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Effect of delayed tending on development of beech (*Fagus sylvatica* L.) pole stage stand

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Abstract

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The paper deals with assessment of the long-term experiment (45 years of investigation) in beech (*Fagus sylvatica* L.) stand with delayed tending started at stand age of 60 years. The research was performed on four partial plots by different methods of their management: (i) plot with heavy thinning from below (C degree according to the German forest research institutes from 1902), (ii) plot with the free crown thinning (thinning interval of 5 years), (iii) plot with the free crown thinning (thinning interval of 10 years) and (iv) control plot (with no thinning). From qualitative point of view, the best results according to the number of target (crop) trees were found on plots tended by the free crown thinning (thinning interval of 5 years), and the worst on plots with heavy thinning from below and/or plot with no tending (control plot). Consequently, the results showed lower number of target (crop) trees in comparison with our assumption and/or the model developed for beech stands in the past. On the other hand, from quantitative point of view, the best results were achieved on plot tended by heavy thinning from below, followed by the plot with the free crown thinning (thinning interval of 5 years).

Keywords

beech, crop trees, quantitative production, stand structure, tending

Introduction

Tending of each forest stand has a crucial importance for its development. As a rule, it takes more than half of rotation age of forest stand. For the management of beech stands originated from natural regeneration, is very important not only the method of their tending, but also the stand age, when to start with tending.

The papers dealt with the history of beech stands tending in Slovakia (Štefančík, 1985) and other literature focused on problems of thinning in beech stand (Štefančík, 1984) concluded, that tending of beech stands had not so special tradition in comparison to France, Denmark or Germany. It should be stated, that tending was realized only according to foreign knowledge and poor experiences of internal forest practitioners. The systematic research started at the end of the 50-ies, of the last century.

The aim of the research at this time was mainly to find the first scientific results on the mentioned topic under the natural condition of Slovakia. Within the framework of thinning problems, the attention was especially paid to know, which kind of selective thinning method should be considered the most suitable for beech stands under our natural condition. Nevertheless, actual experiences by application of the methods developed abroad, and also the condition of beech premature stands in Slovakia, have been taken into account (Štefančík, 1984).

Research was by the first time focused on the beech thickets, not systematically tended until then (Réh, 1968, 1969) and/or small pole stage stands or pole

stage stands (Šebík, 1969; Štefančík, 1974). Within the framework of the research, all principal silviculture-production questions of thinning started to be solved step by step. In the initial stage of the research it was especially the problem related to thinning type (thinning from below, crown thinning), method of selection (positive, negative) and structure of pure beech stands, as well as thinning intensity, i.e. intensity, frequency and thinning interval, later on.

Effect of two degrees of thinning from below (B and C according to German forest research institutes from 1902) and two crown thinning methods (qualitative according to Schädelin) and the free crown thinning according to Štefančík (1984) started to be verified by the research.

Since the 70-ies of last century, the results of long-term investigation have been published (Štefančík, 1974, 1984; Šebík and Polák 1990; Štefančík et al., 1991, 1996; Štefančík, 2007; Štefančík and Bolvanský, 2011). The outcomes showed better results by application of crown thinning in comparison with thinning from below. Especially, the free crown thinning (Štefančík, 1984, 2007) appeared to be suitable for tending of pure beech stands in Slovakia. Since 1958, the above-mentioned method has been applied in the thinning research of beech stands. Nowadays, after long-term verification it was successfully put into the practise.

The aim of this paper was to ascertain the changes of selected parameters of quantitative and qualitative production in beech stands, tended by different thinning methods for a long time (45 years of investigation).

Material and methods

The research was carried out on the series of permanent research plot (PRP) Cigánka, established in the stand located in compartment 50, forest district Muráň, forest enterprise Revúca. The given beech stand originated from a natural regeneration. The stand age on the PRPs at their establishment (in autumn 1966) was 60 years.

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

On the plot (marked as C) a heavy thinning from below (C degree according to German forest research institutes from 1902) was realized. On the second and the third plot (marked as H and H2), the method of the free crown thinning (according to Štefančík, 1984) was applied. The mentioned method is focused on individual tending of the trees of selective quality (promising and target trees). These trees are selected on the base of the three criteria (quality, dimension and spacing). Thinning interval on plot H is 5 years, and on plot H2 10 years.

