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Thinning in artificially regenerated young beech stands

Výchova v uměle obnovovaných mladých bukových porostech

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Abstract

Although beech stands are usually regenerated naturally, an area of up to 5,000 ha year^{-1} is artificially regenerated by beech in the Czech Republic annually. Unfortunately, these stands often showed insufficient stand density and, consequently, lower quality of stems. Therefore, thinning methods developed for naturally regenerated beech stands are applicable with difficulties. The paper evaluates the data from two thinning experiments established in young artificially regenerated beech stands located in different growing conditions. In both experiments, thinning resulted in the lower amount of salvage cut in following years. Positive effect of thinning on periodic stand basal area increment and on periodic diameter increment of dominant trees was found in the beech stand located at middle elevations. On the other hand, thinning effects in mountain conditions were negligible. Thinning focusing on future stand quality cannot be commonly applied in artificially regenerated beech stands because of their worse initial quality and lower density. However, these stands show good growth and response to thinning, hence their management can be focused on maximising beech wood production.

Key words: diameter growth; basal area; *Fagus sylvatica*; quantity of production

Abstrakt

Ačkoliv jsou bukové porosty obnovovány obvykle přirozeně, v České republice vzniká ročně až 5 tisíc hektarů bukových porostů obnovených uměle. Tyto porosty mají často bohužel nedostatečnou hustotu a v souvislosti s tím i nízkou kvalitu kmenů. Proto je v nich obtížné aplikovat metody výchovy vyvinuté pro porosty obnovené přirozeně. Studie je zaměřena na vyhodnocení dat z dvou experimentů s výchovou založených v mladých uměle obnovených bukových porostech v rozdílných růstových podmínkách. Provedené výchovné zásahy vedly na obou experimentech ke snížení nahodilé těžby v následujících letech. Pozitivní vliv výchovy na periodický přírůst porostní výčetní základny a na periodický tloušťkový přírůst dominantních stromů byl zjištěn ve sledovaných bukových porostech ve středních polohách. Vliv výchovy v horských podmínkách byl nejednoznačný. Kvůli nedostatečné hustotě a kvalitě je obtížné v uměle obnovovaných bukových porostech aplikovat tradiční výchovné zásahy zaměřené na podporu budoucí kvality produkce. Tyto porosty však vykazují dobrý růst a reakci na výchovné zásahy, a proto v nich může být hospodaření zaměřeno na kvantitu produkce bukového dřeva.

Klíčová slova: tloušťkový přírůst; výčetní základna; *Fagus sylvatica*; kvantita produkce

1. Introduction

European beech (*Fagus sylvatica* L.) is the main tree species in the frame of determined natural species composition in the Czech Republic (Plíva 2000). Originally, beech covered more than 40% of forest land. Nowadays, beech is still the main broadleaved tree species in Czech forests, but it represents only 7.8%, i.e. ca 202.6 thousand hectares of the reduced area. Beech was substituted mostly by Norway spruce (*Picea abies* [L.] Karst.). Similar situation is evident in other countries of central Europe.

According to European trends of spruce stand conversion at sites naturally dominated by broadleaves (Spiecker et al. 2004), gradual increase of beech share is expected in the Czech Republic up to recommended 18% (MZe 2013).

Beech stands are usually regenerated naturally because of several advantages, e.g. guarantee of the genetic origin, exclusion of root and stem deformation and, first of all, procuration of adequate stand density. Artificial regeneration especially on clear-cuts can result in lower quality of beech stands (Bednář & Černý 2014) and also in possibly drastic changes in the genetic structure of beech forests (Finkeldey & Ziehe 2004). However, natural regeneration is not applicable at all sites, where beech is planned in the target tree species composition. This relates mainly to the return of beech (within reconstruction) at sites originally naturally dominated by this species but historically planted by spruce. At such places, the importance of artificial regeneration of beech is apparent.

In the last decade, from 3.4 to 4.9 thousand hectares per year were artificially regenerated by beech in the Czech Republic (MZe 2013). Therefore, the area of artificially regenerated beech stands is significant and these stands will need appropriate silvicultural measures – thinning. Beech stands can be influenced by thinning from the point of production parameters (e.g. Abetz & Ohnenus 1999; Tarp et al. 2000; Bastien et al. 2005; Boncina et al. 2007; Hein et al. 2007; Štefančík 2013a) but also in the frame of other forest services. Thinning in beech stands is important for the cycles of carbon (Borys et al. 2013) and nitrogen (Nahm et al. 2006; Dannenmann et al. 2007a), and also climate (Le Goff & Ottorini 1993; Cescatti & Piutti 1998; Barna 2000, 2001; Lemoine et al. 2002; Dannenmann et al. 2007b; Štefančík

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2008). The positive effect of thinning on beech stands (higher increment, longer growth period compared to unthinned stands) under the climate change was confirmed by van der Maaten (2013).

The knowledge of thinning effects on European beech stands is relatively wide, but in most cases it was gathered from naturally regenerated beech stands. Additionally, experiments usually started in nearly mature stands, i.e. first thinning was realised after the age of 40 years (e.g. Utschig & Küsters 2003; Pretzsch 2005; Prka & Krpan 2010; Štefančík 2013a, 2014). Only several studies focused on younger beech stands (Mráček 1989; Le Goff & Ottorini 1993; Skovsgaard et al. 2006; Štefančík 2009, 2013b, 2015; Štefančík et al. 2014; Yücesan et al. 2015).

