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# An influence of different thinning methods on qualitative wood production of European beech (*Fagus sylvatica* L.) on two eutrophic sites in the Western Carpathians

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**ABSTRACT**: The issues related to appropriate management methods of beech stands have been considered as a crucial topic from the past up to now. Although the positive effect of tending on wood quality in beech stands is a generally known fact, the results from long-term experiments are very scarce. We investigated the qualitative production of beech forests, treated by different thinning methods during a long-term period of 53 years. For this purpose two long-term (lasting 53 years with a measurement interval of 5 years) series of research plots were used. On each plot three different thinning methods were applied: i) heavy thinning from below (C-grade according to the German forestry research institutes in 1902), ii) free crown thinning (original thinning method developed in Slovak Republic), and iii) control plot (without treatments). As much as 6,316 trees at the beginning of research and 864 trees at the last measurement were assessed and measured. Chi-squared test was used to quantify the effect of different thinning methods on qualitative wood production. The results showed the highest proportion of target trees, as well as the best average quality of the stem and crown on plots where the free crown thinning was applied followed by the plots with heavy thinning from below and control ones. We found that the proportion (expressed out of the total growing stock of crop trees) of veneers was the highest on plots managed by the free crown thinning (30 and 36%) and the lowest on control (unthinned) plots (10 and 19%). It is concluded that no significant differences between the two studied sites were found, which demonstrates a similar effect of the investigated thinning methods at different places across the region of Slovak Republic, but with similar site conditions. On the other hand, the most appropriate and hence successful thinning method was proved to be the free crown thinning, which is also recommended for management of beech forests from the aspect of silvicultural wood quality.

**Keywords**: European beech; tending; qualitative production; crop trees

Tending of forest stands is crucial for their development since it takes more than half of the rotation period. Beech, as the most abundant tree species in Slovakian forests, has received a high attention from different aspects. Most of the studies published in Slovak Republic and other European countries were focused primarily on the effect of thinning methods on quantitative production.

The influence of moderate thinning from below and qualitative crown thinning upon structure and yield of premature beech stand was found by Šebík (1971). Similarly, two thinning meth-

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ods were compared by Štefančík (1974) under the conditions of naturally regenerated beech stands established in pole-stage stands in Slovak Republic. It was heavy thinning from below (C-grade according to German forestry research institutes in 1902) and the free crown thinning, which was a new method developed in Slovak Republic (Štefančík 1984). The above-mentioned authors, as well as Réh (1968) emphasised the necessity to start with the first interventions already in thickets or no later than in pole-stage stands. On the other hand, Štefančík (2013a) investigated also the effect of delayed tending (started at the age of 60 years) on development of beech stands. Based on the results of long-term research carried out not only in Slovak Republic, but also abroad (Assmann 1968; Kennel 1972; Polge 1981; Pardé 1982), Šebík and Polák (1990) concluded the main outcomes related to effects of different thinning methods on quantitative production in beech stands. LeGoff and Ottorini (1993) investigated thinning and climate effects on the growth of beech in experimental stands in France. They analysed more closely the response of beech to thinning (the course of annual basal area growth after thinning). The thinning trial consists of four treatments (thinning grades) defined as light, moderate, heavy and control. Dhôte (1997) carried out the research on dominant stem diameter in order to assess the long- and short-term effects of thinning on their growth. A remarkable study was published by Pretzsch (2005) on the basis of ten European beech (*Fagus sylvatica* L.) thinning experiments in Germany. He scrutinized how moderate and heavy thinning from below (B and C-grade) affects the production of merchantable volume compared with light thinning (A-grade).

Apart from the mentioned topic related especially to production responses of beech to examined thinning procedures, the attention has also been paid to the impact of thinning methods on the quality of beech wood. Réh (1968) investigated the qualitative structure of pure beech thicket (age 14–18 years) that originated from natural regeneration and/or large-scale shelterwood system applied. No intervention had been realised up to the establishment of plots. He found that the quality of crown was considerably lower than that of stem. Šebík (1970) assessed the state of quality and influence of first crown thinnings upon the quality of stem and crown in premature beech stands. During the period of 27 years Korpeľ (1988) investigated the experiment established in the thicket (age 11 to 15 years) focused on the influence of tending measures (cleaning and positive crown thinning) on stem quality and beech stand development. The papers by Štefančík (1974, 1975, 1976) compared the stem and crown quality in relation to three different thinning regimes: positive crown thinning (the free crown thinning), heavy thinning from below (C-grade) and control (with no treatment). A special thinning method (quality selection group thinning) was published by Kató and Mülder (1983). While the above-mentioned papers assessed the stem quality from a silvicultural point of view, based especially on evaluation of visible external signs of stem, some authors (Keller et al. 1976; Ferrand 1982) focused their research on the analysis of wood interior signs (wood density, strains or torsion torque).