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

Characteristic	PRP Cigánka
Establishment of PRP	Autumn 1966
Age of stand [years]	60 (in 1967)
Site index	30
Geomorphologic unit	Stolické vrchy
Exposition	Northwest
Altitude [m]	560
Inclination [degree]	20
Parent rock	Gneiss (biotitic)
Soil unit	Haplic Cambisol (Dystric)
Forest altitudinal zone	4th beech
Ecological rank	A (Acid)
Management complex of forest types	405 – acid beech woods
Forest type group	*Fagetum pauper* (Fp) higher tier
Forest type	4301 woodrush beech woods (higher tier)
Average annual temperature [°C]	5.5
Sum of average annual precipitation [mm year^{-1}]	918

The plot marked as 0 is control (with no thinning).

No planned silvicultural interventions were carried out up to establishment of PRPs. The first measurement was performed in 1967. Since establishment of PRPs, 10 biometrical measurements were realized on each partial plot with the interval of 5 years, including the intervention (only on treated plots) with thinning interval of 5 years (plot C and H) and/or 10 years (plot H2). On all plots, the standard biometrical measurement and evaluation of stem and crown of trees were carried out.

Within the framework of the measurement, the quantitative parameters (breast height diameter, both height of tree and base of tree crown, crown width) were assessed according to silvicultural and commercial classification. They were focused on evaluation of each tree, and separately on the trees of selective quality (promising and target trees).

Silvicultural classification consists of:

a) Biosociological position of trees according to growth (tree) classes (Štefančík, 1984):
   1. dominant tree
   2. co-dominant tree
   3. intermediate tree
   4. suppressed tree – decreased
   5. suppressed tree – dying out
b) Degree of stem quality:
   1. well-shaped and straight, best stem quality, without burrs

2. average shaped – average stem quality, crooked only in upper third of the stem, low number of burrs
3. bad shaped – worse quality of the stem, high number of burrs, very crooked

c) Degree of crown quality:
According to the type (form of ramification): 1. crown with continuous axis of stem up to the top of tree; 2. bouquet (cluster); 3. broom; 4. forked.
According to size: 1. oversized; 2. normal size; 3. small size, asymmetrical developed, but able to regenerate; 4. too small size, not able to regenerate.
According to crown density (sufficiency of foliage): 1. good density with complete foliation, also inside of the crown; 2. sufficient density, with foliation in outside of the crown only; 3. sparse, foliation quite well; 4. very sparse, insufficient foliation.

Within the framework of commercial classification, only lower part of the stem up to crown base was assessed, separately for lower and upper half of the stem, respectively. Quality classes: 1. very high (A), 2. average (B), low quality, but industrial wood (C), 4. fuelwood (D).

The calculation of the results was performed by standard methods for tending evaluation and production-silviculture relations, utilized the software package of QC Expert and growth simulator Sibyla (Fabrika, 2005). To find out the statistical significance of the differences, the single-factor analysis of variance (ANOVA) was used.

Results and discussion

Diameter structure

The diameter development of the investigated PRPs is characterized by the diameter frequency distribution (Figs 1 and 2), as well as by the values of mean diameter (d_g) presented in Table 2.

In the initial stage of the research, the course of curves of diameter frequency distribution was found similar to all partial plots (Fig. 1). It is a type of left-hand asymmetric distribution, typical for young stands, as well as for the middle age ones, which were untouched (neglected by tending) until then. This is also the case of PRP Cigánka, where tending started at the growth stage of pole stage stand (60 year old), which is considered to be too delayed for beech stands. On the base of numerous experimental experiments, it is recommended to start with tending already in the thickets (Réh, 1968, 1969; Jurča and Chroust, 1973; Korpeľ et al., 1991) and/or no later than in small pole stage stand (Štefančík, 1974). The highest values of the mean diameter (d_g) were found on plot C, and the lowest on control plot (0).

After 45 years under different thinning regime, the differences among the plots increased (statistical significant differences at the level $\alpha = 0.05$ were found only between plot C and each other plots). The order of plots remained unchanged, when the highest values of d_g were found on plot C (heavy thinning from below),