As it was mentioned, forest practitioners can use a wide spectrum of recommendations from naturally regenerated beech stands, in which thinning started in the second half of the rotation period. Knowledge from younger and artificially regenerated stands is still insufficient.

Therefore, the aim of the presented work was to evaluate the results from two thinning experiments established in young beech stands growing under different site conditions. The analysis focused on the meaningfulness of thinning in young artificially regenerated beech stands from the point of growth and production. We hypothesized that the thinning in low-quality stands would at least support the quantity of production.

2. Methods

2.1. Study area

Long-term thinning experiments in artificially regenerated beech stands are not very frequent in the Czech Republic. From the experimental base managed by the Forestry and Game Management Research Institute, only two series established in different site conditions were applicable for this analysis (Table 1): Destne in Natural forest region (NFR) 25 – Orlicke hory Mts. (Eastern Bohemia) and Roblin in NFR 8b – Cesky kras (Central Bohemia).

Destne series is located at an elevation of 890 m on WSW-facing slope (16°) on the transition from hyperdystric sceletic cambisol to entic sceletic podzol on mica schist to gneiss bedrock. Mean annual temperature (1961–2000) is 3.6 – 4.0°C, mean annual sum of precipitation is 1,251 – 1,300 mm for the same period.

Roblin series is located at an elevation of 345 m on NW-facing slope (5.5°) on leptosol on limestone bedrock. Mean annual temperature (1961–2000) is 8.6 – 9.0°C, mean annual sum of precipitation is 551 – 600 mm for the same period.

2.2. Experiments

The effect of thinning on growth and development of young beech stands was observed at both above mentioned series. Tree stem quality of all artificially planted stands was moderate or poor (due to relatively high number of forked and "wolf" trees, Fig. 1). The stem quality was evaluated only at the start of the experiments using the following scale: 1 – a straight stem, 2 – a forked stem or a stem with one-side crookedness, 3 – a stem with two-sides crookedness or a „wolf" tree.

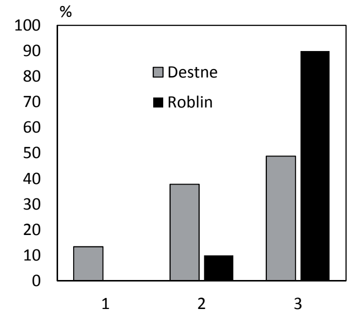

Fig. 1. Mean percentage of trees by stem quality in the frame of selected groups: Destne - „promising trees" (500 tress ha^{-1}), Roblin – „dominant trees" (200 trees ha^{-1}). Scale: 1 – straight stem, 2 – forked stem or stem with one-side crookedness, 3 – stem with two-side crookedness or „wolf" tree.

The series of Destne was established in 1996 as a part of a long-term experimental stationer (Kantor 1981). The stands were planted in spring 1982 with the initial density of about 10 thousand trees per ha. In 1996 (stand age of 15 years), four comparative plots were established, each with an area of 0.09 ha. Plot C is a control plot, from which only dead, dry and broken trees were removed during the observation period. The first thinning (positive selection) at plot T1 was performed at the age of 15 years (1996). One or two neighbours of "promising" trees were removed from above to release the "promising" trees. These trees were selected from the main canopy if they had relatively straight stems and regular crowns, and were marked at density of 500 individuals per hectare. However, due to the above mentioned poor stand quality, the criteria for their selection were milder compared to classic positive selection in high quality beech stands (e.g. Štefančík 1973). Next management interventions were applied at the age of 28 years (2009). One and two neighbours of "promising" trees were removed from above at plots T1 (second thinning with positive selection) and T3 (first thinning with positive selection), respectively. Negative selection from above (i.e. forked and wolf trees removed) was performed at T2 plot.

Table 1. Basic information about experimental series.

Locality	Age[1] [y]	Coordinates	Elevation [m]	Temperature[2] [°C]	Precipitation[3] [mm]	Group of forest sites[4]
Destne	15	50°19′23′′ 16°21′22′′	890	3.6–4.0	1 251–1 300	*Piceeto – Fagetum acidophilum*
Roblin	28	49°57′51′′ 14°18′33′′	345	8.6–9.0	551–600	*Querceto – Fagetum illimerosum trophicum*

[1]At first thinning, [2]Mean annual air temperature for period of 1961–2000, [3]Mean sum of precipitation for period of 1961–2000, [4]According to Viewegh et al. (2003) .

The series of Roblin was established in 1999 from a former experiment with plantation density initiated in 1971 (Mráček 1989). The stands with their initial densities from 4.4 to 13.3 thousand beeches were thinned to 50% density (i.e. mean density of 5.5 thousand trees ha^{-1}) after ten years. Two comparative plots (0.2 ha each) were established in Roblin with different initial plantation density.

Plot C is a control plot, i.e. only dead and broken trees were removed during the observation period. The first thinning was performed at plot T at the age of 28 years as negative selection from above (forked and wolf trees removed). The second thinning, focused again on negative selection from above, was realised at the age of 33 years (2004).

