
		(indd·ha^{-1})	% of TP	(m^2·ha^{-1})	% of TP	(m^3·ha^{-1})	% of TP	(indd·ha^{-1})	(m^2·ha^{-1})	ITS	(m^3·ha^{-1})	ITS
0		3,284	86.1	24.4	35.2	194	21.0	3,812	69.2	2.395	921	6.105
H	37–90	3,588	86.4	41.6	53.1	355	37.4	4,152	78.5	2.655	948	6.128
C		3,420	90.4	31.8	43.1	267	27.2	3,784	73.7	2.504	980	6.268
H2	45–90	1,688	82.3	38.0	53.9	448	44.4	2,052	70.5	2.140	1008	3.397

N – number of trees; G – basal area; V_{7b} – volume of timber of 7 cm in diameter and more, ITS – Index of total stand, TP – total production, C – plot with heavy thinning from below, H – plot with free crown thinning, thinning interval of 5 years, H2 – plot with free crown thinning, thinning interval of 10 years, 0 – control plot (with no treatment)

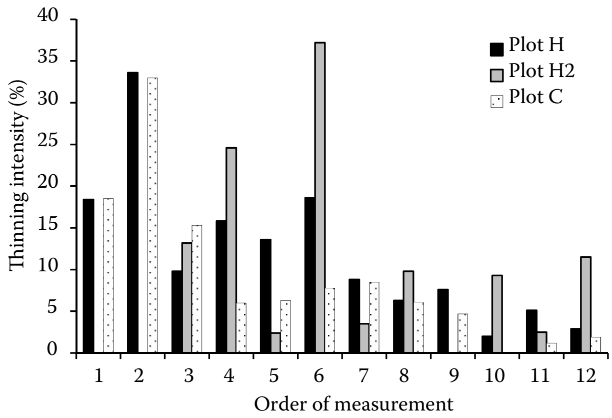

Fig. 4. Thinning intensity according to basal area during the period of investigation lasting for 45 (53) years

Development of quantitative production. The development of quantitative production characteristics during the investigated period is presented in Tables 2 and 3. After the long-term research (45 and/or 53 years) the highest values of stand parameters (basal area, merchantable volume) were found on the control plot (with no tending) and plot tended by heavy thinning from below as opposed to the plots treated with free crown thinning (plot H and H2) where the lowest values were registered. These results are in accordance with the findings of numerous thinning experiments established in the past, summarised by Assmann (1968), Šebík, Polák (1990); Utschig, Küsters (2003); Pretzsch (2005); Štefančík (2013a,b).

The analysis of the total decrease (thinning, self-thinning, abiotic injurious factors) according to basal area and volume of timber of 7 cm in diameter and more for the research period showed the highest percentage on plots tended by free crown thinning (H, H2) and the lowest on the control plot (Table 3), which is in accordance with our results found on other PRPs (Štefančík 2013a,b). It was also confirmed by the values of relative decrease (expressed by thinning intensity in percentage) according to the basal area (Fig. 4).

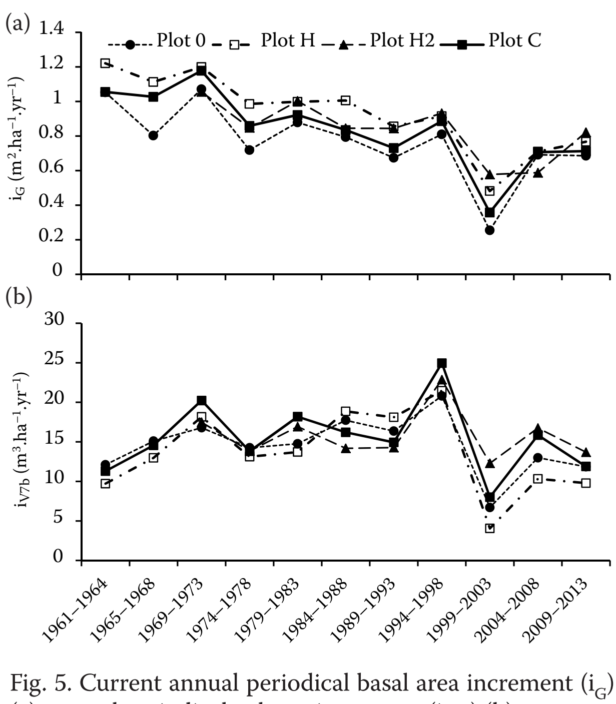

Fig. 5. Current annual periodical basal area increment (i_G) (a), annual periodical volume increment (i_{V7b}) (b)

As for the total production (according to the basal area and volume of timber of 7 cm in diameter and more), the highest values were found on the plot with heavy thinning from below, followed by plots with free crown thinning (plot H and H2). The same results were also obtained by the index of the total stand found in the research period. Similar outcomes were also published by Pretzsch (2005), who assessed 10 long-term investigated experiments in detail, established in various regions of Germany in the past. He compared three types of thinning from below (weak, moderate and heavy grade) at the stand age of 100 years. In most cases heavy thinning from below (C grade) dominated, according to total production the values from 409 to 806 m^3·ha^{-1} were reached.

On our three PRPs (Jalná, Cigánka and Zlatá Idka) after the same period of investigation (53 years) comparing systematic tending by the same methods, the values of basal area and volume of timber of 7 cm in diameter and more ranged from 34.5 to 39.7 m^2·ha^{-1} and 540 to 560 m^3·ha^{-1}, respectively (Štefančík 2013a–b). These values are only a little different when compared with the data found on Kalša PRP, analysed in this article (32.5 and 36.9 m^2·ha^{-1} or 561 and 593 m^3·ha^{-1}, respectively).

From the quantitative aspect, the higher values were obtained on plots tended by free crown thinning and heavy thinning from below, contrary to the control plot, characterized by the lowest ones. It was also confirmed by the values of the total mean annual volume increment: plot H2 – 11.2 m^3·ha^{-1}·yr^{-1}, plot C – 10.9 m^3·ha^{-1}·yr^{-1}, plot H – 10.5 m^3·ha^{-1}·yr^{-1}, and control plot 0–10.2 m^3·ha^{-1}·yr^{-1}. Nevertheless, the above-mentioned values are higher in comparison with those presented by Pretzsch (2005) – 9.3 m^3·ha^{-1}·yr^{-1}, which could be caused by the higher age of analysed stands (38 to 179 years old). It is a generally known fact that the mean annual volume increment decreases in relation with stand age (Priesol, Polák, 1991). The above-mentioned trend was also observed on investigated PRPs, where decreased current annual periodical basal area increment (i_G) and current annual periodical volume increment were found (Fig. 5).

CONCLUSIONS

Based on the long-term investigation (45 and/or 53 years) of beech stands, where different tending methods were applied, changes in the stand structure could be observed. The highest mean diameter (d_g) as well as mean height (h_g) were found on the plots managed by heavy thinning from below. The lowest values were observed on the plots tended by free crown thinning (5-year thinning interval). Structural differentiation expressed by indices according to Füldner (1995) showed the highest values on the plots managed by free crown thinning. From the aspect of quantitative production (according to the basal area and volume of timber of 7 cm in diameter and more), the highest values of total production were found on the plot tended by heavy thinning from below, followed by plots with free crown thinning. Taking into account the index of total production, the lowest values were found out on the plot where tending started later than on the other three plots (at the stand age of 45 years) and thinning interval was 10 years. Overall, it can be concluded that obtained results confirmed the favourable effect of tending in beech stands. However, the findings suggest that delayed and less intensive tending can result in lower quantitative production.

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