Tending of beech forests is directed to reaching a sufficient number of trees with the highest quality to ensure the highest value production in the forest maturity. Mlinsek and Bakker (1990) analysed the butt lengths of 50 elite stems of beech 140–150 years old from two sites in Slovenia. The results showed that trees with uniform and moderate radial growth produced the greatest amount of knot-free wood. The proportion of high-quality timber (selected future crop trees) as compared to other trees in the stand was the topic of research carried out by Štefančík (1974) and Hein et al. (2007). The timber assortment structure of mature beech trees in stands was also calculated by Poljanec and Kadunc (2013) on the basis of estimated quality (veneer, sawlogs). Based on the research on the mentioned topic, it can be concluded that assessment of qualitative production depends on a number of factors (especially thinning method and intensity, stand age).

The problem of the relationship between thinning methods and quantitative production should be considered as studied in quite a sufficient way, however, the studies on qualitative production that concluded long-term systematic research and carried out by the same methodology are scarce. It can be summarized that applying the early and systematic tending, the better quality of the crown and stem is reached. Consequently, using a thinning method based on individual selection results in a higher proportion of the target (crop) trees in comparison with untended stands.

The quality of forests can be assessed by two approaches. In the first approach, the quality of all trees in the stand is assessed and hence it is called the mass (total) quality of the forest stand. This is a question of silvicultural and commercial quality as well. The second approach includes assessment of a

Table 1. Basic characteristics of the permanent research plots (PRP) Jalná and Koňuš

| Characteristic | Jalná | Koňuš |
|---|---|---|
| Establishment of PRP | 1959 | 1961 |
| Age of stand (yr) | 36 | 30 |
| Site index | 28 | 28 |
| Geomorphologic unit | Štiavnické vrchy | Vihorlatské vrchy |
| Aspect | W | NNW |
| Altitude (m) | 610 | 510 |
| Slant (degrees) | 15 | 16 |
| Parent rock | andesite-tuff agglomerate and andesites | Andesite |
| Soil unit | eutric cambisol | eutric cambisol |
| Forest altitudinal zone | 3$^{th}$ oak-beech | 3$^{th}$ oak-beech |
| Soil nutrient regime | fertile mesophilous | fertile mesophilous |
| Forest type | 311 – fertile oak beechwoods | 310 – fresh oak beechwoods |
| Forest site type group | *Querceto-Fagetum* (QF) | *Fagetum pauper* (Fp) lower tier |
| Average annual temperature (°C) | 6.2 | 6.5 |
| Average annual precipitation (mm·yr$^{-1}$) | 850 | 900 |

sample of trees (so called target trees) which have a required quality of the stem and crown. This is called the selected quality of the stand (Štefančík 1976).

The aim of this study is to investigate the qualitative production of beech forests on two sites which are similar in terms of site conditions and were treated using different thinning methods on a site (but the same methods between sites) during a long-term period of 53 years.

## MATERIAL AND METHODS

Two sets of permanent research plots (PRP) at the localities Jalná and Koňuš were selected for the study (Table 1). Forests on the plots originate from natural regeneration and were treated using a large-scale shelterwood cutting system. Both forest stands are of approximately the same age and grow on sites with similar ecological conditions. Each set included three plots. The plots on which the forest was treated using heavy thinning from below was called C with C-grade according to the German forestry research institutes in 1902. The plot marked with H was treated using the free crown thinning method (the method based on aiding to selected dominant or co-dominant trees with the highest wood quality – promising and target trees) developed by Štefančík (1984). The above-mentioned method is focused on individual tending of the trees of selective quality (promising and target trees). These trees were selected at the age of 36 years (PRP Jalná) and 30 (38) years (PRP Koňuš) according to the following criteria: (1) satisfactory quality characteristics of stem and crown; (2) suitable dimensional requirements (diameter, height), and (3) appropriate spacing in the stand. According to the social position, these trees have to be dominant or co-dominant and for a practical reason they 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 with 0 was the control plot where no treatments were applied.

There were no intentional treatments applied to the forests before establishing the research plots. As many as 12 measurements have been carried out on the plots so far. All trees on the plots with DBH higher than or equal to 3.6 cm were marked and numbered at the beginning. Parameters related to stem and crown quality were assessed to allow for silviculture and commercial quality assessment of the forest.

