Structure, quality, production, LAI and dendrochronology of 100 years old Austrian pine (*Pinus nigra* ARNOLD*)* stand

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ABSTRACT: The paper evaluates the growth, structure, production, quality, leaf area index and dendrochronology of 100 years old Austrian pine (*Pinus nigra* ARNOLD) monoculture situated in the forest type group *Fageto-Quercetum* in the locality Horné Lefantovce (Nitrianska Streda Forest District, Topoľčianky Forest Enterprise). Codominant trees, trees with stem of high quality, with medium-sized crown, medium dense and straight crown are the most abundant in the stand. The tree number in the stand is 1,024 trees/ha, basal area 51.75 m^2/ha, growing stock 571.56 m^3/ha, aboveground biomass stock 348.76 t/ha and leaf area index 21.85 ha/ha. Dendrochronological analyses examined the response in individual sample trees and minimum annual ring width was found in 1920, 1922, 1925, 1929, 1933, 1938, 1944, 1946, 1947, 1949, 1952, 1954, 1963, 1968, 1976, 1982, 1990, 1993, 1998, 2001. Marked maximum values of annual ring width in the years 1919, 1923, 1926, 1930, 1936, 1937, 1941, 1948, 1951, 1955, 1959, 1966, 1972, 1975, 1980, 1985, 1997 were found as a positive productive feature. Beginning in the year 1993, dry Austrian pine trees occurred in the stand as a result of the fungal infection by *Sphaeropsis sapinea* (Fr.) Dyko et Sutton.

Keywords: *Pinus nigra* ARNOLD; structure; production; LAI; dendrochronology; *Sphaeropsis sapinea* fungus

In Slovakia the Austrian pine (*Pinus nigra* ARNOLD) is one of the most intensively utilised introduced woody plants. It is very often grown in towns and villages as a decorative species, and it is also quite abundant in Slovak forests where it plays an important role in amelioration and production. The most frequent was the planting of this species on degraded and devastated soils. The results of growing this species in the area of the Malé Karpaty Mts. (Paule, Réh 1975; Tokár 1981, 1985a,b, 1987) and the Tríbeč Mts. (Tokár 1989a,b) showed that it was possible to obtain highly productive mature stemwood of high quality at sites with forest types *Fageto-Quercetum, Querceto-Fagetum* and *Fagetum pauper*. In the context of global warming, we can suppose further increasing interest in the growing of this species (Beran, Šindelář 1996; Tokár 1999).

In this paper we present the development of the structure, growth, quality and production of 100 years old, homogeneous Austrian pine stand in the area of the Tríbeč Mts. The results of dendrochronological analyses allow us to conclude about the influence of climate factors on the trends of annual diameter increment over the last decades.

The study of the adaptation of introduced woody plants to conditions of this country is very important for an assessment of the influence of climatic conditions on the growth and production of the species growing outside their natural distribution range.

In their annual rings the trees "remember" the conditions governing in the environment during their diameter growth (Bitvinskans 1987).

The diameter growth of trees is differently influenced by a number of factors in the external environment and by their mutual interactions.

The width of annual rings depends on whether the tree metabolism is fully active (they are the relations between the tree metabolic rate and physiology and site ecological conditions). According to Schweingruber et al. (1986) this fact is reflected in high or low cambium activity in the individual years of the tree life.

MATERIAL AND METHODS

The permanent research plot PRP Lefantovce of the area 50 × 50 m was established in Stand No. 1114 in the territory of Nitrianska Streda Forest District, Topoľčianky Forest Enterprise. The stand age is 100 years, group of forest types *Fageto-Quercetum*, soil type is brown forest soil, stocking 0.7, southern exposure, stand composition Austrian pine 100%.

All trees growing on PRP have been numbered. The diameter at breast height (dbh) of each tree was measured with a metal calliper to the nearest 0.1 cm. The trees were divided into classes according to their status in the stand: Class 1 – dominant, Class 2 – codominant, Class 3 – subdominant, Class 4 – dominated.

The *stem quality* was classified according to the following three-point scale: Degree 1 – stem of high quality, straight, without knots, Degree 2 – stem of medium quality, curved only in the upper part, a small number of knots, Degree 3 – stem of poor quality, considerably curved, with a high number of knots.

