Development of target (crop) trees in beech (*Fagus sylvatica* L.) stand with delayed initial tending and managed by different thinning methods

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ABSTRACT: We evaluated the research on silviculture-production in the last 45 years in a 105-year-old beech stand, not tended up to its stand age of 60 years. Four alternatives (tending regime) were studied for development of the target (crop) trees. These were: (*i*) plot with heavy thinning from below (C degree 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). Target trees in the stand were selected and marked at the beginning of the study. Their development was analysed in relation to the method of tending. Based on the 45-year research period, we conclude that the most favourable results were obtained on plots tended by free crown thinning (thinning interval of 5 or 10 years) in comparison with plots tended by heavy thinning from below or with the control plot (without any tending).

Keywords: European beech; target (crop) trees; different tending

There are numerous papers dealing with the development of beech stands from various points of view (Assmann 1961; Freist 1962; Štefančík 1974; Fleder 1987; Šebík, Polák 1990; Kató, Mülder 1992; Franz, Röhle 1993; LeGoff, Ottorini 1993; Pretzsch 1996; Štefančík et al. 1996, Štefančík, Bolvanský 2011; Vacek, Hejcman 2012). It is a generally known fact that the tending of stands is considered a crucial silvicultural measure, especially for broadleaved (beech) tree species.

Many years ago, the attention was paid to research on the structure and methods of beech stand management in Denmark, Germany, Switzerland and France. Consequently, the first results of the research and practical knowledge were assessed and concluded (Assmann 1961; Vyskot et al. 1962). Later on, the results of a long-term research performed in beech stands were available (Šebík, Polák 1990; Štefančík et al. 1996). From a qualitative point of view, better results were found by the application of crown thinning in comparison with thinning from below. Moreover, an early and heavy crown thinning have been recommended (Spellmann, Nagel 1996; Guericke 2002).

In the Slovak Republic, a special (original) method of crown thinning was developed for the tending of beech stands, at the end of the 50s in the last century. It was the free crown thinning Štefančík (1984), which appeared to be suitable for the tending of pure beech stands in Slovakia. The above-mentioned selective method is focused on individual tending and/or cultivation of a desired number of target (crop) trees. These trees represent the "storage" of the best quality ones, as well as the "stand skeleton" ensuring the favourable static stability of the stand. Moreover, target trees are also the main bearers of the quantitative production in beech stands (Štefančík 1984). Cultivation of target trees depends on various factors, for

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example site, thinning method, as well as stand age. Stand age can be considered as one of the crucial facts when target (crop) trees are selected (determined).

There are several approaches how to select crop trees in beech stands, taking into account certain criteria or norms (Altherr 1981; Štefančík 1984; Abetz, Ohnemus 1999). It should be concluded that an optimal stand age seems possible for the selection of target trees, even before the age of 40 years of the stand (Bouchon et al. 1989; Spellmann, Nagel 1996; Guericke 2002). On the other hand, Lüpke (1986) recommended that the first thinning in pure beech stands should be done at the age of 45 to 55 years. Determination (selection) and subsequent cultivation of these trees at older age could result in a low number of desired crop trees at rotation age. We have analysed 45 years of our research in order to find out how delayed tending (that started at the stand age of 60 years) can influence the development of target trees in a beech stand located in the central Slovak Republic.

The objective of this paper is to analyse and assess the development of target (crop) trees and to evaluate the changes related to their tending methods used for the study period of 45 years.

MATERIAL AND METHODS

The study was conducted in a beech (*Fagus sylvatica* L.) pole-stage stand established on the series of permanent research plot (PRP) Cigánka, located in the area of the Muráň Forest District, Revúca Forest Enterprise. The beech stand originated from natural regeneration. The stand age on the PRPs at the time of their establishment (in autumn 1966) was 60 years.

The mentioned series of PRPs consists of four partial plots (C, H, H2, 0), each of an area 0.25 ha. The detailed description of the Cigánka PRP is presented in Table 1.

On the plot (marked as C) a heavy thinning from below (C degree according to the German forest research institutes from 1902) was realized. On the second and the third plot (marked as H and H2), the method of free crown thinning, according to Štefančík (1984), was applied. The thinning interval on plot H and H2 was 5 or 10 years, respectively.