The silviculture quality classification included:

(a) Sociological position of trees according to Štefančík (1974):
- dominant tree
- co-dominant tree
- suppressed tree still vital to reach the forest crown level
- suppressed tree but not vital to reach the forest crown level

– dying or dead suppressed tree

(b) Stem quality grades:
- straight high-quality stem without knots, with no visible external damage
- average-quality stem, curvature allowed only in the higher one third part of the stem, low number of small knots (1 or 2 knots per running meter) is allowed, with no external damage (fungi, insects, necrosis)
- low-quality stem with a high number of knots (more than 2 knots per running meter), with twisted or stem with curvature, with external visible damage (fungi, insects, necrosis)

(c) Crown quality: According to shape and type of branching: 1. with one continuous stem axis to the tree top; 2. bunch-like crown; 3. broom-like crown; 4. forked-stem crown. According to the size: 1. appropriate-sized symmetric crown; 2. smaller-sized suppressed crown, but able to regenerate; 3. overlarge-sized crown; 4. small-sized crown, unable to regenerate. According to density (foliation): 1. very dense crown, with full foliage (90–100%) also inside the crown; 2. dense, with foliage (75 < 90%) also inside the crown; 3. less-density crown (foliation 40 < 75%); 4. very sparse, highly defoliated crown (foliation < 40%).

For suppressed trees (3rd–5th sociological class), the crown is assessed using only three quality grades: 1 – good, 2 – average, and 3 – bad.

Concerning the commercial quality assessment, only the lower part (lower half) of the stem to the height of the crown base was assessed using the following classes: 1 – high quality (A), 2 – average quality (B), 3 – lower quality (industrial wood) (C), and 4 – firewood (D). Consequently, commercial quality is defined as the external quality of the stem that directly presents the assumed utilisation of wood mass, hence estimation of assortments. At the beginning of the research (the age of 36 years) the trees were evaluated only using the traits related to stem defects. In the last measurement the criterion was also the diameter in order to compare with Slovak standards No. STN 48 0056).

The average value of crown and stem quality was calculated to assess the total silvicultural quality. Changes in the quality during the study period were quantified using a "*pom*" index (Štefančík 1974) (Eq. 1):

$$pom = (q_{t1}/q_{t2}) \times 100 \quad (1)$$

where:

$q_{t1}$ – average quality at the beginning of the period,

$q_{t2}$ – average quality at the end of the study period.

In case that the index was higher than 100, the quality was considered to have increased and vice versa. Average quality was calculated for the total forest stand and also separately for trees growing in the main crop level (1st and 2nd sociological position) and for suppressed trees (3rd–5th sociological position). The same approach was applied to the assessment of commercial quality using the method developed by Štefančík (1974, 1976).

Chi-squared test was used to quantify the effect of different thinning methods. Differences in the proportions of best-quality trees between different thinning methods were quantified and tested. Homogeneous groups of different silvicultural treatments were identified for the proportion of quality categories within each locality and for individual quality variables (stem quality, quality of the lowest part of the stem, and crown quality) and displayed in Fig. 1. Differences between the first and last measurements were tested by Chi-squared test and indicated in Fig. 1 by *P*-value (or ns for non-significant differences).

## RESULTS

### Silvicultural quality of forest stands

The stem and crown quality of trees growing in the forest crop level at the beginning of the study was higher than that of suppressed ones (Table 2). Both crown and stem quality of the trees from the forest crop level (1st and 2nd sociological position) was found to be slightly better in Jalná at the beginning.

After long-term tending (during the study period of 53 years), the average stem quality of the total stand in Jalná increased only on the H plot where the free crown thinning was applied. Here the proportion of best-quality trees significantly increased (Fig. 1a–b, $P < 0.05$). On the other hand, the stem quality decreased on the control plot and on the plot tended by heavy thinning from below, although there was no significant change in the proportion of the best-quality trees ($P > 0.05$). The crown quality of trees increased only on the plots with thinning (both C and H), while it decreased on the control plot. The highest proportion of the best-quality stems (1st quality class) was found on the H plot (10%), while the lowest on the control plot (0.5%). Slightly more than 4% of the best-quality stems were found on the C plot. The same results were obtained for the crown quality (Fig. 1c–d), however, the only significant change

in the proportion of best-quality trees was found for the main crop on the H plot (Fig. 1d).

On the contrary, stem quality has generally decreased on all plots at the Koňuš locality during the last 53 years. The proportion of the best-quality trees, similarly to Jalná, has significantly increased ($P < 0.05$) only on the H plot (Fig. 1a–b). On other plots the increase was not found to be significant ($P > 0.05$). Interestingly, crown quality has increased on all plots, although the change in the proportion of trees with best-quality crowns was not significant ($P > 0.05$). Even for the main crop layer the change in crown quality was not significant (Fig. 1d), which is different from Jalná. The plots where the forest was tended by thinning (C and H) were found to reach the highest proportion of the high-quality stems (3.7% and 1.7%, respectively) compared to the plot left without treatments (0.6%). The same trend was found for crown quality (Fig. 1).