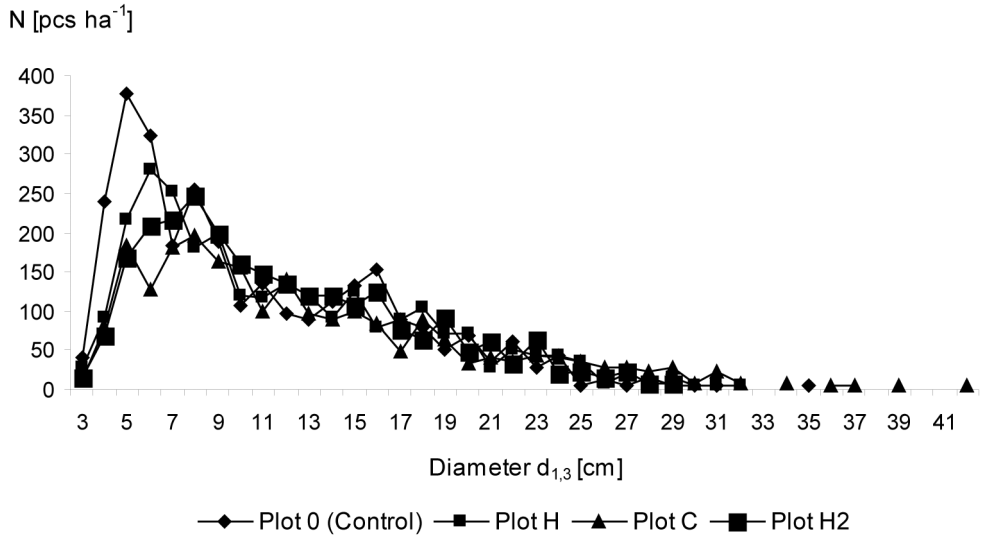

Fig. 1. Diameter frequency distribution on plots in the initial stage of the research in 1967.

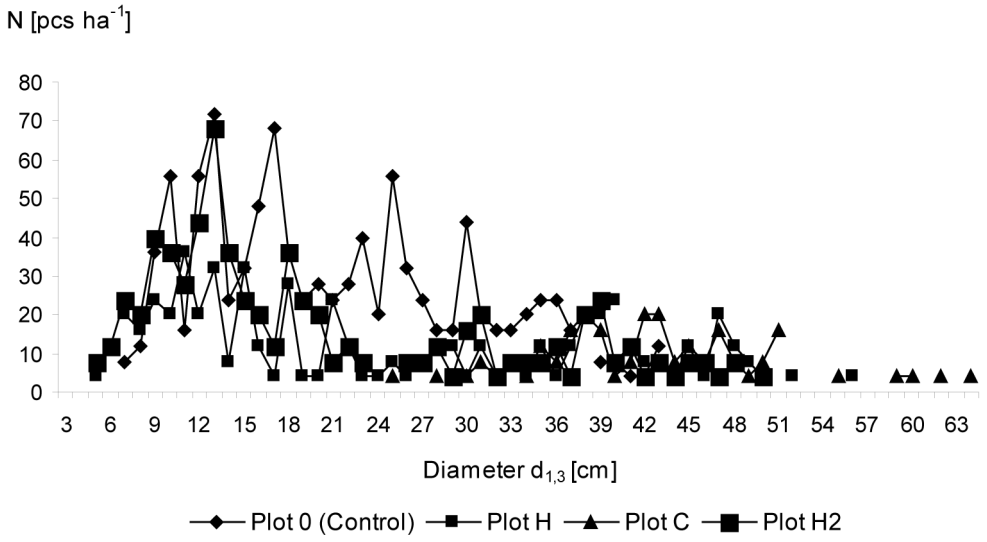

Fig. 2. Diameter frequency distribution on investigated plots in 2012.

and the lowest on control plot (with no treatment), Table 2. Simultaneously, the diameter frequency distribution was more or less changed to double-peak course (Fig. 2). The above-mentioned development response the thinning methods realised. On the plots tended by the free crown thinning (H, H2), the interventions

Table 2. Development of stand characteristics

Plot	Stand	Age	N	G	V_{7b}	Mean	
						Diameter $d_{1,3}$ [cm]	Height [m]
		[year]	[pcs ha^{-1}]	[m^2 ha^{-1}]	[m^3 ha^{-1}]	[d_g]	[h_g]
0	Total	60	2,940	34.784	337.444	12.3	19.1
	Main	65	2,276	35.768	357.892	14.1	19.8
		70	2,004	35.956	392.920	15.1	21.4
		75	1,736	36.980	437.292	16.5	23.3
		80	1,592	38.036	477.004	17.4	24.7
		85	1,472	38.604	516.368	18.3	26.2
		90	1,224	39.208	537.228	20.2	26.7
		95	1,144	41.404	570.180	21.5	26.7
		100	1,068	41.556	585.912	22.3	26.6
		105	1,012	43.956	631.524	23.5	26.9
H	Total	60	2,632	36.436	365.172	13.3	20.1
	Main	65	1,140	25.888	303.516	17.0	23.2
		70	816	22.480	286.980	18.7	25.0
		75	756	23.120	300.944	19.7	25.1
		80	624	21.172	287.976	20.8	26.2
		85	620	25.128	351.032	22.7	26.6
		90	584	27.388	389.152	24.4	26.8
		95	584	31.064	455.964	26.0	27.4
		100	564	31.724	485.060	26.8	27.5
		105	548	34.452	540.876	28.3	27.8