The above-mentioned method is focused on the individual tending of trees of selective quality (promising and target trees). Target (crop) trees were selected at the age of 60 years according to the following criteria: (*i*) satisfactory quality characteristics of stem and crown; (*ii*) suitable dimensional requirements (diameter, height), and (*iii*) appropriate spacing in the stand. These trees should be visibly marked in the stand. They allow the forest manager to get a good orientation in the marking of further thinning. In each replication the thinning of these trees must be comprehensively assessed in accordance with the criteria mentioned above. The plot marked as 0 is control (with no thinning).

Table 1. Basic characteristics of the series of permanent research plots (PRP) Cigánka

Characteristic	PRP Cigánka
Establishment of PRP	Autumn 1966
Age of stand (years)	60 (in 1967)
Site index	28
Geomorphologic unit	Stolické vrchy
Exposition	Northwest
Altitude (m)	560
Inclination (degree)	20
Parent rock	Gneiss (biotitic)
Soil unit	Haplic Cambisol (Dystric)
Forest altitudinal zone	4^{th} beech
Ecological rank	A (Acid)
Management complex of forest types	405 – acid beechwoods
Forest type group	*Fagetum pauper* (Fp) higher tier
Forest type	4301 woodrush beechwoods (higher tier)
Average annual temperature (°C)	5.5
Sum of average annual precipitation ($mm \cdot yr^{-1}$)	918

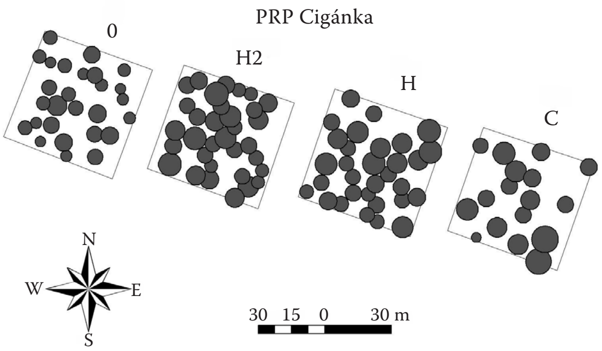

Fig. 1. Arrangement of plots and target (crop) trees with their crown cross-section areas

0 – control plot (without tending), H – free crown thinning (thinning interval of 5 years), H2 – free crown thinning (thinning interval of 10 years), C – heavy thinning from below (C degree according to German forest research institutes from 1902)

No planned silvicultural interventions were carried out up to the establishment of the PRPs. The first measurement was performed in 1967. Since the establishment of PRPs, 10 biometrical measurements were accomplished on each partial plot with the interval of 5 years, including the felling (only on treated plots), with the thinning interval of 5 years (plot C and H) and/or 10 years (plot H2). All the trees were numbered and marked at 1.3 m above the ground – in order to measure their diameter (DBH). On all plots, biometrical measurements and evaluation of the stem and crown quality of trees have been carried out in accordance with standard methods developed for the long-term research on silviculture-production problems in thinning. The following characteristics were measured: diameter $d_{1.3}$, tree height, crown base height, crown size, and silvicultural evaluation was carried out, including the trunk and crown quality assessment. A special attention was paid to the tending of target trees according to the methodology developed by Štefančík (1984).

The experimental data were processed by mathematical and statistical evaluation, using Microsoft Excel and QC Expert software, as well as the growth simulator SIBYLA (Fabrika 2005) only for stand map creation and for calculation of stand characteristics. The statistical significance of differences was assessed by ANOVA.

RESULTS

Information related to target (crop) tree (TT) development, representing the qualitative production in commercial forests, is presented in Table 2. With regard to the quantitative parameters, the highest values were found on plot C and/or the lowest on plot H2 in the initial stage of research. The number of TT ranged from 176 to 208 trees·ha^{-1}.

During the tending period of 45 years, the situation was changed unambiguously in favour of plots tended by free crown thinning (H and H2). On the mentioned plots, a double number of TT was cultivated in comparison with the plot tended by heavy thinning from below (plot C) (Fig. 1).

The same results were obtained when we took into account the production parameters (basal area, volume of the timber to the top of 7 cm o.b.). The analysis of statistical data showed the impact of the tending method on diameter (DBH) and height of TT (Table 2). Stand characteristics on plot C (including quantitative parameters of TT) were higher due to thicker target trees at the beginning of research in comparison with the other plots. The mentioned fact resulted in statistically significant differences ($\alpha = 0.05$) mainly between plot C and the other plots. The proportion of TT in the main stand is considered a very important parameter. The plots managed by 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 values of the mean periodic annual diameter increment (i_d) of target trees in the 5-year period of the research are presented in Fig. 2.