The *crown quality* was assessed according to the following criteria:

a) Size: 1. medium (reaching up to 1/3 of the stem, appropriately wide), 2. large (reaching up to 1/2 of the stem, appropriately wide), 3. small (encompassing a too small part of the stem, too narrow)

Table 1. Basic characteristics of Austrian pine (*Pinus nigra* ARNOLD) monoculture on PRP Lefantovce in 2002, converted per 1 ha

Observed characteristics		
Age (years)		100
Stocking		0.7
Tree number		1,024
Basal area (m^2)		51.75
Mature growing stock (m^3)		571.56
Aboveground biomass stock (t)		348.76
Mean stem	dbh (cm)	24.73
	height (m)	23.9
	volume (m^3)	0.558
	aboveground biomass (t)	0.341
	needle area (m^2)	213.52
Leaf area index (ha)		21.85

b) Branch density: 1. medium dense, 2. dense, 3. thin

c) Type: 1. regular, coaxial with the stem up to the treetop, regularly distributed, 2. fork-shaped, 3. witches' broom, 4. considerably deformed, asymmetrical.

The numbers of trees belonging to the individual classes according to diameter, stem quality and crown quality were expressed in per cent.

Thirty trees were selected on PRP and measured with Blume-Leiss altimeter to the nearest 0.5 m. The values were substituted into Michajlov's equation, and the height graphical representation was constructed. From the diameter values, basal area (m^2) and stand volume (m^3) were calculated according to Schwappach's weight tables (Halaj 1963; Šmelko 2000) for the Austrian pine with the values converted per one hectare.

The aboveground biomass production was determined using the destructive method (sample trees). The total number of sample trees in the stand was determined as seven, according to the optimum area (stratified) selection (Šmelko 1963) (proportional to the weight and standard deviation in the tree classes and the required allowable error 8%).

On each sample tree, diameter at breast height (dbh), tree height, crown length and width were measured. The destruction analysis provided the following data: weight of stem, branches, twigs and needles (one to five years old). We used a KAMOR scale with the capacity of 50 kg and accuracy of 0.1 kg. The dry mass proportion was determined on the basis of three trees representing the tree classes. From the individual stem thirds, branches, twigs, needles and fruits of these trees representative samples were obtained that were oven-dried in the laboratory at 105°C. For the individual biomass components, the dry mass proportions corresponding to the bark were determined.

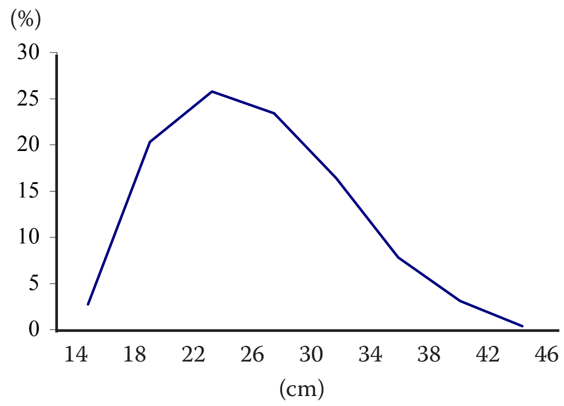

Fig. 1. Relative frequency of diameter classes in black pine (*Pinus nigra* ARNOLD) in the locality Horné Lefantovce

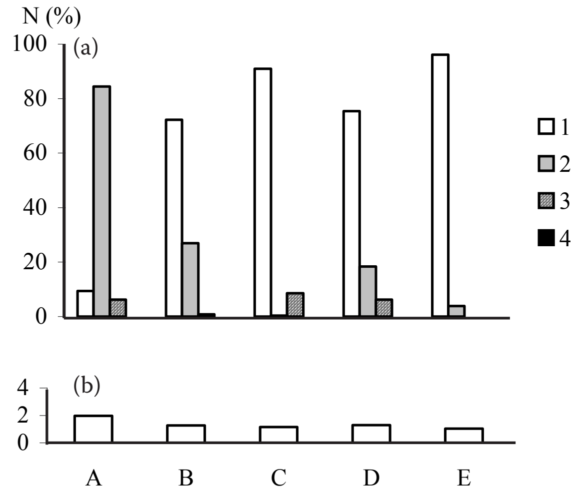

Fig. 2. The distribution of relative frequencies of black pine (a) and the expression of average values (b) in dependence on tree classes (A), stem quality (B), crown size (C), crown density (D) and crown type (E)