The investigation was done separately for main crop trees (trees of the 1st and 2nd sociological position). At the Jalná locality, an increase in both stem and crown quality (by app. 16% and 35%, re-

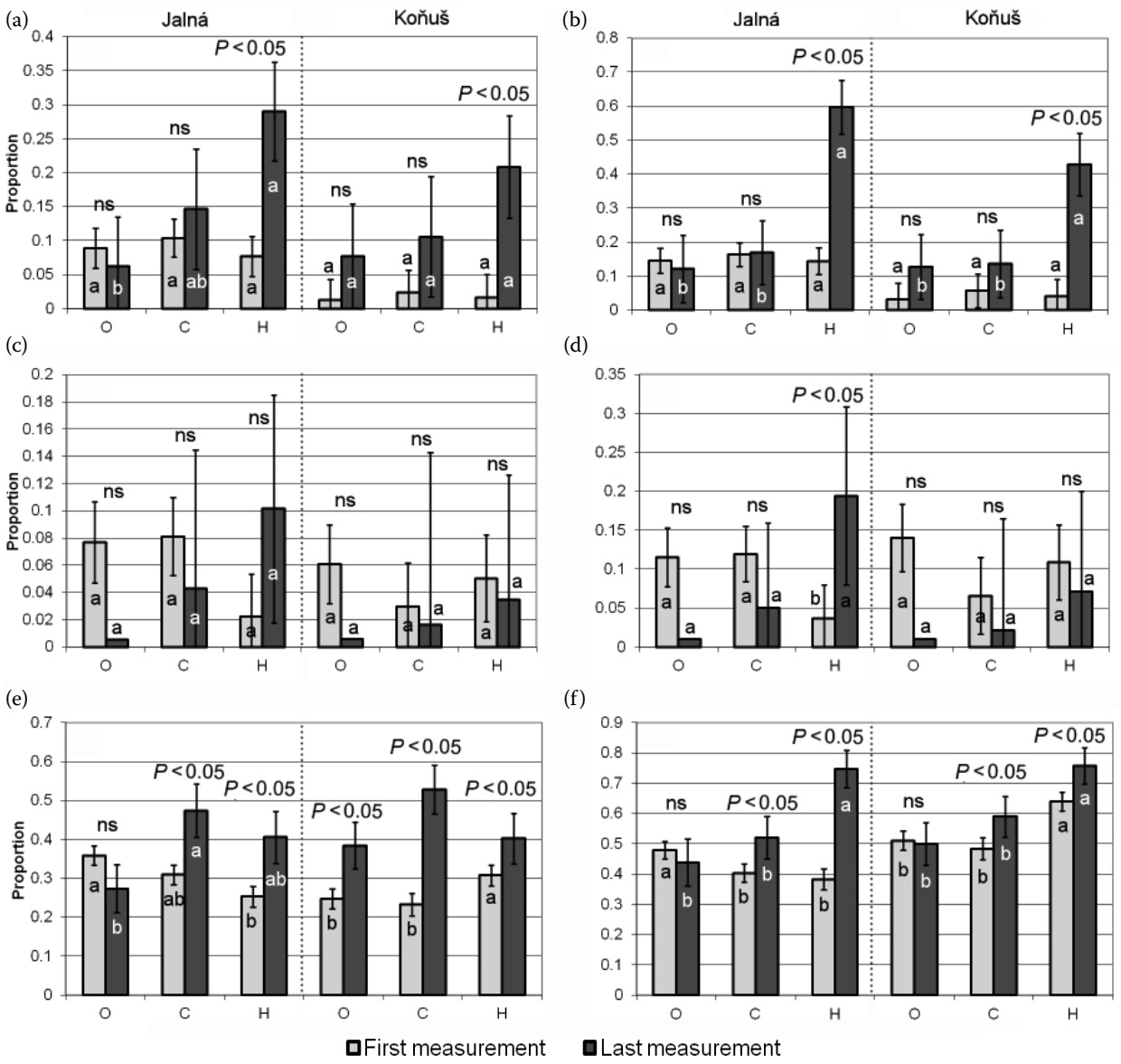


Fig. 1. Proportion of best-quality trees (1st stem and crown quality class) as assessed at the establishment of the plots (beginning of the study period) and at the last measurement for different thinning methods (0 – control plot without tending, C – plot with heavy thinning from below, H – plot with the free crown thinning) and at different localities (Jalná, Koňuš); whiskers denote the standard errors of the proportions, (a) stem quality of the whole stand, (b) stem quality of the main crop layer, (c) crown quality of the whole stand, (d) crown quality of the main crop layer, (e) quality of the lowest part of the stem for the whole stand, (f) quality of the lowest part of the stem for the main crop layer; ns – non-significant differences; a, b and ab – homogeneous groups