It can be seen that since the period 1987–1991 and 1997–2001, the highest i_d has been found on plots tended by free crown thinning (plot H and H2). The second interesting fact was registered in the period 2002–2006, when the evident decrease of i_d was observed on each plot. Statistical analysis of differences between partial plots showed a significant influence of the tending method on values of i_d (statistically significant differences at $\alpha = 0.05$). Concerning the mean air temperature, a more or less balanced trend could be recorded in 5-year periods. However, a slightly increasing trend should be reported also in the case of average precipitation sum.

In order to obtain results on the possibly different productivity of target trees in relation to the thinning method applied, the total average volume increment was measured with the following values: 5.37 m^3·ha^{-1}·yr^{-1} on plot H, 4.47 m^3·ha^{-1}·yr^{-1} on plot H2, 3.09 m^3·ha^{-1}·yr^{-1} on plot C, and 2.45 m^3·ha^{-1}·yr^{-1} on control plot. It is noteworthy that the obtained values showed a twofold higher volume increment on the plot tended by free crown thinning in comparison with the control plot. Practically, the same order was also found for

Table 2. Development of the basic characteristics of target (crop) trees

Plot	Age (yr)	Number of trees (stems·ha^{-1})	Basal area		Volume of timber to the top of 7 cm over bark		Mean	
			(m^2·ha^{-1})	(% out of the main stand)	(m^3·ha^{-1})	(% out of the main stand)	diameter $d_{1,3}$ (d_g) (cm)	height (h_g) (m)
0	60	200	6.688	19.2	80.992	24.0	20.6[a]	25.4[a]
	65	152	6.136	17.2	73.948	20.7	22.7[a]	25.0[a]
	70	116	5.872	16.3	77.832	19.8	25.4[a]	27.4[a]
	75	112	6.352	17.2	89.340	20.4	26.9[a]	29.1[a]
	80	104	6.868	18.1	101.140	21.2	29.0[a]	30.4[a]
	85	104	7.752	20.1	121.744	23.6	30.8[a]	32.4[a]
	90	112	9.096	23.2	135.260	26.2	31.9[a]	32.4[a]
	95	112	10.24	24.1	164.096	28.8	34.1[a]	32.7[a]
	100	108	10.38	25.0	164.004	29.0	35.0[a]	32.2[a]
	105	108	11.42	26.0	191.048	30.3	36.7[a]	32.4[a]
H	60	188	6.428	25.2	79.308	29.1	20.9[ac]	25.6[b]
	65	140	6.556	25.3	87.876	29.0	24.4[ac]	27.7[b]
	70	124	7.244	32.2	105.380	36.7	27.3[ac]	30.0[b]
	75	128	8.768	37.9	131.672	43.8	29.5[ac]	30.8[b]
	80	128	10.200	48.2	157.580	54.7	31.9[ac]	31.8[ac]
	85	120	11.636	46.3	184.400	52.5	35.1[b]	32.6[ac]
	90	124	13.58	49.6	218.008	56.0	37.4[b]	32.8[ac]
	95	124	15.796	50.8	258.128	56.6	40.3[b]	33.4[ac]
	100	124	16.700	52.6	272.588	58.6	41.4[b]	33.2[ac]
	105	124	18.332	53.2	320.988	59.3	43.4[b]	33.5[ac]
H2	60	176	6.512	24.0	81.312	29.4	21.7[a]	26.0[ab]
	65	144	6.676	23.0	84.868	27.6	24.3[a]	26.3[ab]
	70	140	7.572	31.8	104.664	36.8	26.2[a]	28.7[a]
	75	140	8.676	33.4	123.592	38.6	28.1[a]	29.3[a]
	80	140	10.032	45.6	148.028	53.0	30.2[a]	30.5[a]
	85	136	11.46	45.9	177.632	53.1	32.8[ab]	31.9[a]
	90	136	12.916	49.4	204.184	57.5	34.8[ab]	32.3[a]
	95	136	14.688	50.8	233.732	58.7	37.1[ab]	32.5[a]
	100	132	15.084	51.8	237.056	59.5	38.2[ab]	32.4[a]
	105	132	16.724	52.6	282.404	60.3	40.2[ab]	32.7[a]
C	60	208	10.372	38.3	138.636	40.1	25.2[b]	27.5[c]
	65	136	9.892	37.1	152.656	39.3	30.4[b]	31.6[c]
	70	96	8.660	32.0	139.584	33.6	33.9[b]	33.2[c]
	75	92	9.368	36.0	156.372	37.1	36.0[b]	34.3[c]
	80	96	11.176	39.3	195.800	40.6	38.5[b]	35.6[b]
	85	76	10.584	33.2	191.996	34.1	42.1[c]	36.9[b]
	90	72	11.172	34.8	217.608	36.5	44.5[c]	38.2[b]
	95	68	11.856	33.7	239.500	35.8	47.1[c]	39.4[b]
	100	68	12.42	34.5	251.928	36.5	48.2[c]	39.5[b]
	105	68	13.303	34.3	277.620	35.6	49.9[c]	40.0[b]