2.3. Data collection and analysis

Diameter at breast height (all trees) and height (30 representatives per plot according to diameter structure) were measured annually. Mortality (dead, dry and broken trees) and stem quality were also evaluated. The presented paper is focused on the development of stand density (N), diameter at breast height (DBH), diameter distribution and basal area (G) from the beginning of the experiment to the age of 33 (Destne) and 42 (Roblin) years. The mean stem diameter was calculated as mean quadratic diameter; the mean diameter of dominant trees was calculated from 200 thickest trees ha^{-1}. We used 25 and 75% percentiles for the representation of data variability for "promising" and "dominant" trees. Due to the design of experiments (plots are not replicated), the results were evaluated without statistical inferential methods.

3. Results

3.1. Stand density and basal area

The stand density (N) in Destne experiment was from 8.4 to 9.2 thousand trees per ha at the age of 15 years (Table 2). The corresponding basal area (G) was from 4.5 to 5.9 m^2 ha^{-1}. At that age, about 14% of N (i.e. 22% of G) was removed by the first thinning at plot T1. The following thinning was realised at the age of 28 years, when 14%, 15% and 20% of N (i.e. 10%, 14% and 23 % of G) was removed from plots T1, T2 and T3, respectively.

At the end of the observation period (age of 33 years), the density of the stands ranged from 2.5 to 3.1 thousand trees ha^{-1}, and their basal area from 23.3 to 27.6 m^2 ha^{-1}. Totally, from 5.8 to 6.2 thousand trees ha^{-1} were removed from the stands by thinning or salvage cutting during the period of observation. The salvage cuts (dead, dry and broken trees together) represented 70%, 90%, 85% and 100% of the total number of removed trees from plots T1, T2, T3 and C, respectively.

The periodic basal area increment (thinning and salvage cuts included) was from 27 to 31 m^2 ha^{-1} during the period of observation (higher – 30 and 31 m^2 – at plots C and T3, and lower – 27 m^2 – at plots T1 and T2). The highest share (28%) of salvage cuts on periodic G increment was found at the control plot, while this share was lower at the thinned plots (20, 24 and 18% on T1, T2 and T3).

The thinning at Roblin experiment started later compared to Destne. At the age of 28 years, the density of stands was 2.6 and 2.2 thousand trees ha^{-1} at plots C (control) and T (thinned), respectively. The corresponding basal area (G) was 26.7 and 24.6 m^2 ha^{-1} (Table 2). At the given age, 20% of N (26% of G) was removed by the first thinning. The second thinning was performed 5 years later (at the age of 33 years), when 18% of N (14% G) was removed. At the end of the observation period (age of 42 years), the stand density ranged from 1.2 (plot T) to 1.8 (plot C) thousand trees ha^{-1}, and stand basal area from 27 and 35 m^2 ha^{-1}.

In total, 905 (plot T) and 825 (plot C) trees ha^{-1} were removed from the stands by thinning or salvage cutting during the period of observation. The salvage cuts (dead, dry and broken trees together) represented 70% and 100% of the total number of removed trees from plots T and C, respectively. The periodic basal area increment (thinning and salvage cuts included) was higher at the thinned plot (13.9 m^2 ha^{-1})

Table 2. Number of trees ha^{-1} (N) and basal area (G) at sample plots of experiments Destne (on top) and Roblin (at the bottom).

Destne	Plot	Age 15 y (1996)			Age 28 y (2009)			Age 33 y (2014)	Period 15 – 33 y (1996–2014)			
		BT	T	AT	BT	T	AT	BT	Salvage cut (SC)	Incr.+T	Incr.+T+SC	% SC vs. Incr.
N [trees ha^{-1}]	C	9189			5167			3133				
	T1	8389	1211	7178	4000	567	3433	2533	4078			
	T2	8767			3978	600	3378	2578	5589			
	T3	8744			4633	911	3722	2844	4989			
G [m^{2}ha^{-1}]	C	5.3			24.4			27.6	8.5	22.3	30.8	28
	T1	5.9	1.3	4.6	22.3	2.3	20.0	23.8	5.4	21.5	26.9	20
	T2	5.8			22.3	3.2	19.1	23.3	6.6	20.7	27.3	24
	T3	4.5			23.6	5.3	18.3	23.6	5.4	24.4	29.8	18

Roblin	Plot	Age 28 y (1999)			Age 33 y (2004)			Age 42 y (2013)	Period 28 – 42 y (1999–2013)			
		BT	T	AT	BT	T	AT	BT	Salvage cut (SC)	Incr.+T	Incr.+T+SC	% SC vs. Incr.
N (trees ha^{-1})	C	2605			2055			1780	825			
	T	2210	530	1680	1565	275	1290	1205	200			
G (m^2 ha^{-1})	C	26.7			29.4			35.0	4.4	8.3	12.7	35
	T	24.6	7.2	17.4	21.9	3.1	18.8	27.1	1.2	12.8	14.0	9

BT – before thinning, T – thinning, AT – after thinning, C – control plot, T – thinned plot, see Methods for more explanation.

compared to the control plot (12.7 m^2 ha^{-1}). On the other hand, the share of the salvage cut on periodic G increment was higher at the control plot (35%) compared to the thinned plot (only 9%).

3.2. Diameter structure

At the age of 15 years, diameter classes from 2 to 6 cm represented practically the whole diameter distribution at all observed plots in the experiment of Destne (Fig. 2). Prior to the second thinning at plot T1 (and the first thinning at plots T2 and T3), i.e. at the age of 28 years, we found a wider range of diameter distribution from 2 to 20 cm. Trees with diameter 14 cm and more represented 11%, 9%, 10% and 8% at plots T1, T2, T3 and C, respectively.

