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# Influence of phytotechnology on growth, production and leaf area index of black walnut (*Juglans nigra* L.) monocultures in Slovakia

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**ABSTRACT**: In the paper we evaluate the influence of crown thinning with positive selection, different intensity (moderate PRP III and heavy PRP IV) and 5-year frequency on development of growth, production, quality and leaf area index of black walnut (*Juglans nigra* L.) monocultures growing on the series of three permanent research plots (PRP) Sikenica (Levice Forest Enterprise, Levice Forest District) as observed in 1978–2003. The trends of development of mean stem, basal area, standing volume and aboveground dendromass (in dry matter) were mainly influenced by heavy crown thinning. The index of growth was as follows: basal area 169.01%, standing volume 262.12%, aboveground dendromass (in dry matter) 324.48%. At the age of 64 years the black walnut monocultures tended by heavy crown thinning had the following parameters: basal area 31.03 $m^2$/ha, standing volume 463.88 $m^3$/ha and aboveground dendromass 194.98 t/ha. Mean periodic increment reached the values: basal area 0.51 $m^2$/ha/year, standing volume 11.48 $m^3$/ha/year and dendromass 5.39 t/ha/year. The index of increment percent growth was: basal area + 31.75%, growing stock + 30.85% and dendromass + 0.79%, compared to the control. The total production was also significantly influenced by heavy thinning. At the stand age of 64 years the tended stands had the total basal area of 4.92 $m^2$/ha, total volume production of 572.77 $m^3$/ha and total weight production of 246.04 t/ha. The total mean increment of basal area is 0.67 $m^2$/ha/year, of volume 8.95 $m^3$/ha/year and of weight 3.84 t/ha/year, which is by 24.07%, 23.96% and 16.01% more than on the control plot. The leaf area index at the age of 64 years ranges from 6.54 ha/ha (PRP III) to 7.82 ha/ha (PRP V). Dendrochronological analyses revealed minimum widths of annual rings in the years 1952, 1961, 1968, 1971, 1975, 1981, 1983, 1985, 1993, 2000, maximum ones in 1951, 1957, 1959, 1967, 1974, 1979, 1982, 1984, 1989, 1999.

**Keywords**: black walnut; thinnings; growth; production; dendrochronology; leaf area index

To introduce or not to introduce any alien woody plants into Slovak forests? And if yes, which ones? It is still an urgent issue, mainly because some exotic woody plants can contribute to forest production and also increase the stability and biodiversity of forest ecosystems to some extent. In conditions of Central Europe, together 10 criteria determining the choice in introduction of alien woody plants have been proposed (Beran, Šindelář 1996; Frýdl, Šindelář 2004): sufficient production capacity, high wood quality, adaptability to the site, positive or no influence on the soil, resistance to abiotic factors, pests and diseases, exclusion of disease spreading, acceptable sensitivity or sufficient resistance to possible climate change, excluded invasive effects on indigenous vegetation and capacity of natural regeneration.

In Central Europe Douglas fir (*Pseudotsuga taxifolia*), grand fir (*Abies grandis*), red oak (*Quercus rubra*), black walnut (*Juglans nigra*) comply best with the above-mentioned criteria, and in the case of specific sites black locust (*Robinia pseudoacacia*) and Austrian pine (*Pinus nigra*) are also suitable to a smaller extent (Frýdl, Šindelář 2004).

The hitherto experience with commercial importance of the walnut (*Juglans nigra* L.) highly appreciates a very precious wood material (Beran, Šindelář 1996; Réh 1994, 1996; Šindelářová

1973), valuable seeds (Šika 1957) and fast growth rate at favourable sites (Beran, Šindelář 1996; Holubčík 1968; Hríb et al. 2003; Prudič 1991; Tokár 1995, 1996a,b, 1998a,b, 2000). For these reasons, the tree species is recommended for more intensive growing in forests.

In this paper we evaluate the development of dendromass production (volume and weight) in black walnut monocultures growing on the series of permanent research plots (PRP) Sikenica influenced by different phytotechnology (thinning) performed in 1978–2003. We also examined tree dendrochronology during the development and drew conclusions about connections with the stand production.

An annual ring series is a long-term record of the history of diameter increments in the tree or even in the stand. This record can be evaluated quantitatively as the magnitude of diameter increment is influenced by age, genetic predispositions and external environment, that means the annual ring width is a multivariate function of age and external influences (climatic factors, pollutant load, disasters, changes in moisture and light conditions, silvicultural measures) (Drápela, Zach 1996).

## MATERIAL AND METHODS

The series of permanent research plots (PRP) Sikenica (Levice Forest District) has three plots, each 50 × 50 m in size. The series was established in 1978, in stand 9b. The stand was established in 1939, by sowing walnut seeds of native provenience at a triangular spacing of 2 × 2 m. In 1978, the stand was aged 39 years. Since the establishment, two cleanings were performed. In 1978 the stand was subjected to a delayed, fairly heavy thinning and other thinnings were performed in 1983, 1988, 1993, 1998. As for the typology (Hančinský 1972) the stand belongs to the forest type group *Ulmeto-Fraxinetum populeum* (UFp), soil type blackland, and it is situated at an altitude of 150 m above sea level, climatic region A (warm).

Besides the diameter structure and the vertical storeys of the stand (social classes), we also assessed crown and stem quality (Table 1). In addition to the basal area and stand volume production (Halaj 1963 for oak; Šmelko 2000), on each PRP and after each evaluation, the weight production was also determined on sample trees (aboveground dendromass in dry matter). The number of sample trees was determined for each plot separately, using the method of stratified selection according to the presence of separate basal areas in the tree classes and encountering the required allowance (Šmelko, Wolf 1977). The converted values of dry mass of the individual components of aboveground biomass (stem, branches, one-year twigs, leaves and leaf area) were put in correlation with the diameter $d_{1.3}$ and the relation was fitted with a parabola of 2nd degree. Such approximated values of the biomass were converted according to the proportions of trees in the stand diameter structure per 1-ha area.