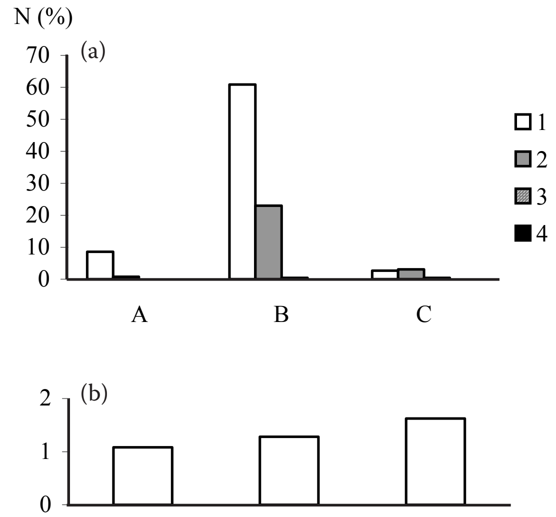

Fig. 3. The distribution of relative frequencies of stem quality (a) and of average values (b) in dependence on tree classes: 1. tree class (A), 2. tree class (B) and 3. tree class (C)

The photosynthetically active surface of needles on the Austrian pine was determined using Burger's rule, according to which a 1g amount of green weight of Austrian pine needles has a surface of 55 cm^2 (Polster 1950 in Steinhubel 1973). The suitability of this rule in our conditions was justified by Steinhubel (1973).

Dendrochronology was examined using 15 trees in total. The selection of sample trees was performed on the basis of tree classes (dominant and codominant trees), considering also the diameter structure of the stand. From each of the selected trees we sampled with Pressler's sampler an increment core at the diameter at breast height (dbh). The drill directions were different in different trees. The samples were labelled, glue-fixed onto wood boards and processed. The width of annual rings was measured with a digital positiometer, functioning in the framework of the DAS (Digital Analysis System, Janíček 1991) installed at the Faculty of Forestry of the Technical University in Zvolen. The dating of the separate annual ring series – synchronisation, filtering of the aging trend (standardisation) and the calculation of annual ring indexes were accomplished using the above-mentioned DAS system (Janíček 1991). The measured values of annual ring width were fitted with Hugershof's function and a polynomial of the 4th degree.

Climatic characteristics, data on atmospheric precipitation such as monthly sums and air temperatures such as mean monthly temperatures were obtained from a rainfall station at Horné Lefantovce and a climatic station at Hurbanovo, respectively.

RESULTS

Number of trees, diameter and height structure of stand

The stand comprises 1,024 Austrian pine trees per 1 ha (Table 1). In terms of diameter structure, the stand is a mature pole stand stemwood with the average stem diameter dbh = 24.73 cm. The most frequent diameter classes in the stand are (Fig. 1) 22 and 26 cm (25.78%, 23.44%). The most frequent height class (Fig. 2A) are codominant trees (84.38%), the proportion of dominant trees is 9.37%, of subdominant 6.25%, and dominated trees are not present at all. The average tree height is 23.9 m.

Quality of stem and crown

The most frequent in the stand (Fig. 2B) are trees with stems of high quality (72.27%), the proportion

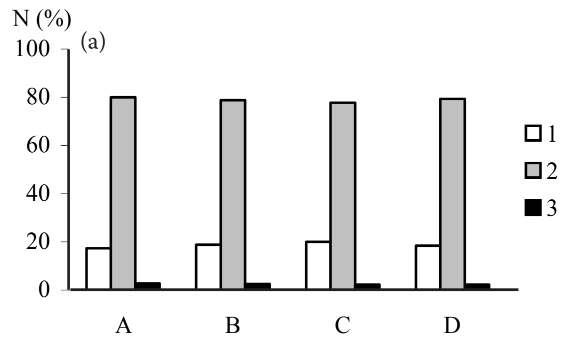

Fig. 4. The distribution of relative frequencies (a) in dependence on the basal area (A), volume production (B), aboveground biomass (C) and LAI (D) in tree classes (1, 2, 3)

of trees with stem of intermediate quality is 26.95% and the trees with stem of low quality account for 0.78%.

According to the crown size (Fig. 2C), the most frequent are trees with medium-sized crown (91.02%); the least frequent are trees with large crown (0.39%). The average crown size is 1.17. The majority of dominant trees has medium-sized crown, similarly like codominant trees. The intermediate trees have small crown in general.