Table 2. Development of stand characteristics – continued

Plot	Stand	Age	N	G	V_{7b}	Mean	
						Diameter $d_{1,3}$ [cm]	Height [m]
		[year]	[pcs ha^{-1}]	[m^2 ha^{-1}]	[m^3 ha^{-1}]	[d_g]	[h_g]
H2	Total	60	2,568	35.500	354.504	13.3	20.1
	Main	65	1,552	28.968	307.740	15.4	21.0
		70	1,032	23.808	284.196	17.1	23.6
		75	992	25.948	319.808	18.3	24.0
		80	800	22.012	279.256	18.7	24.5
		85	784	24.992	334.212	20.2	25.7
		90	740	26.128	355.132	21.2	25.4
		95	732	28.916	398.292	22.4	25.5
		100	712	29.128	418.452	22.8	25.6
		105	704	31.792	468.432	24.0	26.1
C	Total	60	2,308	40.060	444.152	14.9	21.6
	Main	65	520	26.696	387.996	25.6	29.8
		70	440	27.096	416.032	28.0	31.5
		75	324	26.024	420.956	32.0	33.2
		80	312	28.468	482.532	34.1	34.7
		85	312	31.896	563.500	36.1	35.9
		90	280	32.104	595.804	38.2	37.2
		95	280	35.168	668.400	40.0	38.0
		100	272	36.052	690.564	41.1	38.2
		105	272	38.728	778.980	42.6	38.8

N, number of trees; G, basal area; V_{7b}, volume of the timber to the top of 7 cm o.b.
C → plot with thinning from below. H → plot with thinning from above, thinning interval 5 years. H2 → plot with thinning from above, thinning interval 10 years. 0 → control plot (with no treatment).

were performed in the whole vertical profile, which resulted in a better diameter differentiation. It was also confirmed by the values of indices of diameter differentiation (TM_d) according to (Füldner, 1995), which were found the highest, just in the plots treated by the free crown thinning (for H = 0.578 and H2 = 0.516). The values above 0.500 represent the strong type of differentiation. For comparison, in the control plot it was 0.398 (medium type of differentiation) and the lowest values of indices were obtained in plot C (0.173 – little differentiation), where total suppressed level of the stand was removed by the treatment.

Height structure

The height (stand) structure of the investigated plots was expressed by the relative number in the growth (tree) classes (Fig. 3). The proportion of trees in the crown level of the stand (1st + 2nd growth class) and the suppressed level of the stand (3rd to 5th growth class) is very important from the silvicultural point of view. The structure depends especially on site, tree species, stand age and tending measures (Šebík and Polák, 1990).

In the initial stage of the research, the height structure was practically the same. The proportion of the suppressed level of the stand ranged from 28.4% on control plot to 29.9% on plot H2. The differences (shifts) in the height structure (proportion between the crown level of the stand and the suppressed one), after 45 years of investigation were found only at about 10% (plot 0 and H). Contrary to the mentioned plots, plot H2 remained unchanged. These results are in accordance with the outcomes published by Šebík and Polák (1990), who stated the shift of the trees to the higher growth (tree) classes, when heavy crown thinning was applied. The mentioned authors also concluded that decreased number of co-dominant trees in the stand with shade-bearing species is typical, together with increased amount of the suppressed ones. The most proportioned are being the fourth, or the 4th and the 5th growth class, which was also confirmed by our research on PRP Cigánka. The similar results were published by