As for the thinning method, PRP III and IV are treated by crown thinning with positive selection of different intensity (moderate on PRP III and heavy on PRP IV) and 10-year frequency. The purpose is to promote the development of black walnut stands with the aim to reach maximum production of the highest quality. The used thinning method is based on the tending of promising trees – in this case trees belonging to the 1st and 2nd tree classes, with the diameter thicker than the mean diameter at breast height – dbh in the stand and higher than the mean height in the stand. In addition to dimensional criteria, qualitative indicators (1st and 2nd classes of stem and crown quality) and distance between future crop trees are also considered. The results of volume and dry mass production are compared with the control plot.

The leaf area index (LAI) was determined from the photosynthetically active leaf surface that was measured with an EJKELKAMP photoplanimeter on three representative samples (3 × 100 leaves) for each stand type. Then we calculated conversion coefficients (weight of fresh leaves in kg divided by leaf area in $m^2$ in fresh state) which were thereafter used for conversion in all sample trees.

For the purpose of dendrochronology, in total 15 trees were processed. The sample trees were se-

Table 1. Evaluation of tree class, stem and crown quality

| Evaluation degree | Tree class | Stem quality | Crown quality | | |
|---|---|---|---|---|---|
| | | | size | | type |
| 1 | dominant | high | average | average | regular |
| 2 | codominant | medium | long | very dense | fork-shaped |
| 3 | intermediate | low | small | open | bouquet |
| 4 | suppressed | | | | irregular (deformed) |

lected according to the tree classes (dominant trees, codominant trees). From each tree, at breast height (1.3 m above the ground), one sample with Pressler's borer was drilled. The drilling directions were different on different trees. The samples were labelled, glued onto wooden boards and treated.

The measurement of annual ring width was performed using a digital positionmeter provided with the program DAS (Digital Analysis System, Janíček 1991), at the Faculty of Forestry of TU Zvolen. The dating of the individual series of annual rings – synchronisation was also performed in the DAS system.

The filtering of the age trend (standardisation) and calculation of the annual ring indexes were also done using the DAS system, after the synchronisation.

The measured widths of annual rings were fitted with Hugershof's function and a polynomial function of the 4$^{th}$ degree.

Climatic characteristics (mean monthly temperature in °C, monthly precipitation sum in mm, monthly sum of global radiation in KWh/m$^2$, sunshine hours and air humidity in %) were provided by the Slovak Agricultural University in Nitra (Špánik et al. 1995, 2002).

Correlation coefficients were calculated between the curve of mean annual ring indexes (CMARI) of the examined black walnut trees and the monthly data of the local atmospheric conditions (mean monthly temperature in °C, monthly precipitation sum in mm, mean monthly sum of global radiation in KWh/m$^2$, monthly sunshine hours and monthly air humidity in %) in the vegetation periods 1970 to 2000.

## RESULTS

### Development of stand structure and biosociological status of trees in the stand

The homogeneous stands of black walnut in the locality Sikenica (local name Hrable) have been grown from seed. The seed was of autochthonous origin and was collected from parent trees of an older stand at the site. The seeding was performed in spring 1939 into overall prepared soil, the applied method was pit seeding at a triangular spacing, with row distance 2 m and the distance between pits in a row also 2 m. Even-aged stands with more or less uniformly distributed trees over the plot were established in this way. The establishment of a thinning experiment in 1978 was preceded by two cleanings aimed to remove undesirable species from natural seeding and malformed black walnut trees.

Since 1978, the PRP series was subjected to five thinning interventions. The survey performed in 2003 resulted in the following tree numbers: PRP III (moderate thinning) 436 trees/ha, PRP IV (heavy thinning) 444 trees/ha and PRP V (control) 656 trees/ha.

According to the diameter structure, the stands are in the stage of maturing stemwood (Korpeľ et al. 1991).

As early as in 1984, we observed good natural regeneration of black walnut on PRP (2,404 trees per 1 ha, Tokár 1988, 1998a), at present complemented by trees from the natural seeding of *Negundo aceroides* MOENCH from a stand in the neighbourhood, by the Hron river.

In terms of the stand structure and social structure in black walnut monocultures growing on the PRP series Sikenica, as observed in 1978 (Fig. 1A) codominant trees were most abundant (61.82% – PRP IV to 70.62% – PRP III).

The influence of dynamic changes in 1979–2003 was reflected in the following stand composition: codominant trees increased to 86.61% (PRP IV) – 94.64% (PRP III), comprising also former subdominant trees (Fig. 2A). The proportion of codominant trees on the control plot was 74.39% only.

The mean tree class increased from the value of 2.26 to 2.03 (PRP III) and from 2.31 to 2.03 (PRP IV). An increase from 2.35 to 2.19 was recorded on the control plot.

### Development of mean stem values

The development of mean stem values (Table 2) as observed over 25 years, was influenced most significantly by heavy crown thinning (PRP IV). In this case the highest growth index compared to the control and also the highest index of increment percent were reached (+33.97% for dry dendromass to +112.48% for mean stem volume).

### Development of basal area, growing stock and aboveground dendromass

The values of the basal area of black walnut monocultures aged 64 years are (Table 3) from 27.93 m$^2$/ha (PRP III) to 33.95 m$^2$/ha (PRP V), with the highest growth index (169.01%) recorded on PRP IV (heavy thinning).