As for the crown density (Fig. 2D), the Austrian pine growing in mature stemwood monocultures mostly creates medium dense crowns (75.39%), less frequent are dense crowns (18.36%) and the scarcest are thin crows (6.25%). Dominant and codominant trees most frequently have dense crowns, intermediate trees thin crowns. The mean crown density is 1.31.

According to the crown type (Fig. 2E), the most frequent are trees with regular crown (96.09%). The proportion of trees with fork-shaped crown is 3.91%. The average value of crown type in the stand is 1.04. Trees with regular crowns are prevailing in all the classes.

Examining the dependence of stem quality on the tree class (Fig. 3), we found the highest quality of stems in dominant trees (8.59%) and in codominant trees (60.94%). The mean stem quality in these classes was 1.08 and 1.28, respectively. The lowest (1.62) was the quality of subdominant trees.

Examining the relation between the quality of stem and the quality of crown, we found the highest quality in stems of crowns with medium-sized or large crowns, medium dense or dense, regularly shaped. The trees with small, thin, irregular crowns had stems of only intermediate quality.

Basal area, volume and weight production

The 100 years old Austrian pine stand had the basal area of 51.75 m^2 (Table 1), with the majority of trees (Fig. 4A) in the second tree class (79.91%).

Table 2. Results of dendrochronological analysis on Austrian pine (*Pinus nigra* ARNOLD) sample trees in Horné Lefantovce

	Max	Min	Average
Age	96	79	90
Value of annual ring width	5.82	0.12	1.38
Sensitivity	0.382	0.275	0.318
Autocorrelation 1st degree	0.904	0.409	–
Mean correlation	–	–	0.454
Interval trend	–	–	69%
Signal/noise rate	–	–	12.461
Expressed population signal	–	–	0.926

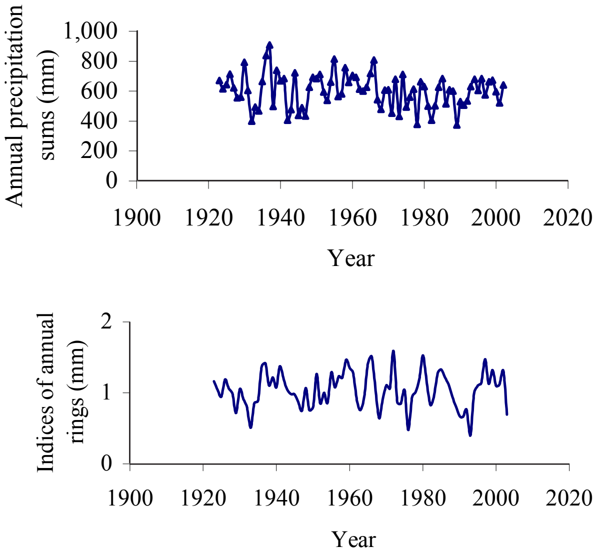

Fig. 5. Indices of the radial growth of *Pinus nigra* ARNOLD in Horné Lefantovce and annual precipitation sums in mm (1923–2002)

The growing stock of large timber in the stand is 571.56 m^3/ha (Fig. 4B), the highest proportion 78.72% (449.92 m^3/ha) is represented by codominant trees. The proportion of dominant trees is 18.82% (107.6 m^3/ha) and of dominated 2.46% (14.04 m^3/ha). The aboveground biomass stock is 348.76 t/ha (Fig. 4C) while the second tree class accounts for the largest proportion (77.75%); the first class accounts for 19.99% (69.73 t/ha) and the third for 26% (7.89 t/ha).

Table 3. Number, maximum, minimum and mean value of the width of annual rings in examined Austrian pine trees (*Pinus nigra* ARNOLD)

Sample tree	Tree number on PRP	Max	Min	Mean
1	82	4.68	0.35	1.439
2	88	2.55	0.22	1.257
3	88	4.98	0.12	1.918
4	94	4.98	0.22	0.983
5	92	4.02	0.52	1.559
6	79	3.63	0.64	1.610
7	92	5.82	0.28	1.058
8	94	5.06	0.17	1.025
9	88	4.70	0.55	1.880
10	89	2.98	0.27	0.964
11	92	4.35	0.30	1.226
12	90	5.60	0.44	1.520
13	93	5.82	0.31	1.571
14	93	2.02	0.22	1.010
15	95	5.82	0.48	1.660