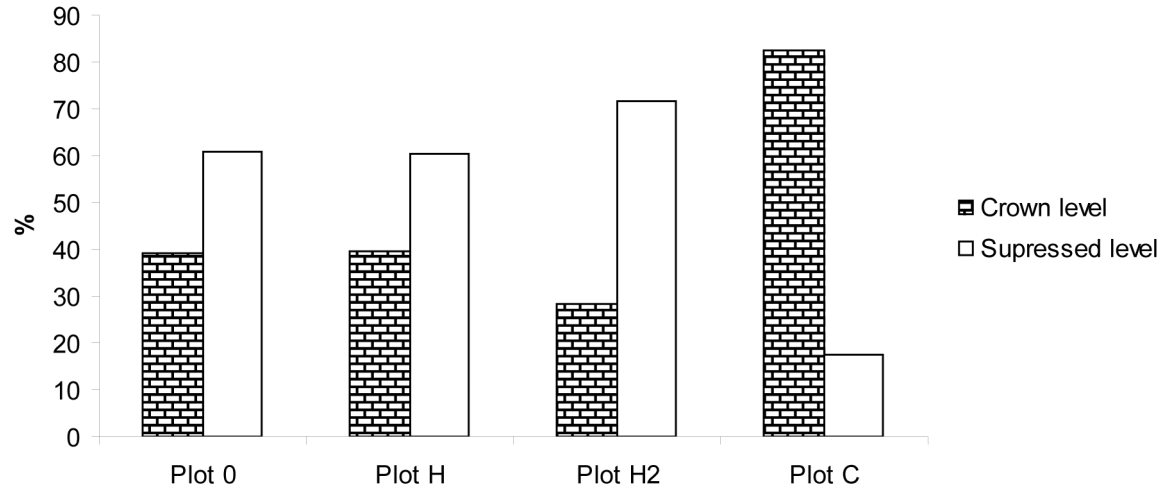

Fig. 3. Relative number according to the growth classes on plots after 45 years in 2012.

Assmann (1968) for 102 years old beech stand tended by mild crown thinning, where proportion of the crown level of the stand and the suppressed level of the stand was found of 53.8% and 46.2%, respectively.

The highest changes were registered on plot C (heavy thinning from below), where in a consequence of removed suppressed level of the stand remained only intermediate individuals (the 3rd growth class) with low proportion of 17.6%.

Very interesting should be considered the fact, that control plot left to self-development showed practically the same height structure in comparison with the plots tended by the free crown thinning (Fig. 4). This was also confirmed by the statement published in the past (Štefančík, 2007), that according to its conception, the mentioned thinning method is very similar to principles of close to nature silviculture. It was also proved by the values of indices characterized the vertical structure (APi) according to Pretzsch (1992). On the plots with the free crown thinning, the values were found of 0.791 and 0.758. For example, in the stand with a selection structure, the mentioned index is able to achieve the value of 0.900 (Pretzsch, 1992). For comparison, we suggest, that on the control plot (0) in PRP Cigánka, the index was found of 0.447. Consequently, the indices of the height differentiation (TM_h) according to Füldner (1995) were found the highest for plots tended by the free crown thinning (H = 0,514 and H2 = 0,439), contrary to control plot (0.302) and plot C (0.037).

As for the comparison of the values of the mean height (h_g), after 45 years, the highest differences (statistical significant at the level $\alpha = 0.05$) were found between plot C and each other plots. The rest three plots showed similar values, but differences among them were statistically insignificant.

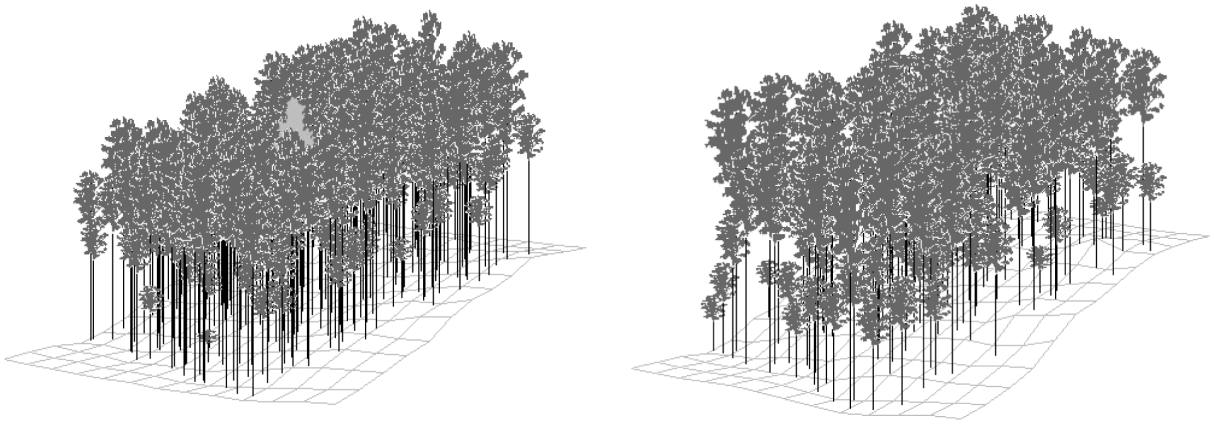

Fig. 4. Stand structure on PRP Cigánka plot 0 (left) and plot H (right).