The growing stock at the stand age of 64 years is from 381.12 m$^3$/ha (PRP III) to 463.88 m$^3$/ha (PRP IV). The highest growth index (262.12%) is on PRP IV (heavy thinning from above), where the highest mean periodic increment (11.48 m$^3$/ha/year) and in-

Table 2. Mean stem parameters in black walnut (*Juglans nigra* L.) monocultures on the PRP series Sikenica in 1979–2003

| PRP | Variable | Stand age | | Growth index (%) | Mean periodic increment | | Index *p* (%) in relation to *V* |
|---|---|---|---|---|---|---|---|
| | | 39 years (1978 after intervention) | 64 years (2003 before intervention) | | abs. | % (*p*) | |
| III | $d_{1.3}$ (cm) | 16.610 | 28.200 | 169.78 | 0.460 | 2.77 | 139.19 |
| | *h* (m) | 18.500 | 26.300 | 142.16 | 0.310 | 1.67 | 99.40 |
| | *v* ($m^3$) | 0.285 | 0.874 | 306.67 | 0.023 | 8.07 | 143.85 |
| | *m* (kg) | 68.340 | 398.200 | 582.67 | 13.190 | 19.30 | 116.05 |
| IV | $d_{1.3}$ (cm) | 16.050 | 29.100 | 181.31 | 0.520 | 3.24 | 162.81 |
| | *h* (m) | 17.400 | 28.600 | 164.37 | 0.490 | 2.82 | 167.86 |
| | *v* ($m^3$) | 0.260 | 1.044 | 400.00 | 0.031 | 11.92 | 212.48 |
| | *m* (kg) | 66.820 | 439.140 | 657.20 | 14.890 | 22.28 | 133.97 |
| V (control) | $d_{1.3}$ (cm) | 16.610 | 24.820 | 149.43 | 0.330 | 1.99 | 100.00 |
| | *h* (m) | 17.800 | 25.300 | 142.13 | 0.300 | 1.68 | 100.00 |
| | *v* ($m^3$) | 0.285 | 0.692 | 242.81 | 0.016 | 5.61 | 100.00 |
| | *m* (kg) | 61.330 | 316.400 | 515.90 | 10.200 | 16.63 | 100.00 |

$d_{1.3}$ – diameter $d_{1.3}$, *h* – height, *v* – volume, *m* – weight

crement percent (6.49%) were also observed, which is by 30.85% more compared to the control. The loss of volume production on PRP III (moderate thinning) was 13.71% compared to the control.

The aboveground biomass in dry state at the stand age of 64 years is from 173.61 t/ha (PRP III) to 207.56 t/ha (PRP V). The highest growth index (324.48%) was observed on PRP IV (heavy thinning from above). The same PRP also showed the highest increment percent (8.97%), which is only by 0.79% more compared to the control plot. The control plot has fairly high standing volume and aboveground dendromass because there are also higher tree numbers per one hectare. The formation of volume and weight production was positively influenced by heavy thinning.

### Development of total basal area, total volume production and total aboveground dendromass production

The values of total basal area (stock + thinning + other losses – mortality, stolen wood) at the stand

Table 3. Basal area (*G*), growing stock (*V*) and aboveground dendromass in dry state (*M*) in black walnut (*Juglans nigra* L.) monocultures on the PRP series Sikenica in 1979–2003

| PRP | Variable | Stand age | | Growth index (%) | Mean periodic increment | | Index *p* (%) in relation to PRP *V* |
|---|---|---|---|---|---|---|---|
| | | 39 years (1978 after intervention) | 64 years (2003 before intervention) | | abs. | % (*p*) | |
| III | *N* (trees/ha) | 892 | 436 | – | – | – | – |
| | *G* ($m^2$/ha) | 18.58 | 27.93 | 150.32 | 0.37 | 1.99 | 94.31 |
| | *V* ($m^3$/ha) | 183.98 | 381.12 | 207.15 | 7.88 | 4.28 | 86.29 |
| | *M* (t/ha) | 60.96 | 173.61 | 284.79 | 4.51 | 7.40 | 83.15 |
| IV | *N* (trees/ha) | 902 | 444 | – | – | – | – |
| | *G* ($m^2$/ha) | 18.36 | 31.03 | 169.01 | 0.51 | 2.78 | 131.75 |
| | *V* ($m^3$/ha) | 176.97 | 463.88 | 262.12 | 11.48 | 6.49 | 130.85 |
| | *M* (t/ha) | 60.09 | 194.98 | 324.48 | 5.39 | 8.97 | 100.79 |
| V (control) | *N* (trees/ha) | 1,050 | 656 | – | – | – | – |
| | *G* ($m^2$/ha) | 22.22 | 33.95 | 152.79 | 0.47 | 2.11 | 100.00 |
| | *V* ($m^3$/ha) | 202.80 | 454.32 | 224.02 | 10.06 | 4.96 | 100.00 |
| | *M* (t/ha) | 64.40 | 207.56 | 322.30 | 5.73 | 8.90 | 100.00 |

Table 4. Total basal area (*G*), total growing stock (*V*) and total aboveground dendromass in dry state (*M*) in black walnut (*Juglans nigra* L.) monocultures on the PRP series Sikenica in 1979–2003

| PRP | Variable | Stock in 2003 | Thinning interventions in 1978–1998 | Other losses | Total as to 31. 12. 2003 | Total mean increment (TMI) | Index TMI in relation to PRP *V* |
|---|---|---|---|---|---|---|---|
| III | *N* (trees/ha) | 436 | 515 | 29 | 980 | – | – |
| | *G* ($m^2$/ha) | 27.93 | 9.54 | 0.52 | 37.99 | 0.59 | 109.26 |
| | *V* ($m^3$/ha) | 381.12 | 80.98 | 5.96 | 468.06 | 7.31 | 101.25 |
| | *M* (t/ha) | 173.61 | 38.85 | 2.87 | 215.33 | 3.36 | 101.51 |
| IV | *N* (trees/ha) | 444 | 554 | 19 | 1,017 | – | – |
| | *G* ($m^2$/ha) | 31.03 | 11.42 | 0.47 | 42.92 | 0.67 | 124.07 |
| | *V* ($m^3$/ha) | 463.88 | 103.67 | 5.22 | 572.77 | 8.95 | 123.96 |
| | *M* (t/ha) | 194.98 | 48.36 | 2.70 | 246.04 | 3.84 | 116.01 |
| V (control) | *N* (trees/ha) | 656 | | 238 | 894 | – | – |
| | *G* ($m^2$/ha) | 33.95 | | 0.76 | 34.71 | 0.54 | 100.00 |
| | *V* ($m^3$/ha) | 454.32 | | 8.06 | 462.38 | 7.22 | 100.00 |
| | *M* (t/ha) | 207.56 | | 4.15 | 211.71 | 3.31 | 100.00 |

age of 64 years are from 37.99 $m^2$/ha to 42.92 $m^2$/ha, which is from + 9.26% to 24.07% more than in the control (Table 4).