Table 2. Silvicultural and commercial quality on sites

| Plot | Age (yr) | Silvicultural quality | Level of the stand | | Total | Commercial quality | Level of the stand | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | | crown | suppressed | | | crown | suppressed | |
| **Jalná PRP** | | | | | | | | | |
| 0 | 36 | stem | 2.34 | 2.70 | 2.48 | lh | 1.77 | 2.38 | 2.01 |
| | | *pom* | 100 | 100 | 100 | *pom* | 100 | 100 | 100 |
| | | crown | 2.07 | 2.55 | 2.26 | uh | 2.19 | 2.74 | 2.41 |
| | | *pom* | 100 | 100 | 100 | *pom* | 100 | 100 | 100 |
| | 89 | stem | 2.75 | 2.95 | 2.85 | lh | 1.77 | 2.43 | 2.09 |
| | | *pom* | 85.2 | 91.6 | 87.3 | *pom* | 100 | 97.9 | 96.0 |
| | | crown | 2.21 | 3.00 | 2.60 | uh | 2.64 | 3.05 | 2.85 |
| | | *pom* | 93.3 | 84.9 | 86.8 | *pom* | 82.9 | 89.8 | 84.7 |
| H | 36 | stem | 2.46 | 2.68 | 2.57 | lh | 1.93 | 2.44 | 2.18 |
| | | *pom* | 100 | 100 | 100 | *pom* | 100 | 100 | 100 |
| | | crown | 2.03 | 2.47 | 2.24 | uh | 2.35 | 2.71 | 2.52 |
| | | *pom* | 100 | 100 | 100 | *pom* | 100 | 100 | 100 |
| | 89 | stem | 2.12 | 2.88 | 2.51 | lh | 1.31 | 2.73 | 2.03 |
| | | *pom* | 116.2 | 92.9 | 102.4 | *pom* | 147.1 | 89.7 | 107.6 |
| | | crown | 1.51 | 2.80 | 2.16 | uh | 1.94 | 2.88 | 2.42 |
| | | *pom* | 134.5 | 88.2 | 103.7 | *pom* | 121.2 | 93.8 | 104.3 |
| C | 36 | stem | 2.38 | 2.77 | 2.52 | lh | 1.87 | 2.50 | 2.11 |
| | | *pom* | 100 | 100 | 100 | *pom* | 100 | 100 | 100 |
| | | crown | 2.14 | 2.73 | 2.36 | uh | 2.20 | 2.86 | 2.44 |
| | | *pom* | 100 | 100 | 100 | *pom* | 100 | 100 | 100 |
| | 89 | stem | 2.71 | 2.81 | 2.72 | lh | 1.66 | 2.31 | 1.75 |
| | | *pom* | 87.7 | 98.4 | 92.6 | *pom* | 112.7 | 108.3 | 120.4 |
| | | crown | 2.13 | 3.00 | 2.25 | uh | 2.56 | 2.69 | 2.58 |
| | | *pom* | 100.4 | 90.9 | 104.8 | *pom* | 85.7 | 106.3 | 94.7 |
| **Koňuš PRP** | | | | | | | | | |
| 0 | 30 | stem | 2.36 | 2.77 | 2.60 | lh | 1.71 | 2.57 | 2.22 |
| | | *pom* | 100 | 100 | 100 | *pom* | 100 | 100 | 100 |
| | | crown | 2.35 | 2.92 | 2.69 | uh | 2.30 | 3.03 | 2.74 |
| | | *pom* | 100 | 100 | 100 | *pom* | 100 | 100 | 100 |
| | 83 | stem | 2.77 | 2.93 | 2.83 | lh | 1.72 | 2.12 | 1.88 |
| | | *pom* | 85.4 | 94.6 | 92.0 | *pom* | 99.6 | 121.3 | 118.5 |
| | | crown | 2.27 | 3.00 | 2.56 | uh | 2.71 | 2.90 | 2.78 |
| | | *pom* | 104.1 | 97.2 | 105.3 | *pom* | 85.1 | 104.6 | 98.4 |
| H | 30 | stem | 2.37 | 2.80 | 2.62 | lh | 1.51 | 2.49 | 2.09 |
| | | *pom* | 100 | 100 | 100 | *pom* | 100 | 100 | 100 |
| | | crown | 2.27 | 2.89 | 2.63 | uh | 2.29 | 3.00 | 2.71 |
| | | *pom* | 100 | 100 | 100 | *pom* | 100 | 100 | 100 |
| | 83 | stem | 2.39 | 2.97 | 2.70 | lh | 1.31 | 2.62 | 2.00 |
| | | *pom* | 98.9 | 94.4 | 97.1 | *pom* | 114.9 | 95.2 | 104.4 |
| | | crown | 1.66 | 2.89 | 2.30 | uh | 2.34 | 2.99 | 2.68 |
| | | *pom* | 136.8 | 100 | 114.1 | *pom* | 97.9 | 114.4 | 101.0 |