Development of quantitative production

The development of stand characteristics during the investigated period is presented in Tables 2 and 3. At establishment of the plots, the highest initial number of trees (N) was found on control plot (0) and the lowest on plot C. After 45 years, the order was not changed, whereby on control plot remained 34.4% out of the initial number of trees, but on the plot C only 11.8%.

As for the other stand characteristics (basal area – G, and volume of the timber to the top of 7 cm o.b. – V_{7b}), the highest values were found on plot tended by heavy thinning from below and the lower on plots with the free crown thinning (H, H2). These results are in accordance with the experiences of numerous thinning experiments established in the past, concluded by Assmann (1968), Šebík and Polák (1990), Štefančík (1990).

The analysis of the total decrease (thinning, self-thinning, abiotic injurious factors) according to G and V_{7b} for the period of 45 years showed the highest percentage on plots tended by the free crown thinning (H, H2) and the lowest on control plot (Table 3).

As for the total production (according to G and V_{7b}), the highest values were found on plot with heavy thinning from below and the free crown thinning (thinning interval of 5 years). The same results were also obtained, by expression of growth index of the total production in investigated period. It suggests suitable effects of even though delayed tending measures in beech stands. Additionally, beech species is well-known of its very good responses to liberation (releasing) up to the oldest period (Assmann, 1968; Šebík and Polák, 1990). It was fully confirmed by the results from PRP Cigánka.

It should be concluded, that from quantitative point of view, the best results were obtained on plots tended by heavy thinning from below and the free crown thinning with thinning interval of 5 years, contrary to control plot (0), characterized by the worst outcomes. It was also confirmed by the values of the current annual increment on basal area and/or volume increment in 5 years periods (Figs 5 and 6). The total mean annual volume increment during the investigated period was found 14.3 $m^3 ha^{-1}$ on plot C, followed by plot H – 11.1 $m^3 ha^{-1}$, plot H2 – 9.0 $m^3 ha^{-1}$ and control plot – 8.7 $m^3 ha^{-1}$.

Development of target (crop) trees

Information related to the target (crop) trees (TT) development, representing qualitative production in commercial forests is presented in Table 4. It can be seen, that from quantitative parameters point of view, in the initial stage of the research, the highest values were found on plot C and/or the lowest on plot H2. Number of TT ranged from 176 to 208 individuals per hectare.

During the tending period of 45 years, the situation was changed unambiguously in favour of plots treated by the free crown thinning (H and H2). On the mentioned plots, double number of TT was cultivated in comparison to plot tended by heavy thinning from below (plot C). The same results were obtained, if we take into account the production parameters (basal area, volume of the timber to the top of 7 cm o.b.). The proportion of TT out of the main stand is considered to be a very important parameter. The plots managed by the free crown thinning showed also the best results according to the mentioned quantitative parameters in comparison with plots tended by heavy thinning from below, or control plot. The model of the future mature beech stand developed by Štefančík (1984) assumed at stand age of 110–130 years, in acid site, the number of TT presented 173 to 200 trees per hectare and 376 $m^3 ha^{-1}$ of volume of the timber to the top of 7 cm o.b. Its proportion had to be of 75% out of the main stand. Mean diameter $d_{1.3}$ was assumed to achieve 40 cm. It can be seen, that the results from the PRP Cigánka obtained at stand age of 105 years are very close to the mentioned model, except for number of TT, which is much lower. It is a consequence of delayed tending, which started at stand age of 60 years. It is a generally