Table 4. Chronology of radial growth of *Pinus nigra* ARNOLD in Horné Lefantovce

Year	0	1	2	3	4	5	6	7	8	9
1920	1.41	1.64	1.34	2.05	1.69	1.50	1.81	1.56	1.44	1.02
1930	1.43	1.19	1.02	0.64	1.04	1.05	1.66	1.68	1.27	1.41
1940	1.23	1.54	1.34	1.17	1.09	1.10	0.98	0.83	1.18	0.82
1950	0.88	1.39	0.91	1.09	0.94	1.42	1.20	1.38	1.37	1.68
1960	1.57	1.47	1.03	0.88	1.11	1.66	1.75	1.27	0.76	1.06
1970	1.37	1.30	1.97	1.05	1.05	1.29	0.62	1.19	1.28	1.51
1980	1.93	1.51	1.08	1.24	1.67	1.68	1.49	1.40	1.19	1.04
1990	0.85	0.81	0.92	0.49	1.26	1.41	1.49	1.83	1.34	1.49
2000	1.20	1.10	1.14							

Leaf area index

The examined 100 years old Austrian pine mature stemwood monoculture with stocking 0.7 has the leaf area index (Table 2) 21.85 ha/ha (Fig. 4D): the first tree class 18.49% (4.04 ha/ha), the second 79.22% (17.31 ha/ha) and the third 2.29% (0.50 ha/ha).

Corresponding to the needle age we obtained the following representation: one year old 27.54% (6.02 ha/ha),two years old 50.40% (11.01 ha/ha), three years old 19.01% (4.15 ha/ha), four years old 3.00% (0.66 ha/ha) and five years old 0.05% (0.01 ha/ha).

Dendrochronological analyses

Dendrochronological analyses performed on 15 Austrian pine sample trees revealed responses of individual trees to the changing environmental conditions as well as to the concrete conditions for the tree growth. The minimum annual ring width 0.12 mm was measured in sample tree 3, the maximum annual ring width 5.82 mm in tree 13 (Table 2). The average number of annual rings in a series was 90, maximum 96, minimum 79. The mean sensitivity of the individual annual ring curves was 0.318. The Austrian pine is a woody plant with low moisture demands, tolerating also dry sites. For this reason, it can also be supposed to resist to the expected climate change. The minimum width of annual ring in the individual sample trees ranged between 0.12 to 0.64 mm. The average value of this parameter was (Table 3) 0.964–1.918 mm. The maximum value was 2.55–5.82 mm.

Negative years that means the years with narrower rings were: 1920, 1922, 1925, 1929, 1933, 1938, 1944, 1946, 1947, 1949, 1952, 1954, 1963, 1968, 1976, 1982, 1990, 1993, 1998, and 2001 (Fig. 5).

Positive years that means the years with more distinct rings were: 1919, 1923, 1926, 1930, 1936, 1937, 1941, 1948, 1951, 1955, 1959, 1966, 1972, 1975, 1980, 1985, 1997.

The reduction in growth increment was identified in the years 1927–1929, 1931–1933, 1942–1944, 1960–1963, 1967–1968 and mainly in 1986–1990.

Restoration periods followed in 1934–1937, 1964–1966, 1969–1972, 1977–1980, 1983–1986 and 1994–1997.

Correlation coefficient between annual sums of precipitation and mean indices of annual ring curve in the years 1923–2002 was 0.47.

Correlation coefficient between sums of precipitation for a warm half-year (April to September) and mean indices of annual ring curve was 0.61.

Correlation coefficient between monthly sums of precipitation and mean indices of annual ring curve during the vegetation period showed lower values: for June 0.42, July 0.41 and for August only 0.12. At the beginning of vegetation period the diameter radial growth of black pine was also in moderate correlation with sums of monthly rainfalls in March, April and May. The respective correlation coefficients were 0.26; 0.29 and 0.33.

Correlations between the mean index curve and mean monthly temperatures were much lower than the respective correlations involving the sum of precipitation and exhibited a negative pattern (correlation coefficient = –0.24), which points to a negative but very low effect of air temperatures on diameter growth during the period April–September.

The highest coefficient of correlation between mean index curve and mean monthly air temperature was calculated for July (r = –0.22) and August (r = –0.24).