Table 2. to be continued

| Plot | Age (yr) | Silvicultural quality | Level of the stand | | Total | Commercial quality | Level of the stand | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | | crown | suppressed | | | crown | suppressed | |
| C | 30 | stem | 2.50 | 2.78 | 2.67 | lh | 1.78 | 2.78 | 2.36 |
| | | *pom* | 100 | 100 | 100 | *pom* | 100 | 100 | 100 |
| | | crown | 2.33 | 2.93 | 2.68 | uh | 2.38 | 3.11 | 2.80 |
| | | *pom* | 100 | 100 | 100 | *pom* | 100 | 100 | 100 |
| | 83 | stem | 2.66 | 2.95 | 2.71 | lh | 1.53 | 1.90 | 1.59 |
| | | *pom* | 93.9 | 94.4 | 98.3 | *pom* | 116.4 | 146.5 | 148.7 |
| | | crown | 2.12 | 3.00 | 2.26 | uh | 2.63 | 2.90 | 2.68 |
| | | *pom* | 110.0 | 97.7 | 118.4 | *pom* | 90.2 | 107.3 | 104.8 |

0 – control plot (without tending), H – plot with the free crown thinning, C – plot with heavy thinning from below, lh – low half of the stem, uh – upper half of the stem, *pom* – index, crown level of the stand – dominant and co-dominant trees (1st and 2nd sociological position), suppressed level of the stand – suppressed trees (3rd – 5th sociological position)

spectively) was recorded only on the H plot (the free crown thinning). On the contrary, a decrease in stem quality was found on all the plots at the Koňuš locality. Nevertheless, crown quality has increased in trees on all the plots, with the highest rate on the H plot, then C and the control plot, respectively.

## Commercial quality of forest stands

At the beginning of the study period, stem quality of dominant and co-dominant trees (1st and 2nd sociological position) was better (for both lower and upper parts of the stem) than that of suppressed ones (Table 2). At the Jalná locality, the quality of the lower part of all stems increased during the 53 years only on the plots treated by thinning, but the increase was essentially higher on the C plot than on the H plot. Concerning the upper part of the stem, an increase in quality was found only for the plot with the free crown thinning (H plot). On the contrary, an increase in the quality of the lower part of stems was recorded for all the plots at the Koňuš locality, but the increase was greater on the plot treated by heavy thinning from below. As for the upper part of the stem, the quality increased only on the plot treated by thinning.

However, the lower part of the stem (for the forest crown level only) is the most important for the grading of stems into final assortments. Therefore, we focused on a change in the quality of this part of stem in the next analyses. At both localities, the quality generally increased, but it was most obvious for the plots treated by the free crown thinning compared to the control ones, where the quality did not change during 53 years. At both localities, the highest proportion of the first quality class was found on plots treated by the free crown thinning (nearly 75%), while the lowest proportion was on the control plots (44–50%).

Besides the stem quality, the classification of trees into commercial assortment classes depends on the diameter of individual trees (thresholds for particular assortments are defined by the Slovak standards No. STN 48 0056. The results showed the better quality of trees in forests treated by the free crown thinning (Fig. 2).

## Selected quality of forest stands

This category is represented by best-quality trees in the forest which are usually selected at a particular age of the forest stand using specific and fixed criteria. These trees are called the trees of selective quality (promising and target trees) which have the best quality, as well as play an important role for increasing the static stability of the forest stand. At the beginning of research the number of the above-mentioned trees ranged from 296 to 348 trees per hectare on Jalná PRP and/or 160–304 individuals on Koňuš PRP (Table 3).