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

Plot	Age range	Total decrease of trees						Total production				
		N		G		V_{7b}		N	G		V_{7b}	
	[years]	[pcs ha^{-1}]	% of TP	[$m^2 ha^{-1}$]	% of TP	[$m^3 ha^{-1}$]	% of TP	[pcs ha^{-1}]	[$m^2 ha^{-1}$]	Index of total stand	[$m^3 ha^{-1}$]	Index of total stand
0	60–105	1,928	65.6	12.856	22.6	98.616	13.5	2,940	56.812	1.633	730.140	2.164
H	60–105	2,084	79.2	29.688	46.3	321.528	37.2	2,632	64.140	1.760	862.404	2.362
H2	60–105	1,864	42.6	27.192	46.1	291.424	38.4	2,568	58.984	1.662	759.856	2.143
C	60–105	2,036	88.2	27.884	41.9	307.660	28.3	2,308	66.612	1.663	1,086.640	2.447

N, number of trees; G, basal area; V_{7b}, volume of the timber to the top of 7 cm o.b.; TP, total production.
C → plot with thinning from below. H → plot with thinning from above, thinning interval 5 years. H2 → plot with thinning from above, thinning interval 10 years. 0 → control plot (with no treatment).

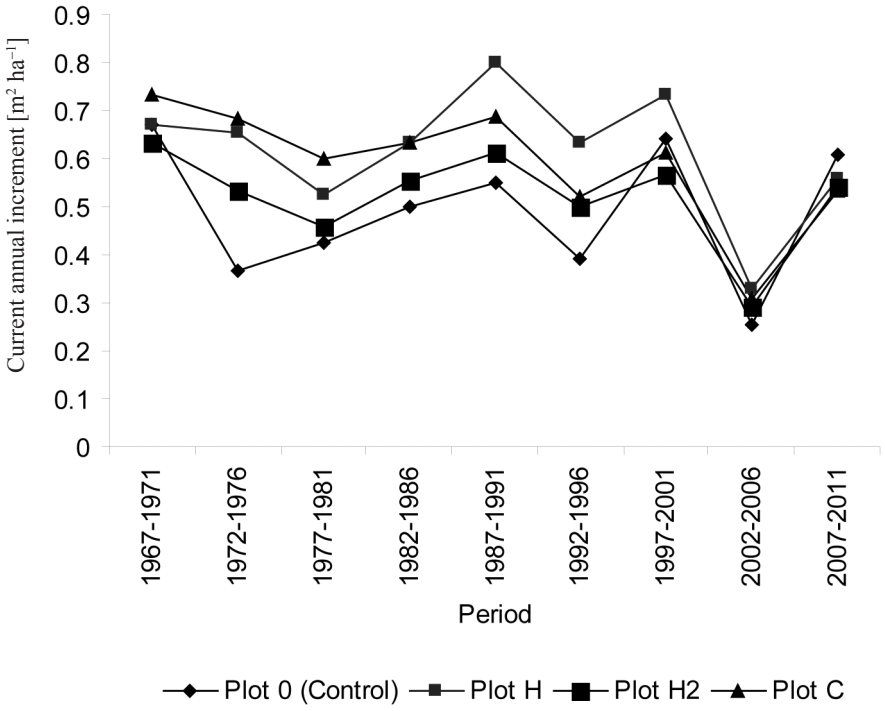

Fig. 5. Current annual basal area increment in the 5 years period of investigation.