At the end of the observation period (age of 33 years), the diameter distribution spread towards thickest trees (Fig. 3). We found that the number of trees ha^{-1} with diameter

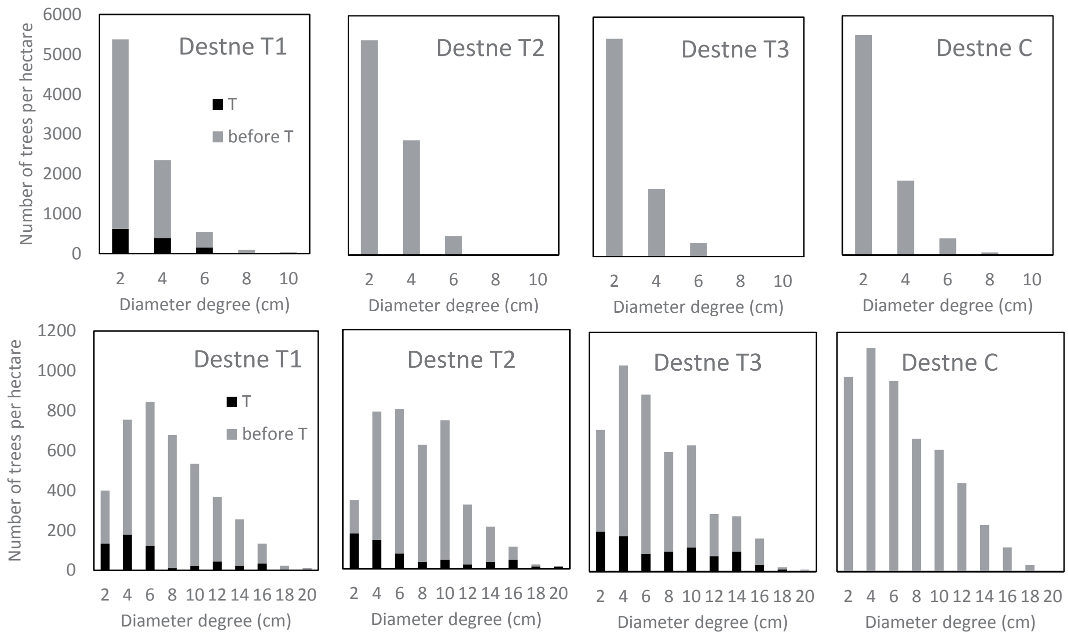

Fig. 2. Diameter structure of beech stands with presentation of thinning (T) at the age of 15 (above) and 28 (below) years in the experiment of Destne (T1, T2 and T3 – thinned plots, C – control plot, see Methods for more explanations).

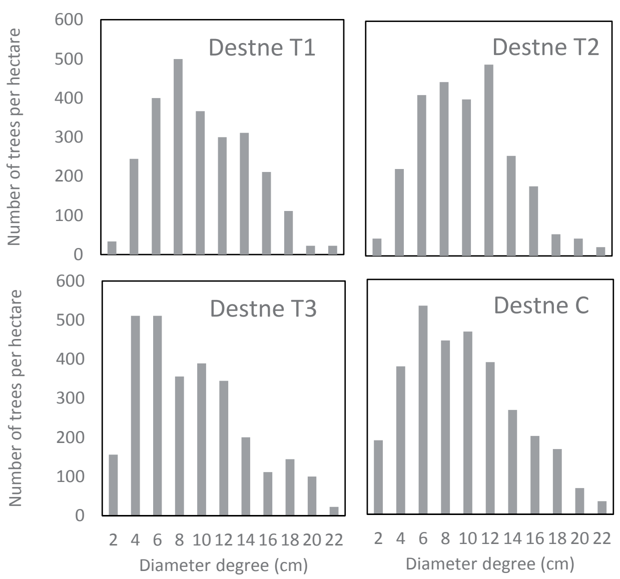

Fig. 3. Final diameter structure of beech stands at the end of the observation period (age of 33 years) in the experiment of Destne (T1, T2 and T3 – thinned plots, C – control plot, see Methods for more explanations).

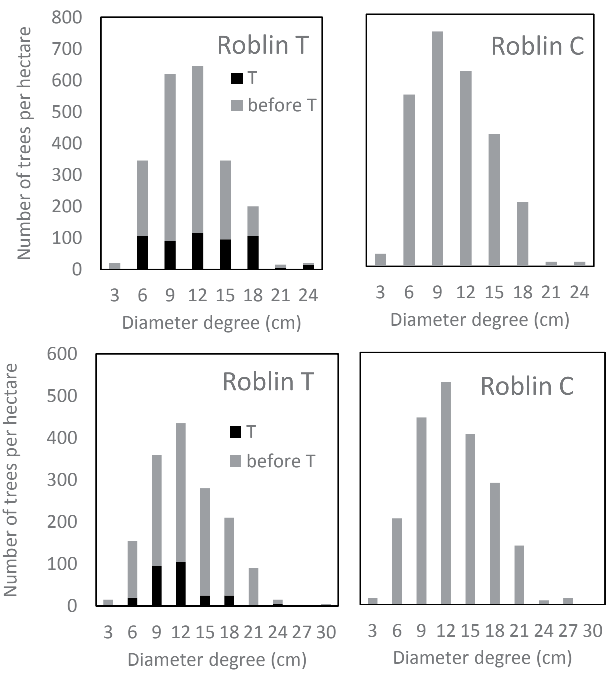

Fig. 4. Diameter structure of beech stands with presentation of thinning (T) at the age of 28 (above) and 33 (below) years in the experiment of Roblin (T – thinned plot, C – control plot, see Methods for more explanations).