The total volume production (Table 4) in the tended black walnut monocultures ranges from 468.06 $m^3$/ha (PRP III) to 572.77 $m^3$/ha (PRP IV), which makes the difference from + 1.25% to + 23.96%, as compared to the control. The total mean increment is from 7.31 $m^3$/ha/year (PRP III) to 8.95 $m^3$/ha/year (PRP IV), which is by + 1.25% (TVP III)to 23.96% (PRP IV) more than on the control plot.

The total aboveground dendromass production in the examined stands is from 215.33 t/ha (PRP III) to 246.04 t/ha (PRP IV). The values of total mean increment range from 3.36 t/ha/year (PRP III) to 3.84 t/ha/year, which is from + 1.51% (III) to + 16.01% (IV) more compared to the control plot (Table 4).

It can be seen from the results that the black walnut monocultures tended by heavy crown thinning with positive selection have both higher growing stock and higher total production than the untended monocultures. The homogeneous stands of black walnut tended by moderate thinning from above with positive selection have lower growing stock than the untended stands and practically the equal total production.

Table 5. Growing stock of promising trees in black walnut (*Juglans nigra* L.) monocultures on the PRP series Sikenica in 1979–2003

| PRP | Variable | Year | | Growth index (%) | Mean periodic increment | | Index *p* (%) to PRP *V* |
|---|---|---|---|---|---|---|---|
| | | 1978 | 2003 | | abs. | % (*p*) | |
| III | *N* (trees/ha) | 148 | 132 | – | – | – | – |
| | *G* ($m^2$/ha) | 3.08 | 10.16 | 329.87 | 0.28 | 9.09 | 95.58 |
| | *V* ($m^3$/ha) | 43.22 | 142.44 | 329.56 | 3.97 | 9.18 | 79.00 |
| | *M* (t/ha) | 14.30 | 64.03 | 447.76 | 1.99 | 13.92 | 78.33 |
| IV | *N* (trees/ha) | 172 | 160 | – | – | – | – |
| | *G* ($m^2$/ha) | 3.64 | 14.70 | 403.85 | 0.44 | 12.08 | 127.02 |
| | *V* ($m^3$/ha) | 49.19 | 229.04 | 465.62 | 7.19 | 14.62 | 125.82 |
| | *M* (t/ha) | 16.67 | 94.32 | 565.81 | 3.11 | 18.66 | 105.01 |
| V (control) | *N* (trees/ha) | 164 | 140 | – | – | – | – |
| | *G* ($m^2$/ha) | 3.47 | 11.78 | 339.48 | 0.33 | 9.51 | 100.00 |
| | *V* ($m^3$/ha) | 43.30 | 169.00 | 390.30 | 5.03 | 11.62 | 100.00 |
| | *M* (t/ha) | 13.73 | 74.64 | 543.63 | 2.44 | 17.77 | 100.00 |

### Leaf area index (LAI)

In 1978, when the thinning experiment was established and the black walnut stands were 39 years old, the LAI values were 4.60 ha/ha (PRP III) and 4.70 ha/ha (PRP IV, V). In 2003, at the stand age of 64 years LAI values were as follows: 6.54 ha/ha (PRP III), 7.24 ha/ha (PRP IV), 7.82 ha/ha (PRP V).

For the tended black walnut stands the LAI values per tree are 150 $m^2$ (PRP III) – 164 $m^2$ (PRP IV). On the control plot the value is only 119 $m^2$, because of a lower number of trees.

### Aboveground dendromass and leaf area index of promising trees

In 1978, at the stand age of 39 years, 148 to 172 promising trees were selected and permanently marked on each of the plots (Table 5). The basal area of the selected trees ranged from 3.08 $m^2$/ha (PRP III) to 3.64 $m^2$/ha (PRP IV), standing volume from 43.22 $m^3$/ha (PRP III) to 49.19 $m^3$/ha (PRP IV) and aboveground dendromass from 13.73 t/ha (PRP V) to 16.67 t/ha (PRP IV).

In 2003, at the stand age of 64 years the promising trees were evaluated and marked once more. Their number ranged from 132 trees/ha (PRP III) to 160 trees per ha (PRP IV), basal area from 10.16 $m^2$/ha (PRP III) to 14.70 $m^2$/ha (PRP IV), standing volume 144.44 $m^3$/ha (PRP III) to 229.04 $m^3$/ha (PRP IV) and weight of aboveground dendromass 64.03 t/ha (PRP III) to 94.32 t/ha (PRP IV).

The highest growth index in all the variables as measured on promising trees was found on PRP IV (heavy thinning), with the best conditions for development of promising trees, which is also documented by the index of increment percentage of the studied variables in comparison with the control plot (higher by 5.01–27.02%).

Table 6. Basic dendrochronological characteristics of black walnut (*Juglans nigra* L.) on the PRP series Sikenica

| | Max | Min | Average |
|---|---|---|---|
| Age | 60 | 44 | 50 |
| Value | 4.21 | 0.35 | 1.49 |
| Sensitivity | 0.362 | 0.251 | 0.308 |
| Autocorrelation first lag | 0.692 | –0.127 | 0.339 |
| Mean correlation | | 0.530 | |
| Interval trend | | 67 | |
| Signal/noise ratio | | 16.948 | |
| Expressed population | | 0.944 | |

### Stem and crown quality

The black walnut monocultures on the PRP series Sikenica have a very high quality of mean stem, with the values (Fig. 1B) ranging from 1.33 (PRP V) to 1.51 (PRP III) in 1978, and from 1.13 (PRP IV) to 1.40 (PRP III) in 2003. The dynamic changes in 1979–2003, caused by the thinnings, were reflected in an improvement of mean stem quality by 0.11 (PRP III) to 0.24 (PRP IV). On PRP V (control) mean stem quality was improved only by 0.09 degree.