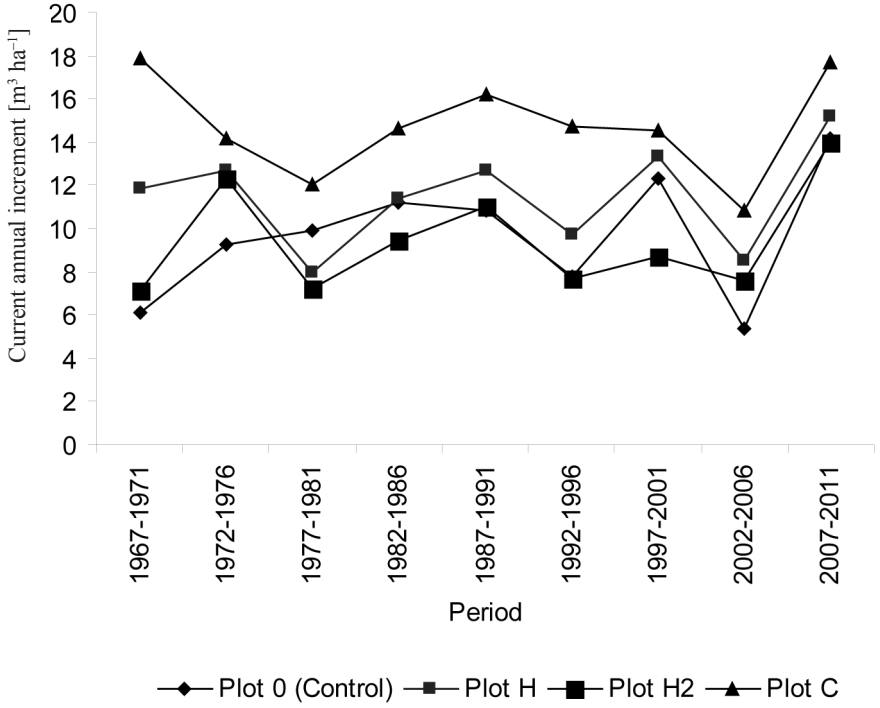

Fig. 6. Current annual volume increment in the 5 years period of investigation.

Table 4. Development of target (crop) trees

Plot	Age	N	G		V_{7b}		Mean	
	[years]	[pcs ha^{-1}]	[m^2 ha^{-1}]	% out of main stand	[m^3 ha^{-1}]	% out of main stand	diameter $d_{1,3}$ [cm] [d_g]	height [m] [h_g]
0	60	200	6.688	19.2	80.992	24.0	20.6	25.4
	105	108	11.420	26.0	191.048	30.3	36.7	32.4
H	60	188	6.428	25.2	79.308	29.1	20.9	25.6
	105	124	18.332	53.2	320.988	59.3	43.4	33.5
H2	60	176	6.512	24.0	81.312	29.4	21.7	26.0
	105	132	16.724	52.6	282.404	60.3	40.2	32.7
C	60	208	10.372	38.3	138.636	40.1	25.2	27.5
	105	68	13.303	34.3	277.620	35.6	49.9	40.0

N, number of trees; G, basal area; V_{7b}, volume of the timber to the top of 7 cm o.b.
C → plot with thinning from below. H → plot with thinning from above, thinning interval 5 years. H2 → plot with thinning from above, thinning interval 10 years. 0 → control plot (with no treatment).

known fact, that the best stand age in order to determine and cultivate the TT is considered at the period of 30–40 years (Štefančík, 1974, 1984). As it can be seen, the obtained results from PRP Cigánka showed that it is possible to achieve assumed quantitative production in case of delayed, but systematic tending. On the other hand, it is not possible to cultivate desired qualitative production represented by number of trees with the best quality (target trees), especially on plot managed by heavy thinning from below, or plot without tending.

Conclusions

Based on the 45 years of investigation of beech stand development managed by delayed tending, where different methods of tending were applied, it can be concluded:

- The differences of diverse tending regime were increased between plots after 45 years of investigation in comparison with the initial stage of the experiment. The differences were found significant at the level $\alpha = 0.05$ between plot C and each other plot. From diameter structure point of view, the order of plots remained unchanged. The highest mean diameter (d_g) was found on plot managed by heavy thinning from below, from the initial stage up to now. The lowest one showed the control plot.
- The differences (shifts) in the height structure (proportion of the crown level of the stand and the suppressed level of the stand) on plots during the investigated period of 45 years were found at about 10% on plot 0 and H. For plot H2 it remained unchanged. The highest changes were registered on plot C (heavy thinning from below), where due to removing of the suppressed level of the stand, only intermediate individuals (the 3rd growth class) remained in the stand with lower proportion of 17.6%.
- The control plot, left to the self-development showed practically the same height structure like the plots tended by the free crown thinning (H and H2).
- From quantitative point of view, the best results were found on plots tended by heavy thinning from below and the free crown thinning with thinning interval of 5 years. Consequently, the worst results were obtained from control plot.
- As for the total production (expressed by basal area and volume of the timber to the top of 7 cm o.b.), the highest values were found on plot tended by heavy thinning from below and plot with the free crown thinning (thinning interval of 5 years). The same results were also obtained according to the index of the total production. It suggests suitable effect of tending, although delayed, in older beech stands.
- The number of target (crop) trees in the initial stage of stand ranged from 176 to 208 individuals per hectare. At the stand age of 105 years, after tending for 45 years, the highest number of crop trees was showed by the plot tended by the free crown thinning (124 and 132 pieces per hectare), and the lower by the plots managed by heavy thinning from below and control plot (68 and 108 pieces per hectare, respectively).
- The results, found by long-term investigation (period of 45 years) confirmed, that by systematic and intensive tending, although delayed, it is possible to achieve desired quantitative production, but not qualitative production, represented by the number of the best quality (target) trees, especially on control plot and plot tended by the free crown thinning.

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