After the 53-year study period, the highest number of best-quality trees was found on the plots treated by the free crown thinning compared to the plots with the thinning from below or the control ones. Also other production indicators (basal area and growing stock) were found to be best after the free crown thinning. Also the proportion of target trees from the main crop stand

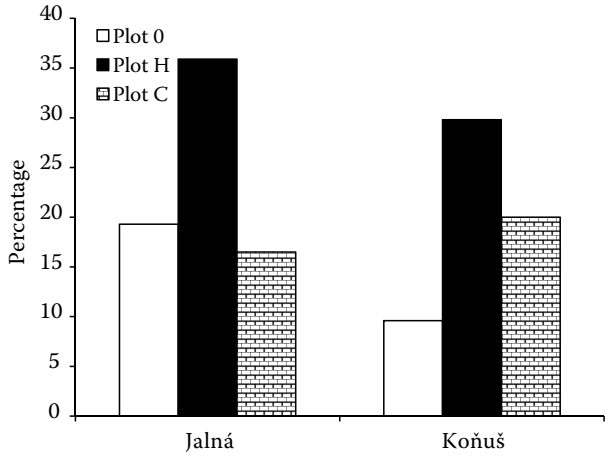


Fig. 2. The proportion of the stem with the application of veneer according to merchantable volume after 53 years of tending

was found to be higher in the stand after the free crown thinning. From the aspect of economic effectiveness, the information related to possible financial evaluation should be very interesting. Therefore, the assessment of the best-quality trees (crop trees only) was carried out according to Slovak standards No. STN 48 0056). We found that the proportion (expressed from the total growing stock of crop trees) of veneers was the highest on plots managed by the free crown thinning (30 and 36%) and the lowest on control (unthinned) plots (10 and 19%).

## DISCUSSION

The advantage of the comparison between the selected localities is that the site properties and the stand age are more or less the same.

Dominant and co-dominant trees are considered to be most important for the total quality of forest stand (stem and crown). For example, Korpeľ (1988) suggested that the proportion of the best-quality trees from the canopy layer (dominant and co-dominant trees) may reach almost 80% at the stand age of 42 years. However, in our study the proportion of these trees was smaller, but it might have been because the stands had not been treated by any thinning before the age of 30–36 years. In addition, the stands in both localities were attacked by bark necrosis (Štefančík, Leontovyč 1966; Štefančík 1974).

Réh (1994) found that the proportion of the best-quality trees at the age of 28 years (after the second cleaning) was around 24%, which is less than what we found in this study for beech forests at the age of 30 years. We found the average stem quality to range from 2.48 to 2.67, which corresponds to the results of Šebík (1970) from 143 research plots in beech forests of Slovak Republic. The same was found for crown quality. In this case the author found that the average crown quality for the western and middle part of Slovak Republic was

Table 3. Development of the trees of selective quality on

| Plot | Age (yr) | Number of trees (trees·ha$^{-1}$) | Basal area | | Merchantable volume | | Mean | |
|---|---|---|---|---|---|---|---|---|
| | | | ($m^2$·ha$^{-1}$) | % out of the main stand | ($m^3$·ha$^{-1}$) | % out of the main stand | diameter $d_{1.3}$ (cm) ($d_g$) | height (m) ($h_g$) |
| **Jalná PRP** | | | | | | | | |
| 0 | 36 | 304 | 3.0 | 11.2 | 16.6 | 13.6 | 11.3 | 13.1 |
| | 89 | 84 | 8.3 | 17.4 | 124.5 | 18.0 | 35.6 | 30.8 |
| H | 36 | 348 | 3.5 | 16.3 | 19.6 | 21.2 | 11.4 | 13.2 |
| | 89 | 168 | 24.7 | 65.7 | 377.5 | 69.7 | 43.3 | 31.1 |
| C | 36 | 296 | 2.9 | 12.1 | 15.7 | 13.2 | 11.2 | 13.1 |
| | 89 | 100 | 12.3 | 26.3 | 191.4 | 26.3 | 39.6 | 31.9 |
| **Koňuš PRP** | | | | | | | | |
| 0 | 38 | 240 | 4.5 | 15.2 | 35.8 | 19.8 | 15.4 | 17.3 |
| | 83 | 84 | 9.0 | 19.9 | 144.6 | 21.1 | 36.9 | 33.1 |
| H | 30 | 304 | 3.5 | 18.1 | 18.2 | 23.7 | 12.1 | 12.1 |
| | 83 | 144 | 21.5 | 57.8 | 335.0 | 61.8 | 43.6 | 31.4 |
| C | 38 | 160 | 3.6 | 16.0 | 29.0 | 16.2 | 16.9 | 17.5 |
| | 83 | 108 | 13.7 | 30.3 | 206.4 | 29.4 | 40.2 | 33.0 |

0 – control plot (without tending), H – plot with the free crown thinning, C – plot with heavy thinning from below

2.28 while for the eastern part it was 2.23. While this corresponds to our results at Jalná locality, different quality was found for the beech forest stand in Koňuš (2.63–2.69). Regarding different thinning methods, Šebík (1971) found out that the thinning from below increased the stem quality of the whole forest stands, which is also in line with our results. Hladík and Sedmák (1996) reported that at the beginning of research the proportion of the best-quality trees (1st and 2nd quality class) was around 50% in the case of heavy thinning from below. In the case of crown thinning and control plot the proportion was around 73% for both. After the third thinning the proportion increased to 77%, 91% and 77%, respectively.