Already at the establishment of the thinning experiment in 1978 (Fig. 1B), the most frequent trees

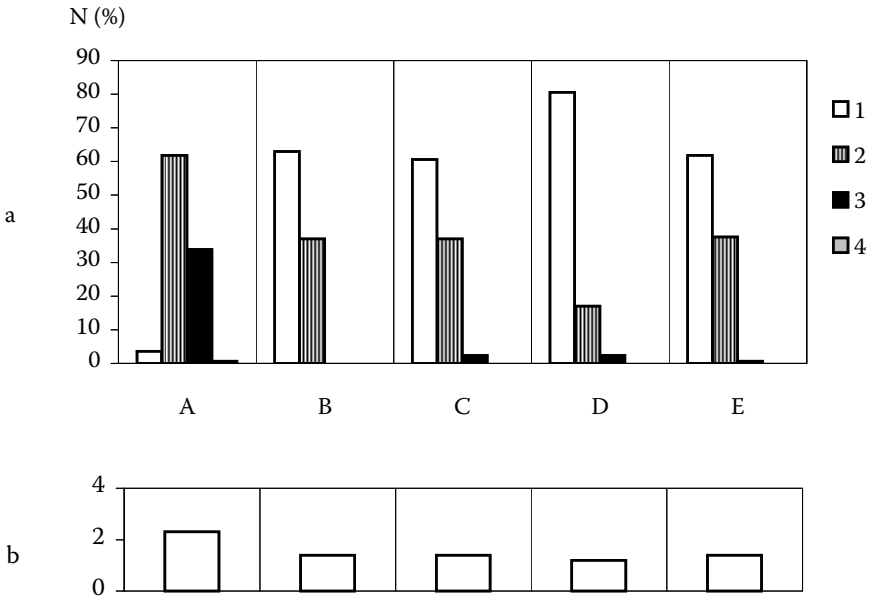


Fig. 1. Relative frequency distribution for *Juglans nigra* L. on PRP IV Sikenica (non mixed tended stand) in 1978 (a) and mean values of the evaluation degree (b) given in dependence on tree classes (A), stem quality (B), crown size (C), crown density (D) and types of crown (E)

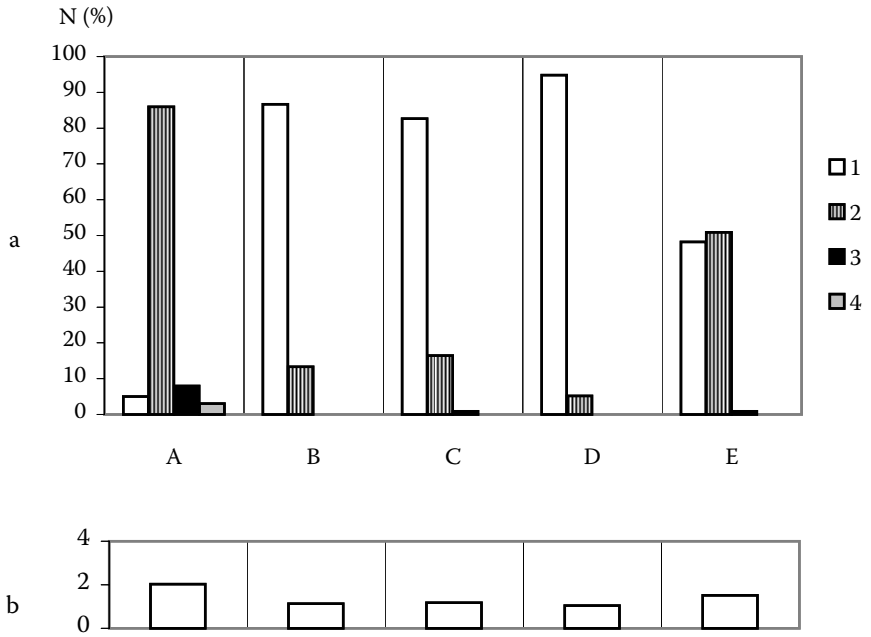


Fig. 2. Relative frequency distribution for *Juglans nigra* L. on PRP IV Sikenica (non mixed tended stand) in 2003 (a) and mean values of the evaluation degree (b) given in dependence on tree classes (A), stem quality (B), crown size (C), crown density (D) and types of crown (E)

on the PRP were trees with high-quality stem: 51.88% (PRP III) to 66.84% (PRP V). The same was true in 2003 (Fig. 2B), with the proportions increasing to 60.30% (PRP III) to 86.72% (PRP IV).

The quality of crown was assessed according to crown size (Figs. 1C and 2C), density (Figs. 1D and 2D) and type (Figs. 1E and 2E).

In 1978 the most abundant trees with medium-sized (50.00% – PRP III to 63.21% – PRP V), medium dense (61.25% – PRP III to 89.64% – PRP V) and straight crowns 55.62% – PRP III to 70.46% – PRP V) were on all plots.

In 2003 trees with medium-sized (66.42% – PRP III to 82.61% – PRP IV), medium dense (76.30% – PRP III to 94.83% – PRP IV) and straight crowns (33.60% – PRP III to 65.48% – PRP V) were also the most abundant.

However, on the PRP series Sikenica trees with fork-shaped crowns are fairly frequent (Figs. 1E and 2E): 28.50% (PRP V) to 42.50% (PRP III) in 1978, 32.74% (PRP V) to 66.40% (PRP III) in 2003. No evident cause of forking has been found. There exists a hypothesis about frost damage to buds and another about genetically conditioned factors.

**Dendrochronological analysis**

According to the dendrochronological analysis summarised in Table 7, minimum values of the width of annual rings (as observed on increment cores taken from sample trees) were recorded in the years 1961, 1968, 1971, 1975, 1981, 1983, 1985, 1993, 2000. The values ranged between 0.72 and 1.38 mm.