14 cm and more was 678 (27% of stand density at the plot), 556 (22%), 578 (20%) and 733 (23%) at plots T1, T2, T3 and C, respectively.

At the older experiment of Roblin, the diameters varied from 3 to 24 cm prior to the thinning at the age of 28 years (Fig. 4). Before the second thinning, i.e. at the age of 33 years, we found the diameters from 3 to 30 cm. Trees with diameter 21 and more cm represented 7 (plot T) and 8% (plot C) of the total number of trees.

At the end of the observation period (age of 42 years), the highest diameter class was 36 cm at both observed plots (Fig. 5). A higher number of thickest trees (with diameter 21 and more cm) was observed at the control plot (355 trees ha^{-1}, i.e. 20% of stand density) compared to the thinned plot (335 trees ha^{-1}, 28%).

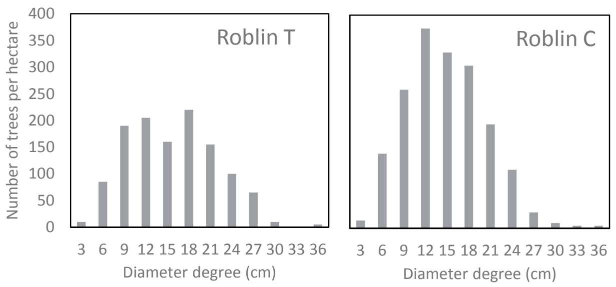

Fig. 5. Final diameter structure of beech stands at the end of the observation period (age of 42 years) in the experiment of Roblin (T – thinned plot, C – control plot, see Methods for more explanations).

3.3. Diameter of promising/dominant trees

In the experiment of Destne, we evaluated the development of DBH of "promising" trees, i.e. trees which were intentionally supported by thinning (one or two of their neighbours were removed from the canopy level). The initial mean diameter of promising trees was 4.9, 4.5, 4.3 and 4.3 at plots T1, T2, T3 and C, respectively (Fig. 6). At the end of the observation period, mean diameters for these trees at the thinned plots were 14.5 (plot T2), 14.7 (T3) and 15.3 (T1) cm. The lowest mean diameter (13.6 cm) was found at the control unthinned plot C. More relevant comparison can be performed by evaluating periodic diameter increment. During the observation period (age of 15–33 years), diameter increment reached 10.0 (plot T2) and 10.4 cm (plot T1 and T3) at the thinned plots, while it was only 9.3 cm at the control plot.

In the experiment of Roblin, the development of DBH was evaluated for "dominant" (200 thickest individuals per hectare) trees because of the applied thinning strategy (very low quality of stands). The initial mean diameter for this group of trees was the same (18.4 cm) at both plots before thinning (age of 28 years). The thinning removed the trees of low quality (plot T) resulting in the decrease of mean diameter of dominant trees to a value of 17.1 cm (Fig. 7).

After the second thinning (at the age of 33 years) this decrease was very small, i.e. from 20.2 to 20.0 cm. The mean diameter of dominant trees at the control plot was 20.9 cm at that age. The differences between the plots continually decreased in the following years and the values practically equalled at the age of 36 years. Six years later (at the end of

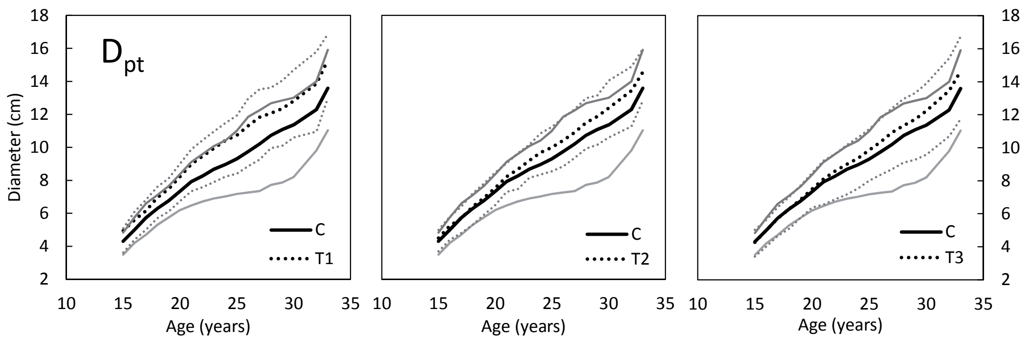

Fig. 6. Mean diameter of „promising" trees (pt) on sample plots of Destne experiment during the observation period between the ages of 15–33 years. Comparison of the control plot C with thinned plots T1 (on the left), T2 (in the middle) and T3 (on the right). Black and grey lines represent mean and percentiles (25 and 75%), respectively. See Methods for more explanations.