0 – control plot (without tending), H – free crown thinning (thinning interval of 5 years), H2 – free crown thinning (thinning interval of 10 years), C – heavy thinning from below (C degree according to German forest research institutes from 1902), values with different letters are significant at $\alpha = 0.05$

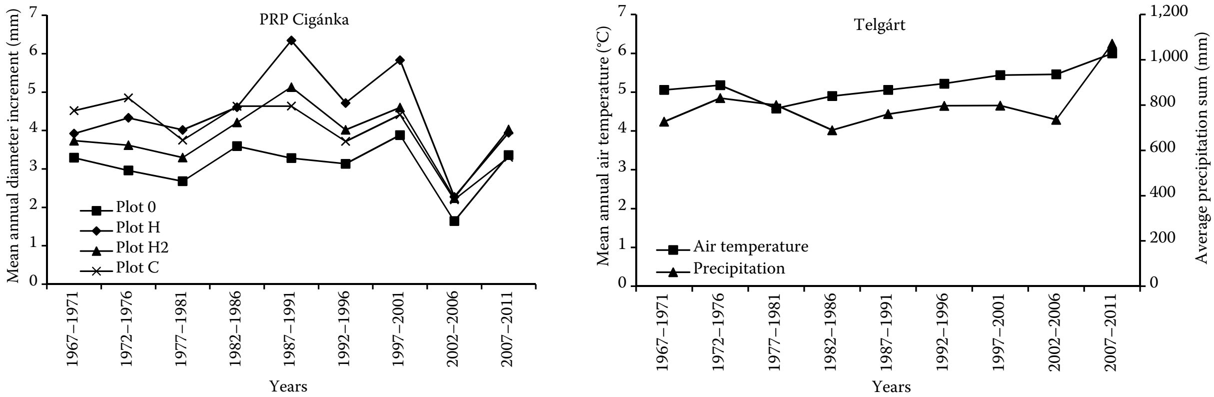

Fig. 2. The mean annual diameter increment on Cigánka PRP in a 5-year period (a), the mean annual air temperature and average precipitation sum from the nearest meteorological station in Telgárt (b)

the total average basal area increment amounting to 0.27 $m^2·ha^{-1}·yr^{-1}$, 0.23 $m^2·ha^{-1}·yr^{-1}$, 0.07 $m^2·ha^{-1}·yr^{-1}$, and 0.11 $m^2·ha^{-1}·yr^{-1}$, respectively.

DISCUSSION

Different opinions are available, related to a desired number of crop trees in beech stands. For example, Abetz (1979) and Altherr (1981) recommended 110 trees·ha^{-1}. A higher number of these trees was pointed out by Spellmann, Nagel (1996) and Guericke (2002) representing 250 and 100–300 selected and marked crop trees, respectively. Later on, due to the development of the crown surface area a decreasing number of crop trees from 200 to 80 stems·ha^{-1} with advancing age was registered. In Switzerland, Kurt (1982) presented 80–120 target trees for beech with desired parameters in relation to DBH as given by yield tables. Based on the study in 20 stands in Switzerland, Leibundgut (1982) recommended 210 crop trees for beech at a top height of 35 m. A lower number of crop trees is typical and common in France, ranging from 80 to 100 trees·ha^{-1} (Bouchon et al. 1989). A similar opinion was published by Klädtke (2002), who pointed out that the selection of more than 100 crop trees is not recommended, because the probability of red heart formation increases strongly due to a much longer production time.