Maximum values were recorded in 1952, 1957, 1959, 1967, 1974, 1979, 1982, 1984, 1986, 1989 and 1999. The maximum values ranged from 1.57 to 2.55 mm. Thinning interventions performed in 1978, 1983, 1988, 1993, 1998 might have had a positive effect on the width of annual rings (e.g. 1979, 1984, 1989, 1999). In 1994, one year after a thinning intervention in the dry year 1993 it was not manifested so unambiguously, only an increase occurred in comparison with the minimum in 1993 and an adverse effect of the drought was manifested also in the next year (Fig. 3).

The mean value of the individual annual ring series was 1.392 to 1.679 mm. The total mean value of annual ring width for all the examined trees was 1.49 mm.

Table 7. Mean chronology of annual ring values of examined black walnut (*Juglans nigra* L.) trees (mm)

| Years | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1950–1959 | | 1.69 | 2.55 | 1.49 | 2.10 | 2.32 | 2.24 | 2.00 | 1.82 | 1.98 |
| 1960–1969 | 1.75 | 1.13 | 1.70 | 1.72 | 1.45 | 1.53 | 1.68 | 1.66 | 0.88 | 1.35 |
| 1970–1979 | 1.35 | 1.18 | 1.50 | 1.49 | 1.57 | 1.38 | 1.54 | 1.62 | 1.68 | 1.69 |
| 1980–1989 | 1.37 | 1.35 | 1.89 | 1.35 | 1.74 | 1.30 | 1.72 | 1.45 | 1.47 | 1.66 |
| 1990–1999 | 1.19 | 1.15 | 1.13 | 0.72 | 1.19 | 1.24 | 1.33 | 1.11 | 1.12 | 1.68 |
| 2000–2002 | 1.09 | 1.06 | 0.96 | | | | | | | |

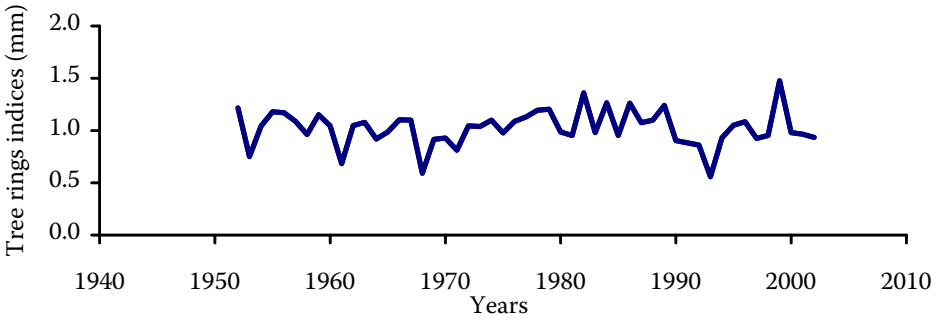


Fig. 3. Mean chronology of annual ring indexes of examined black walnut (*Juglans nigra* L.) trees in Sikenica

Interval trend for all the increment cores (Table 6) had a value of 67% and the population signal of 16.948.

The maximum value of annual ring width (Table 6) was 4.21, minimum 0.35.

Sensitivity of the individual series of annual rings ranged between 0.251 and 0.362. The mean value of sensitivity of all the curves was 0.308.

The correlation coefficient between the curve of mean indexes (CMARI) and climatic characteristics over the vegetation period 1970–2000 points to very low positive correlations ($r_{xy}$ = 0.21 to 0.35 in mean annual humidity) and low negative correlations ($r_{xy}$ = –0.38 to –0.47 in the annual sum of global radiation). The correlation coefficient between the curve of mean indexes of the walnut trees on the PRP Sikenica over the period 1970–2000 and the mean annual humidity is $r_{xy}$ = 0.43. The correlation between the annual sum of sunshine hours and the CMARI curve is $r_{xy}$ = –0.32. The value of correlation coefficient between the annual sum of global radiation and CMARI was ($r_{xy}$ = –0.26). The highest values were reached in July ($r_{xy}$ = –0.26) and August ($r_{xy}$ = –0.42). A slight influence of temperature on the diameter increment in black walnut was evident in September ($r_{xy}$ = 0.21), to the end of the vegetation period; a negative influence was mainly observed in August ($r_{xy}$ = –0.37). The effect of precipitation on CMARI was observed in June and August ($r_{xy}$ = 0.24 and 0.22).

## DISCUSSION

The influence of thinning on the development of stand structure and production was already discussed in our previous papers (Tokár 1991a,b, 1992a,b, 1994, 1995, 1996a,b, 1998a,b, 2000).

The black walnut has been strengthened by thinning interventions and, in the case of mixed stands, the admixed species (red oak, small-leaved linden) also increased their growth rate and production quality. The thinning interventions are based on the choice, marking and growth promotion of promising trees. Trees meeting requirements for both quantity and quality are selected as promising trees (thicker and higher than the mean stand diameter and height, 1st and 2nd degree of stem and crown quality). The number of promising trees should be 250–300 trees per ha (Tokár 1991a,b, 1992a,b, 1994, 1996a,b, 1998a,b, 2000).

Heavy crown thinning with positive selection and 10-year frequency is recommended as the thinning method in black walnut monocultures (Tokár 1992a,b, 1994, 1996a, 1998a, 2000).

In the black walnut stands with admixed red oak or small-leaved linden moderate crown thinning with positive selection and 5-year frequency is recommended (Tokár 1991b, 1995, 1996b, 1998b).

Good results of growth and production of walnut trees were obtained in forest stands in South Moravia (Hríb et al. 2003; Prudič 1991).

According to Pagan (1996), black walnut requires deep, fresh soil of hardwood floodplain forest with accessible groundwater level. In our conditions the tree can compensate lower precipitation by moisture uptake from the groundwater.

According to Drápela and Zach (1996), diameter increment is substantially influenced by the tree sociological status in the stand. There is also a difference in the increment trend between shaded and sunny woody plants. Black walnut requires a sufficient light supply for its height and mainly diameter increment (Pagan 1996; Tokár 2000), which may be positively manifested as an individual response of the remaining trees after thinning intervention.

In a survey Gruber (2002) found the mean width of annual rings in European beech (*Fagus sylvatica* L.) about 1.3 mm/year, in black walnut (*Junglans nigra*) from 1.392 to 1.679 mm/year, according to the individual sample trees. The total mean value of all walnut sample trees was 1.49 mm.