Tree number reduction

In the last years, we recorded on PRP the occurrence of dry pine trees requiring a removal of 264 trees from one-hectare area. The highest numbers of dry trees were in the second and in the third tree class (128 and 124 trees/ha, resp.) in diameter class 18 (104 trees/ha). The drying of the Austrian pine on the plot is caused by the fungus *Sphaeropsis sapinea* (Fr.) Dyko et Sutton, syn. *Diplodia pinea* (Desm.) Kicks. (Kunca 2002). The cut trees had a basal area of 7.99 m^2/ha, growing stock 84.48 m^3/ha, weight 48.25 t/ha and LAI 3.01 ha/ha.

DISCUSSION

Austrian pine belongs to important exotic species, the introduction of which can increase the production capacity of forest stands, mainly in the oak, beech-oak and oak-beech forest vegetation zones. The results of growing this species in the area of the Malé Karpaty Mts. (Paule, Réh 1975; Tokár 1985a,b, 1991) revealed the highest production mainly in mixed stands containing the proportion of Austrian pine up to 30%, growing in the groups of forest types (ftg) *Fageto-Quercetum* (FQ), *Querceto-Fagetum* (QF) and *Fagetum pauper* (Fp). In the Tríbeč Mts., high production is also in Austrian pine monocultures (Tokár 1989a,b). Comparison of growth and production with the corresponding values obtained in the natural distribution range of this species (Petri 1961 in Holubčík 1968) resulted in a smaller height growth and equal volume production. The growing stock in the Austrian pine stands in the Malé Karpaty Mts. reaches high values comparable with the values of the most productive stands in the natural distribution area of this species. Paule and Réh (1975) found in a 110 years old mixed stand of beech and Austrian pine in QF ftg in the Malé Karpaty Mts. the growing stock 708 m^3/ha with majority of Austrian pine trees (72.63%, 514.6 m^3/ha).

The results of a survey of the species in the Malé Karpaty Mts. revealed that to achieve higher production and higher stem quality in Austrian pine requires to grow it in mixed stands with the autochthonous woody plants in two-storey and three-storey stands. The pine admixture should not exceed 30% (Tokár 1985a,b, 1991).

The results of our study also showed highly productive Austrian pine monocultures in the Tríbeč Mts., reaching at the age of 86 years (Tokár 1989a,b) and 100 years higher values than the monocultures in the Malé Karpaty Mts. (by 48.7% and 84%, resp.), and even by 23% higher values than the most productive mixed stands containing the discussed species in the QF ftg.

The aboveground biomass production has been documented in literature only by scarce data. The data recorded by Ovington (1957) in England for artificially established Austrian pine stands aged 18–22 years were 122.38–173.87 t/ha. For the natural stands of this species at the age of 18 and 28 years, Wright and Will (1958 in Vyskot 1973) reported the values of total aboveground biomass 25.76 to 68.32 t/ha. Tokár (1981) determined the total aboveground biomass value of 40.21 t/ha for an 18 years old monoculture in the Malé Karpaty, FQ ftg.

The amount of aboveground biomass production depends on a number of factors (ecological, genetic), phytotechnology of forest stands, etc. It is not possible to compare stands and to neglect the relevant factors.

According to Wendelberger (1962 in Holubčík 1968) the key environmental factors controlling the natural occurrence of Austrian pine are minimum soil moisture content and minimum air humidity.

Holubčík (1968) reported that the Austrian pine is a species associated with climate with warm summers. It has high heat demands in summer and it is equally resistant tot cold. However, its tolerance to harsh winters is lower. On the other hand, it has lower demands on air humidity and soil quality.

The Austrian pine reaches a high leaf area index already at young age. Tokár (1981) gave the value of this parameter 11.05 ha/ha found in 18 years old Austrian pine monoculture and 20.99 ha/ha for 86 years old stemwood monoculture in the Tríbeč Mts. (Tokár 1989b). No values of LAI in the Austrian pine can be found in foreign literature. For 17 and 20 years old stands of Scotch pine Ovington (1957) reported LAI of 9.3 and 10.8 ha/ha.

Dendrochronological analysis confirmed the results obtained by several authors according to whom the growth of woody plants is dependent on a number of environmental factors: species, ecological requirements, site conditions (Šmelko et al. 1992, 1996). According to Šály and Fiedler (1998), the metabolic processes in the Austrian pine take place under lower nutrient contents than in the Scotch pine.