In Slovakia, a model of the future mature beech stand (stand age 110–130 years) was developed by Štefančík (1984). This model presents 5 variants depending on the site conditions (acid and fertile). The number of target trees ranged from 121 to 217 stems·ha^{-1}, within the mean spacing between target trees of 7.6 m. According to the mentioned model applied in Cigánka PRP, the number of crop trees representing 173 to 200 stems·ha^{-1} and 376 $m^3·ha^{-1}$ of the volume of timber to the top of 7 cm o.b are assumed at the stand age of 110–130 years. Its proportion had to be 75% of the main stand. Mean diameter $d_{1.3}$ was supposed to reach 40 cm. It is evident that the results from Cigánka PRP at the stand age of 105 years are very close to the above-mentioned model, except for a much lower number of target trees. It is a consequence of delayed tending, which started at the stand age of 60 years. In general, the best age for determination of crop trees is in the period of 30 to 40 years (Štefančík 1974, 1984; Bouchon et al. 1989; Spellmann, Nagel 1996; Guericke 2002). Results from Cigánka PRP showed that it is possible to achieve the expected quantitative production in the case of delayed, but systematic tending only. On the other hand, it is not possible to cultivate desired qualitative production represented by a number of trees of the best quality (target trees), especially on a plot managed by heavy thinning from below or on a plot without tending.

Besides the number of crop trees, their production characteristics are important in terms of the silviculture. We calculated the mean annual diameter increment (i_d) in order to find growth responses to different thinning regimes. The highest values of i_d were detected on plots tended by free crown thinning (2.3–6.3 mm), and lower ones on the control plot (1.6–3.9 mm). Although the tending started too late, the plasticity of beech species to releasing their crowns by felling even up to an old age is well known, however, the values are lower in comparison with other results. Similarly, according to growth data, Guericke (2002) reported a high annual diameter increment until the age of

140 years, within maximum diameter increment of 12 mm·yr^{-1}. Consequently, 122 years of observations on a thinning trial started in 1871 in an unthinned 42-year-old pole beech stand in Bavaria published by Foerster (1993) confirmed that increment continued to be good even up to the age of 160 years. Similar results were found out by Marušák and Barna (2002) in 100-year-old beech stand in central Slovakia. Diameter increment in the evaluated periods (1989–1995 and 1996 to 2000) was increasing with the increased thinning intensity. Similarly to our results, the lowest diameter increment was shown by the control plot (with no tending).

Similar results to our outcomes were also published by Bobinac (2004), who investigated the stand increment in a beech stand in the period 1986–2002. As for the target trees, the lowest increment of basal area (198%) and volume (278%) occurred on the control plot, and a far greater increase of basal area (256% and 263%) and volume (379% and 399%) was observed on the thinned plots.

Our results related to decreased diameter increment due to climatic factors are in accordance with outcomes published by Biondi (1993). He found a high decrease in tree rings of beech from the central Apennines (Italy) in 1981. Dittmar et al. (2003) found growth depressions in the ring width of 10 beech trees between 1978 and 1980 in Fichtelgebirge (Germany), as well as in 1995. Zawada and Gazda (1998) reported a decrease in diameter increment of annual rings of beech trees at the beginning of the 90s in the last century in Poland. Dittmar et al. (1997) found that beech trees from high elevation sites partly showed a massive growth reduction between 1976 and 1988 in the north of Bohemian mountains. Penninckx et al. (1999) observed a dramatic decrease in ring width in 1981 according to tree ring chronologies of beech trees in a forest stand located in central Belgium. Similarly, very high temperatures during the summer season characterized by episodes of extreme drought were registered in 2003 in forests of Slovakia. Based on the numerous papers mentioned above, we can conclude that high temperature and low precipitation should be considered as the crucial factors affecting growth depression.

Another possible factor able to influence the diameter growth of beech trees could be seed production. A study carried out by Piovesan and Bernabei (1997) focused on relations between summer rainfall in the period 1962–1994 and beech growth and reproductive behaviour, using growth ring data collected in a beech stand located in central Italy. Results indicated that seed production had a negative effect on the growth ring width. The years 2003, 2006 and 2007 were found to be mast years in Slovak beech stands in our research and it corresponds to the periods with decreased diameter increment.

CONCLUSIONS

Long-term research in a 105-year-old beech stand not tended up to its age of 60 years showed significant differences related to target tree development. Target trees were selected and marked at the beginning of the study. During the tending period of 45 years, the situation was changed unambiguously in favour of plots tended by free crown thinning (H and H2). On the mentioned plots, a double number of TT was cultivated in comparison with the 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., mean annual diameter increment, both total average volume and basal area increment).

Based on the 45-year period of research, we conclude that the most favourable results were obtained on plots tended by free crown thinning (thinning interval of 5 or 10 years) in comparison with plots tended by heavy thinning from below or on the control plot (without any tending).

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