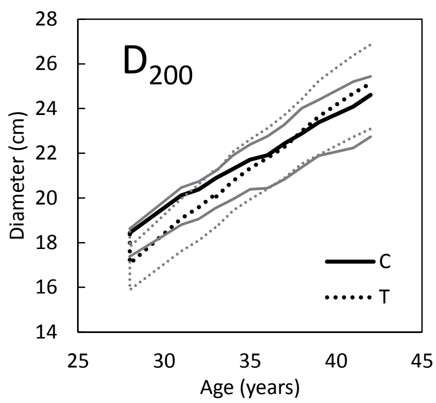

Fig. 7. Mean diameter of "dominant" trees (200 thickest individuals per hectare) at sample plots of Roblin experiment during the observation period between the age of 28 – 42 years. Comparison of control plot (C) with thinned plot (T). Black and grey lines represent mean and percentiles (25 and 75%), respectively. See Methods for more explanations.

the observation period), mean diameter of dominant trees at the thinned plot was greater by about 0.5 cm (25.1 cm) compared to the control plot (24.6 cm). The periodic diameter increment was noticeably higher at the thinned plot (8.0 cm) compared to the control unthinned plot (6.2 cm) during the observation period (age of 28–42 years).

4. Discussion

From the results observed in naturally regenerated beech stands (Štefančík 1984, 2013a, b, c; Štefančík & Bošela 2014; Štefančík et al. 2014) it is clear that thinning based on negative selection from below resulted in better quantity of production. According to today's tending targets, early, and more or less heavy crown thinning is also recommended by Spellmann & Nagel (1996) for beech stands. Additionally, shelterwood system of natural regeneration was found the best from the perspective of future stand quality (Bednář & Černý 2014).

Artificially regenerated beech stands are usually characterised by insufficient density and consequently low quality (Štefančík 2009). This phenomenon can be shown by comparing our results with the data from naturally regenerated stands (Štefančík 2013b). These stands had a higher density (4.2–4.5 thousand trees ha^{-1} prior to the thinning at the age of 36 years) compared to our experiments in Roblin (1.3–1.9 thousand trees ha^{-1} at the age of 36 years) and Destne (2.5–3.1 thousand trees ha^{-1} at the age of 33 years).

On the other hand, the values of stand basal area were comparable: 27–29 m^2 ha^{-1} (Štefančík 2013b) and 23–30 m^2 ha^{-1} (our experiments). Similar results were found in beech stands artificially regenerated on former agricultural land (Štefančík 2009) – density 1.5–2.0 thousand trees ha^{-1} and basal area 28–30 m^2 ha^{-1} at the age of 40 years. It means that stands from artificial regeneration are usually less dense but their mean DBH is greater compared to naturally regenerated stands at the same age. In addition, if stands from artificial regeneration are of low quality (as in our experimental stands), it is better to focus on the quantity of production.

This recommendation is in accordance with older results (Mráček 1989). To ensure sufficient quality, an initial density of 10–12 thousand trees ha^{-1} is recommended for artificial regeneration. On the other hand, about 8 thousand trees ha^{-1} is recommended for planting on sites originally planned for maximising production or in the case when planting material is only of average genetic quality.

The comparison with growth tables confirmed relatively good quantity of production in our stands (Černý et al. 1996). Although our experiments are situated at various growing conditions (Roblin – middle elevation, Destne – mountains), the values of basal area ranged between the tabular values for site index +1 (36) and 5 (26).

The thinning effect in artificially regenerated beech stands was observed by Yücesan et al. (2015). The removal of 40% of basal area in 18-year-old stands of *Fagus orientalis* resulted in significant increase of DBH in the following years. On the other hand, the removal of 19% of basal area promoted diameter increment only marginally. Similarly, Tufekcioglu et al. (2005) found higher (about 17% compared to control) periodic basal area increment three years after thinning in the heavily thinned (37% of G was removed) stand of *Fagus orientalis*. It corresponds with our experiments, especially in the mountain locality of Destne, where 10–23% of basal area was removed and the effect of thinning on basal area increment was unclear. In contrast, higher thinning intensity (26% of basal area removed) at middle elevation in the experiment of Roblin resulted in the increase of the periodic basal area increment compared to the unthinned control plot. Similar results were published by Boncina et al. (2007), who found that despite a lower stand density after thinning, the annual basal area increments of thinned naturally regenerated beech stands were around 20% higher compared to those of the control (unthinned) stands.

The main effect of thinning in our experiments was the lower amount of salvage cut in thinned plots compared to controls during the observation period. In contrast, diameter distribution was still relatively wide (i.e. important amount of thin trees was reserved) at the end of the observation at all plots of both experiments. Low thinning intensity is the probable reason of this result. In the case of higher (40% of basal area removed) thinning intensity (Yücesan et al. 2015), former rich diameter structure of beech stands was equalised.

The support of diameter increment of dominant trees by thinning was clear only in the experiment of Roblin, which is situated in better growing conditions compared to the mountain experiment of Destne. It corresponds with the analyses published by Pretzsch (2005), who found that beech (contrary to spruce) reacts most positively to thinning under rich site conditions and with increment reduction at unfavourable sites. Higher (by about 30–56%) mean annual basal area increment of dominant trees at thinned plots compared to control plots was found also by Boncina et al. (2007).