In this study, the proportion of the best-quality trees (regarding the quality of the lowest part of the stem) was found to be highest on the plots treated by the free crown thinning (more than 50%). However, when only the canopy layer, as the most important part of the forest, was taken into account, the highest proportion of these trees (more than 70%) was found in the forest treated by the free crown thinning compared to other plots where the proportion was less than 60% (heavy thinning from below) or 50% (control plot). The result was the same for both localities. Moreover, the difference was even larger for crown quality when the proportion of the best-quality trees (from the trees of canopy layer) was more than 40% on the plot treated by the free crown thinning, while after the heavy thinning from below or on the control plot it was less than 18%. Badoux (1939) assessed the stem quality in beech stands at the age from 20 to 85 years, where three types of thinning from below (light, moderate and heavy) and thinning from above were applied. He found the highest proportion (28–35%) of best-quality trees (in terms of stem quality) when thinning from above was applied before, which is, however, less than in our study.

Besides the type of thinning, its intensity is considered to be highly important. For example, Utschig and Küsters (2003) suggested that more intensive thinning may produce a higher proportion of the best-quality trees, which in turn compensated the loss in total production which would otherwise be higher when less intensive thinning was applied. A positive effect of higher-intensity thinning was also reported by Poljanec and Kadunc (2013). The mentioned observations were not confirmed by our results. Additionally, the thinning intensity on Jalná PRP (according to basal area) ranged from 1.0% to 24.0% on plot H, and from 0.4 to 22.3% on plot C (Štefančík 2013b). On Koňuš PRP, it was 0–19.2% and 0–20.2%, respectively (Štefančík 2014). It can be seen that in our experiment the thinning intensity was very little different, but the qualitative production (stem, crown) was more different. We are convinced that stem quality and especially crown quality depends first of all on the method applied during tending. It is logical that the method focused on individual selection of trees with the best quality (the free crown thinning method) is favourable in comparison with the method of so called "mass tending", where the future crop trees are not selected and purposely cultivated.

In terms of the economic effectiveness of tending the proportion of sawn-timber stems is the key indicator. Poljanec and Kadunc (2013) reported that beech trees of 50–55 cm in DBH were the highest quality trees. However, the veneer or sawn-timber quality was found only in 1% and 1.6% of the trees, respectively. These proportions were, however, smaller than those found out in this study (16.5–35.9% in Jalná and 9.6–29.8 in Koňuš). They also reported a decrease in stem quality in the forests with stand basal area over 60–65 $m^2 \cdot ha^{-1}$.

Concerning the quality of target trees, the best results were reached in the forest stands treated by the free crown thinning. The advantage of the method focusing on target trees (applying well known Assmann's optimal basal area) was also supported by Hein et al. (2007).

Štefančík (1984) developed a model for a "future rotation-age stand" which assumes the growing stock at the age of 110–130 years to reach 500 $m^3 \cdot ha^{-1}$, 121–180 target trees per hectare, mean diameter of 43–50 cm and growing stock of target trees of 397–425 $m^3 \cdot ha^{-1}$. The growing stock of target trees is assumed to be as much as 79–85% of the canopy layer (main stand) and veneers to reach approximately 48–51% of the total volume of target trees. Results of this study (30 and 36% on plots with the free crown thinning) suggested that the forest stands in both localities (Jalná and Koňuš) are obviously to reach this model even earlier than at the age of 110–130 years.

## CONCLUSIONS

The results of the long-term research focused on the qualitative production proved tending to have a positive effect on stem and crown quality in 80–90 years old beech forests growing on sites

with good nutrient and moisture regime. There were no significant differences between the study sites which demonstrated similar effects of the thinning methods at different places across the region of Slovak Republic, but with similar site conditions. The most appropriate and hence successful thinning method was proved to be the free crown thinning. This method is based on individual selection of the best-quality (promising and crop) trees. It can be concluded that the best results have been reached by the above-mentioned method, if we focus on qualitative production. By the way, the highest quality is the crucial priority in beech silviculture. Based on the long-term outcomes coming also from our other beech experiments in Slovak Republic, the free crown thinning was recommended for management of beech forests. Our field experiences have confirmed that the cultivation of the best-quality trees by the method of the free crown thinning is also successfully utilized by forest practitioners.

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