This finding was also supported by Paulen (1992), who performed dendrochronological analyses in the Mlyňany Arboretum. The author found that the Scotch pine responded more sensitively to changes in the environment, mainly in precipitation, than the Austrian pine.

The Austrian pine and its geographical varieties in the Forest Arboretum Kysihýbel, Holubčík (1968), got over difficulties connected with critical winters 1928/1929, 1955/1956 and 1962/1963 in the same way as the Scotch pine. In the dendrochronological analysis, this fact was evident on minimum ring widths in 1929, 1956 and 1963.

In addition to the studied species in 1987–1993, the beginning of ring width reduction was also observed by Dimitrov et al. (2003) in beech, in which the annual ring width in 1988–1994 decreased to 0.27 and 0.28 mm.

The year 1960/1961 was in Slovakia, similarly like in many other European countries, characterised by drought damage to Austrian pine trees and the damage caused by *Cenangium ferruginosum* (Holubčík 1968).

Rigling and Cherubini (1999) recorded the occurrence of *Cenangium ferruginosum* in Austria where the fungus was identified as the main factor causing the dieback of pine trees in the country. The presence of the fungus was coupled with drought – identified as a predisposition factor.

Ďurský (1990) and Šmelko et al. (1996) reported that the changes in annual ring series responded to the following factors: decrease in groundwater level, permanent water-logging, long drought, nutrient deficiency, changes in light conditions (changes in tree bio-sociological status), mechanical damage to stem, crown and roots, human-induced damage (exhaust gases, acid rain, soil compaction, damage to roots).

In the studied sample trees of Austrian pine we could identify a distinct response to the external climate factors: to possible desiccation damage in spring mainly in the years 1987–1993 and to periods of drought (remarkably dry years 1990, 1992, 1993), triggering the activation of biotic pests – fungi.

It is necessary to mention that the studied 100 years old Austrian pine stand (90 + 10) has already reached the period of natural retardation of the rate of diameter increment – due to its age (natural trend is: at the beginning the diameter increment increases with the age, then the rate reaches the peak – according to the species and the site, and finally it decreases with the age of the tree).

The dieback of Austrian pine trees caused by the fungus *Sphaeropsis sapinea* in Southern Moravia was also reported by Jankovský and Palovčíková (2003). The authors also demonstrated symptoms of a decrease in diameter increment in Austrian pine trees on an example of three growing localities. As a predisposition factor, they identified dry years. This finding is consistent with the results of our dendrochronological analyses. In forestry, drought has been considered an important environmental factor in forest ecosystems (Faško et al. 2003).

Water deficit can be observed on a reduction of annual ring increments (Jankovský, Palovčíková 2003). Our results also proved that the black pine showed a minimal width of annual rings in so called dry years (e.g. 1993).

It is anticipated that climatic changes will bring, with a high certainty, a general increase in long-term means of air temperatures to our territory, but the fluctuation of daily temperatures will not change substantially. It means that the air temperature will irregularly fluctuate around the mean and in 2075 it will be higher by 2 to 4°C than increment years. As for rainfalls it is a more complex problem, but in future, with higher certainty than at present, there will occur long periods with rainfall deficits and short periods with very intensive rainfalls. We can say that the weather course in summer during the last 14 years has been in accordance with the scenario of climatic change, it has even surpassed this scenario as we had weather that was anticipated as late as about 2030 (Lapin in Faško et al. 2003).

CONCLUSION

The paper evaluates the growth, structure, production, quality, dendrochronology and leaf area index in 100 years old monoculture of Austrian pine (*Pinus nigra* ARNOLD) in the forest type group *Fageto-Quercetum*, forest type 2304 – melic grass oak-beech forest with wood rush in the Tríbeč Mts. (Horné Lefantovce locality, Nitrianska Streda Forest District, Topoľčianky Forest Enterprise). The stand consists of Austrian pine trees at an amount of 1,024 trees/ha. According to the individual classification categories, the most abundant are codominant trees (84.38%), trees with stem of very high quality (72.27%), with medium-sized crown (91.02%), medium dense crown (75.39%) and regular crown (96.09%).