Different thinning regimes, growing conditions and a relatively short observation period of our experiments does not allow us to make a general thinning recommendation for forest practice in artificially regenerated beech stands. From the production point of view, some results can be used from long-term studies in naturally regenerated stands (Štefančík 2005, 2013b, 2014). After more than 50-year-long observation it was found that from the perspective of production quantity (total production according to merchantable volume), the best results were almost in all cases obtained at the plots with heavy thinning from below, followed by the free crown thinning. The control plot showed the worst parameters.

5. Conclusion

On the base of the results from the two thinning experiments in young artificially regenerated beech stands we can conclude:

- Relatively good quantity of production (by basal area) of our stands was confirmed by the comparison with growth tables, although our experiments were situated at various growing conditions.
- Thinning resulted in lower amount of salvage cut in following years.
- The effect of thinning on periodic stand basal area increment and on periodic diameter increment of dominant

trees was found in beech stands located in middle elevation.

- In mountain conditions, thinning effects on periodic stand basal area increment and on periodic diameter increment of promising trees were negligible.

Our hypothesis that thinning in low-quality stands will at least promote the quantity of production was confirmed only in the case of beech stands in middle elevation (higher periodic basal area increment and support of diameter growth of dominant trees). On the other hand, in mountain conditions similar thinning effects (with the exception of lower amount of salvage cut) were not found.

Thinning focused on support of future stand quality cannot be commonly applied in artificially regenerated beech stands because of their worse initial quality and density. On the other hand, these stands show good growth and response to thinning. Thus, forest managers can plan thinning focused on quantity of beech wood production.

To confirm the presented trends we recommend to establish related replicated experiments focused on thinning in artificially regenerated beech stands because up to 5 thousand hectares of these stands are annually planted in the Czech Republic.

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References

Abetz, P., Ohnemus, K., 1999: Überprüfung von Z-Baum-Normen für Buche anhand einer Versuchsfläche (Verification of the future-crop-tree-norms (ZB-norm) for beech in a thinning expirement). Allgemeine Forst- und Jagdzeitung, 170:157–164.

Barna, M., 2000: Impact of shelterwood cutting on twig growth in predominant beech trees (*Fagus sylvatica* L.). Ekológia (Bratislava), 19:341–353.

Barna, M., 2001: The impact of shelterwood cutting on twig growth in understoried beech trees (*Fagus sylvatica* L.). Ekológia (Bratislava), 20:191–199.

Bastien, Y., Hein, S., Chavane, A., 2005: Sylviculture du Hêtre: contraintes, enjeux, orientations de gestion (Beech silviculture – constraints, implications, management guidelines). Revue Forestière Française, LVII:111–122.

Bednář, P., Černý, J., 2014: The influence of regeneration fellings on the development of artificially regenerated beech (*Fagus sylvatica* L.) plantations. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 62:859–867.

Boncina, A., Kadunc, A., Robic, D., 2007: Effects of selective thinning on growth and development of beech (*Fagus sylvatica* L.) forest stands in south-eastern Slovenia. Annals of Forest Science, 64:47–57.

Borys, A., Lasch, P., Suckow, F., Reyer, C., 2013: Carbon storage in beech stands depending on forest management regime and climate change. Allgemeine Forst- und Jagdzeitung, 184:26–35.

Cescatti, A., Piutti, E., 1998: Silvicultural alternatives, competition regime and sensitivity to climate in a European beech forest. Forest Ecology and Management, 102:213–223.

Černý, M., Pařez, J., Malík, Z., 1996: Růstové a taxační tabulky hlavních dřevin České republiky (smrk, borovice, dub, buk). Jílové u Prahy, IFER, 245 p.

Dannenmann, M., Gasche, R., Ledebuhr, A., Holst, T., Mayer, H., Papen, H., 2007a: The effect of forest management on trace gas exchange at the pedosphere-atmosphere interface in beech (*Fagus sylvatica* L.) forests stocking on calcareous soils. European Journal of Forest Research, 126:331–346.

Dannenmann, M., Gasche, R., Papen, H., 2007b: Nitrogen turnover and N_2O production in the forest floor of beech stands as influenced by forest management. Journal of Plant Nutrition and Soil Science, 170:134–144.

Finkeldey, R., Ziehe, M., 2004: Genetic implications of silvicultural regimes. Forest Ecology and Management, 197:231–244.

Hein, S., Lenk, E., Klädtke, J., Kohnle, U., 2007: Z-Baum Orientierte Auslesedurchforstung in Buche [*Fagus sylvatica* L.]: Auswirkungen auf Qualität, Sortenstruktur und Wertleistung. Allgemeine Forst- und Jagdzeitung, 178:8–20.

Jurča, J., Chroust, L., Petříček, V., Švenda, A., 1973: Racionalizace výchovy mladých lesních porostů. Praha, SZN, 239 p.

Kantor, P., 1981: Intercepce horských smrkových a bukových porostů. Lesnictví, 27:171–192.

Le Goff, N., Ottorini, J-M., 1993: Thinning and climate effects on growth of beech (*Fagus sylvatica* L.) in experimental stands. Forest Ecology and Management, 62:1–14.

Lemoine, D., Jacquemin, S., Granier, A., 2002: Beech (*Fagus sylvatica* L.) branches show acclimation of xylem anatomy and hydraulic properties to increased light after thinning. Annals of Forest Science, 59:761–766.

Mze, 2013: Zpráva o stavu lesa a lesního hospodářství České republiky v roce 2012. Praha, Ministerstvo zemědělství, 132 p.