The effects of individual climatic factors on diameter growth could be strengthened or weakened (Konnert et al. 1989). In conditions of Central Europe the effects of temperature and moisture are mutually complemented. The air moisture toward

the end of vegetation period has a positive effect on diameter growth of black walnut. Fiedler and Wenk (1973) reported that at the end of vegetation period (August, beginning of September) and end of diameter growth the effect of temperature on diameter increment is negligible, what was also proved by our results. Gruber (2001) confirmed a negative correlation between diameter increment and global radiation toward the end of vegetation period, which is in accordance with our results.

## CONCLUSION

In the paper we assessed the influence of crown thinning with positive selection, different intensity (moderate and heavy) and 10-year frequency on development of growth, production, quality and leaf area index of black walnut (*Juglans nigra* L.) monocultures growing on the series of three permanent research plots (PRP) Sikenica (Levice Forest Enterprise, Levice Forest District) during the period 1978–2003. The trends of development of quantitative characteristics (mean stem, basal area, standing volume, aboveground dendromass and LAI) and qualitative characteristics (stem and crown characteristics) were mainly affected by heavy crown thinning. Dendrochronological analyses revealed minimum and maximum widths of annual rings. In the synergic effect of thinning interventions and climatic conditions, their correlations with the curve of mean annual ring indexes (CMARI) were assessed. Low positive correlations (with air humidity and precipitation) and low negative correlations (with air temperature, global radiation, sunshine hours) were found out.

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# Vplyv fytotechniky na vývoj rastu, produkcie, kvality a indexu listovej plochy rovnorodých porastov orecha čierneho (*Juglans nigra* L.) na Slovensku

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**ABSTRAKT**: V práci sa zhodnocuje vplyv úrovňových prebierok s pozitívnym výberom o rôznej sile (mierna TVP III a silná TVP IV) a intervalom opakovania 10 rokov na vývoj rastu, produkcie, kvality a index listovej plochy rovnorodých porastov orecha čierneho (*Juglans nigra* L.) na sérii troch trvalých výskumných plôch (TVP) Sikenica (Lesný závod Levice, Lesná správa Levice) za roky 1978–2003. Na vývoj stredného kmeňa, kruhovej základne, objemovej zásoby a zásoby nadzemnej dendromasy v sušine najväčším vplyvom účinkovala silná úrovňová prebierka. Index rastu kruhovej základne bol 169,01 %, objemovej zásoby 262,12 % a zásoby nadzemnej dendromasy v sušine 324,48 %. Pri veku 64 rokov dosahujú rovnorodé porasty orecha čierneho vychovávané silnou úrovňovou prebierkou porastovú základňu 31,03 $m^2$/ha, objemovú zásobu 463,88 $m^3$/ha a zásobu nadzemnej dendromasy 194,98 t/ha. Priemerný periodický prírastok mal hodnoty na kruhovej základni 0,51 $m^2$/ha/rok, na objeme 11,48 $m^3$/ha/rok a na hmotnosti dendromasy 5,39 t/ha/rok. Index rastu prírastkového percenta oproti kontrole bol + 31,75 % pri kruhovej základni, + 30,85 % pri porastovej zásobe a + 0,79 % pri zásobe hmotnostnej dendromasy. Celkový priemerný prírastok na kruhovej základni je 0,67 $m^2$/ha/rok, na objeme 8,95 $m^3$/ha/rok a na hmotnosti 3,84 t/ha/rok, čo je oproti kontrole rozdiel + 24,07 %, + 23,96 % a + 16,01 %. Index listovej plochy dosahuje pri veku 64 rokov hodnoty 6,54 ha/ha (TVP III) až 7,82 ha/ha (TVP V). Dendrochronologickými analýzami sa zistilo, že v rokoch 1952, 1961, 1968, 1971, 1975, 1981, 1983, 1985, 1993, 2000 boli dosiahnuté minimálne šírky letokruhov. V rokoch 1951, 1957, 1959, 1967, 1974, 1979, 1982, 1984, 1989, 1999 sa namerali maximálne hodnoty šírok letokruhov.

**Kľúčové slová**: orech čierny; prebierky; rast; produkcia; dendrochronológia; index listovej plochy

Práca zhodnocuje vývoj produkcie dendromasy (v objeme a hmotnosti) rovnorodých porastov orecha čierneho na sérii trvalých výskumných plôch (TVP) Sikenica vplyvom rôznej fytotechniky (prebierok) za roky 1978–2003 a dendrochronológiu počas ich vývoja.

Okrem hrúbkovej štruktúry a výškového postavenia stromov v poraste sa hodnotila kvalita kmeňa a koruny (tab. 1). Okrem kruhovej základne a objemovej produkcie (Halaj 1963 pre dub; Šmelko 2000) sa na všetkých čiastkových TVP pri každom vyhodnotení stanovila vzorníkovou metódou aj hmotnostná produkcia (nadzemná dendromasa v sušine). Počet vzorníkov pre každú prebierkovú TVP sa stanovil metódou stratifikovaného výberu podľa zastúpenia kruhových plôch v stromových triedach a požadovanou chybou stanovenia (Šmelko, Wolf 1977). Ako prebierková metóda sa na TVP III a IV uplatňuje úrovňová prebierka s pozitívnym výberom rôznej sily (mierna TVP III a silná TVP IV) s časovým intervalom 10 rokov. Použitá prebierková metóda je založená na výchove nádejných stromov, za ktoré volíme stromy 1. a 2. stromovej triedy, hrubšie ako je stredná hrúbka $d_{1,3}$ porastu a vyššie ako je stredná výška porastu. Okrem dimenzionálnych hľadísk sa do úvahy berú aj kvalitatívne ukazovatele (1. a 2. stupeň kvality kmeňa a koruny) a rozostup budúcich rubných stromov.

Na vývoj taxačných veličín stredného kmeňa (tab. 2) za 25 rokov najintenzívnejšie vplývala silná úrovňová prebierka (TVP IV), kde sa dosiahol oproti kontrole najvyšší index rastu, ale aj najvyšší index prírastkového percenta (+33,97 % pri hmotnosti sušiny dendromasy až +112,48 % pri objeme stredného kmeňa). Aj na celkovú produkciu väčším vplyvom vplývali silné úrovňové prebierky. Pri veku 64 rokov dosahujú rovnorodé porasty orecha čierneho porastovú kruhovú základňu (tab. 3) 27,93 $m^2$/ha (TVP III) až 33,95 $m^2$/ha (TVP V), pričom najvyšší index rastu (169,01 %) sa zistil na TVP IV (silná úrovňová prebierka).

V uvedenom veku 64 rokov dosiahli vychovávané porasty celkovú kruhovú základňu 42,92 $m^2$/ha, celkovú objemovú produkciu 572,77 $m^3$/ha a celkovú hmotnostnú produkciu 246,04 t/ha, celkovú produkciu nadzemnej dendromasy 215,33 t/ha (TVP III) až 246,04 t/ha (TVP IV) a celkový priemerný prírastok 3,36 t/ha/rok (TVP III) až 3,84 t/ha/rok, čo je oproti kontrolnej TVP +1,51% (III) až + 16,01% (IV) rozdiel (tab. 4). V r. 1978 pri veku porastov orecha čierneho 39 rokov bolo na TVP vytypovaných a trvalo označených 148 až 172 nádejných stromov (tab. 5) s kruhovou základňou 3,08 $m^2$/ha (TVP III) až 3,64 $m^2$/ha (TVP IV), s objemovou zásobou 43,22 $m^3$/ha (TVP III) až 49,19 $m^3$/ha (TVP IV) a zásobu nadzemnej dendromasy 13,73 t/ha (TVP V) až 16,67 t/ha (TVP IV).

Z výsledkov vidno, že nezmiešané porasty orecha čierneho vychovávané silnou úrovňovou prebierkou s pozitívnym výberom v zásobe a celkovej produkcii predstihujú nevychovávané nezmiešané porasty. Rovnorodé porasty orecha čierneho vychovávané miernymi úrovňovými prebierkami s pozitívnym výberom v zásobe zaostávajú za porastami nevychovávanými a v celkovej produkcii sa im vyrovnávajú.

V r. 1978 pri založení pokusu s prebierkami pri veku porastov orecha čierneho 39 rokov bol LAI porastov 4,60 ha/ha (TVP III) a 4,70 ha/ha (TVP IV, V). V r. 2003 pri veku porastov 64 rokov bol LAI 6,54 ha/ha (TVP III), 7,24 ha/ha (TVP IV) až 7,82 ha/ha (TVP V). Pri vychovávaných porastoch orecha čierneho pripadá na 1 strom LAI 150 $m^2$ (TVP III) až 164 $m^2$ (TVP IV), na kontrolnej TVP v dôsledku vyššieho počtu stromov len 119 $m^2$.

Nezmiešané porasty orecha čierneho na sérii TVP Sikenica sú z hľadiska priemernej hodnoty kvality kmeňa veľmi kvalitné. Už pri založení pokusu s prebierkami v r. 1978 (obr. 1B) boli na TVP najviac zastúpené stromy s veľmi kvalitným kmeňom 51,88 % (TVP III) až 66,84 % (TVP V). Aj v r. 2003 (obr. 2b) zostali na TVP najviac zastúpené stromy s veľmi kvalitným kmeňom 60,30 % (TVP III) až 86,72 % (TVP IV). Z hľadiska kvality koruny sa pozornosť venovala veľkosti koruny (obr. 1C, 2C), hustote koruny (obr. 1D, 2D) a typu koruny (obr. 1E, 2E). Avšak aj na sérii TVP Sikenica sú pri orechu čiernom pomerne vysoko zastúpené aj stromy s vidlicovitou korunou (obr. 1E, 2E).

Na dendrochronologické účely bolo spracovaných celkom 15 stromov. Výber vzorníkov bol podľa príslušnosti k stromovým triedam (stromy nadúrovňové, úrovňové). Z každého stromu bol vo výške 1,3 m stromu v tzv. prsnej hrúbke $d_{1,3}$ Presslerovým nebožiecom odobratý 1 vývrt, pričom na každom strome sa smery navŕtania menili.

Hodnoty intervalového trendu podľa tab. 6 pre všetky vývrty sú 67 % a populačný signál 16,948. Senzitivita jednotlivých letokruhových sérií sa pohybovala medzi 0,251–0,362. Priemerná hodnota senzitivity všetkých kriviek je 0,308. Dendrochronologickou analýzou sa zistili minimá šírok ročných kruhov v rokoch 1952, 1961, 1968, 1971, 1975, 1981, 1983, 1985, 1993, 2000, maximálne šírky ročných kruhov boli zaznamenané v rokoch 1951, 1957, 1959, 1967, 1974, 1979, 1982, 1984, 1989, 1999 (tab. 7). Sledovala sa závislosť rastu orecha čierneho reprezentovaného priemernou indexovou letokruhovou krivkou (PILK) a klimatickými cha-

rakteristikami (priemerná mesačná teplota vzduchu v °C, mesačný úhrn zrážok v mm, mesačný úhrn globálneho žiarenia v KWh/m$^2$, trvanie slnečného svitu v hodinách, vlhkosť vzduchu v %). Vplyv sledovaných klimatických charakteristík na PILK sa najviac pozitívne prejavil pri priemernej ročnej vlhkosti vzduchu a negatívny vplyv mesačného úhrnu globálneho žiarenia na konci vegetačného obdobia. Ďalší dendroekologický výskum orecha čierneho z viacerých plôch môže potvrdiť dobré aklimatizačné vlastnosti tejto teplomilnej a svetlomilnej dreviny na území Slovenska, ktorá má kvalitnú produkciu drevnej hmoty (suroviny) pre drevársky priemysel. Pre uvedené vlastnosti môže nájsť orech čierny širšie uplatnenie v lesníckej praxi v nižších vegetačných stupňoch Slovenska.

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