Mráček, Z., 1989: Pěstování buku. Praha, SZN, 224 p.

Nahm, M., Holst, T., Matzarakis, A., Mayer, H., Rennenberg, H., Geßler, A., 2006: Soluble N compound profiles and concentrations in European beech (*Fagus sylvatica* L.) are influenced by local climate and thinning. European Journal of Forest Research, 125:1–4.

Plíva, K., 2000: Trvale udržitelné obhospodařování lesů podle SLT. Brandýs nad Labem, ÚHÚL, 34 p.

Pretzsch, H., 2005: Stand density and growth of Norway spruce (*Picea abies* [L.] Karst.) and European beech (*Fagus sylvatica* L.): evidence from long-term experimental plots. European Journal of Forest Research, 124:193–205.

Prka, M., Krpan, A. P. B., 2010: Impact of Tending Measures on Assortment Structure of Fellings in Central Croatian Beech Stands. Acta Silvatica & Lignaria Hungarica, 6:171–182.

Skovsgaard, J. P., Nordfjell, T., Sørensen, I. H., 2006: Precommercial thinning of beech (*Fagus sylvatica* L.): Early effects of stump height on growth and natural pruning of potential crop trees. Scandinavian Journal of Forest Research, 21:380–387.

Spellmann, H., Nagel, J., 1996: Zur durchforstung von fichte und buche. Allgemeine Forst- und Jagdzeitung, 167:6–15.

Spiecker, H., Hansen, J., Klimo, E., Skovsgaard, J. P., Sterba, H., Teuffel, K. von (eds.), 2004: Norway Spruce Conversion – Options and Consequences. European Forest Institute Research Report, 18, Brill, Leiden, 269 p.

Štefančík, L., 1973: Waldbauliche Analyse einer freien Hochdurchforstung in ungepflegten Buchenstangenhölzern. Forstwissenschaftliches Centralblatt, 92:242–249.

Štefančík, L., 1984: Úrovňová voľná prebierka – metóda biologickej intenzifikácie a racionalizácie selekčnej výchovy bukových porastov. Vedecké práce Výskumného ústavu lesného hospodárstva vo Zvolene, 34:69–112.

Štefančík, I., 2008: The influence of different thinning regime on beech diameter increment under climate change conditions. Lesnícky časopis - Forestry Journal, 54:91–98.

Štefančík, I., 2009: Vývoj bukového porastu založeného na bývalých poľnohospodárskych pôdach. Lesnícky časopis – Forestry Journal, 55:165–180.

Štefančík, I., 2013a: Development of target (crop) trees in beech (*Fagus sylvatica* L.) stand with delayed initial tending and managed by different thinning methods. Journal of Forest Science, 59:253–259.

Štefančík, I., 2013b: Vplyv dlhodobej rozdielnej výchovy na vývoj kvantitatívnej produkcie bukovej žŕdkoviny v oblasti stredného Slovenska. Zprávy lesnického výzkumu, 58:307–313.

Štefančík, I., 2013c: Effect of delayed tending on development of beech (*Fagus sylvatica* L.) pole stage stand. Folia Oecologica, 40:272–281.

Štefančík, I., 2014: Porovnanie kvalitatívnej produkcie dvoch bukových (*Fagus sylvatica* L.) porastov na kyslom stanovišti. Lesnícky časopis - Forestry Journal, 60:231–239.

Štefančík, I., 2015: 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. Journal of Forest Science, 61:98–105.

Štefančík, I., Bošela, M., 2014: An influence of different thinning methods on qualitative wood production of European beech (*Fagus sylvatica* L.) on two eutrophic sites in the Western Carpathians. Journal of Forest Science, 60:406–416.

Štefančík, I., Vacek, S., Podrázský, V., Klouček, T., 2014: Dopad výchovy na kvantitatívnu produkciu bukovej (*Fagus sylvatica* L.) žŕdkoviny v oblasti Vihorlatských vrchov (Slovensko). Zprávy lesnického výzkumu, 59:198–204.

Tarp, P., Helles, F., Holten-Andersen, P., Larsen, J. B., Strange, N., 2000: Modelling near-natural silvicultural regimes for beech – an economic sensitivity analysis, Forest Ecology and Management, 130:187–198.

Tufekcioglu, A., Guner, S., Tilki, F., 2005: Thinning effects on production, root biomass and some soil properties in a young oriental beech stand in Artvin, Turkey. Journal of Environmental Biology, 26:91–95.

Utschig, H., Küsters, E., 2003: Wachstumsreaktionen der Buche (*Fagus sylvatica* [L.]) auf Durchforstungen – 130-Jährige Beobachtung des Durchforstungsversuches Elmstein 20. Forstwissenschaftliches Centralblatt, 122:389–409.

van der Maaten, E., 2013: Thinning prolongs growth duration of European beech (*Fagus sylvatica* L.) across a valley in southwestern Germany. Forest Ecology and Management, 306:135–141.

Viewegh, J., Kusbach, A., Mikeska, M., 2003: Czech forest ecosystem classification. Journal of Forest Science, 49:85–93.

Yücesan, Z., Özçelik, S., Oktan, E., 2015: Effects of thinning on stand structure and tree stability in an afforested oriental beech (*Fagus orientalis* Lipsky) stand in northeast Turkey. Journal of Forest Research, 26:123–129.