The stand has a basal area of 51.75 m^2/ha, growing stock of large timber 571.56 m^3/ha, aboveground biomass stock 348.76 t/ha and leaf area index (LAI) 21.85 ha/ha. In all these categories the proportion of codominant trees was highest.

Dendrochronological analysis identified the ring width minima in the years 1920, 1922, 1925, 1929, 1933, 1938, 1944, 1946, 1947, 1949, 1952, 1954, 1963, 1968, 1976, 1982, 1990, 1993, 1998, 2001.

The maxima were in the years 1919, 1923, 1926, 1930, 1936, 1937, 1941, 1948, 1951, 1955, 1959, 1966, 1972, 1975, 1980, 1985, 1997.

The mean width of annual rings in the individual sample trees ranged from 0.96 to 1.88 mm, mean interval trend was 69%, mean sensitivity 0.318.

The minimum width of annual rings ranged between 0.12 and 0.64 mm, the maximum 2.55 to 5.82 mm.

The measured data also reflected individual responses of the individual trees (sample trees) to growing conditions in the studied years.

Reported is also dieback of Austrian pine caused by the fungus *Sphaeropsis sapinea* (Fr.) Dyko et Sutton.

The effect of the mean monthly air temperatures on diameter growth of black pine during the period 1923–2002 was not as marked as the effect of monthly sum of precipitation mainly in the vegetation period. Correlation coefficient between mean index curve of black pine and monthly sum of precipitation in so called warm half-year (April to September) reached the value 0.61. Droughts might affect the health condition of black pine negatively. In the years with the very low amount of rainfalls (1968, 1993, 2000) the minimal annual rings widths were obtained. Further research on the relationship between annual ring curves of black pine and climatic factors during the last decades of its growth might help to know an impact of climatic extremes during the last years. The exact proportion of particular environmental factors causing damage in black pine has not been known until now. Climatic factors as well as climatic extremes of the last years may tentatively be considered as primary reasons for the lower vitality of black pine.

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Vývoj štruktúry, kvality, produkcie a dendrochronológie 100-ročného rovnorodého porastu borovice čiernej (*Pinus nigra* ARNOLD)

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ABSTRAKT: Práca zhodnocuje rast, štruktúru a produkciu, kvalitu, dendrochronológiu a index listovej plochy 100-ročného nezmiešaného porastu borovice čiernej (*Pinus nigra* ARNOLD) v skupine lesných typov *Fageto-Quercetum*, lesný typ 2304 – medničková buková dúbrava s chlpaňou z oblasti pohoria Tríbeč (lokalita Horné Lefantovce, Lesná správa Nitrianska Streda, Lesný závod Topoľčianky). V 100-ročnej dospelej kmeňovine rastie 1 024 stromov/ha borovice čiernej. Porast dosahuje kruhovú základňu 51,75 m^2/ha, objemovú zásobu hrubiny 571,56 m^3/ha, zásobu nadzemnej dendromasy 348,76 t/ha a index listovej plochy (LAI) 21,85 ha/ha. Najvyšší podiel všetkých ukazovateľov pripadá na úrovňové stromy. Dendrochronologickou analýzou 15 vzorníkov boli stanovené minimálne (0,12–0,64 mm), maximálne (2,55–5,82 mm) a priemerné (0,96–1,92 mm) šírky letokruhov, priemerný intervalový trend (69 %) a priemerná senzitivita (0,318). Za predispozičný faktor poškodenia porastu hubou *Sphaeropsis sapinea* (Fr.) Dyko et Sutton syn. *Diplodia pinea* (Desm.) Kicks možno na základe dendrochronológie označiť sucho.

Kľúčové slová: *Pinus nigra* ARNOLD; štruktúra; produkcia; LAI; dendrochronológia; huba *Sphaeropsis sapinea*

V poraste rastie 1 024 ks/ha borovice čiernej. Z hľadiska hrúbkovej štruktúry ide o 100-ročný porast borovice čiernej vo fáze kmeňoviny s hodnotou stredného kmeňa $d_{1,3}$ = 24,73 cm a výšky 23,9 m. V poraste sú najviac zastúpené úrovňové stromy (84,38 %), nadúrovňové stromy (9,37 %) a vrastavé stromy (6,25 %), podúrovňové stromy úplne chýbajú. Z hľadiska kvality kmeňa sú v poraste najviac zastúpené stromy s veľmi kvalitným kmeňom (72,27 %), stromy s priemerne kvalitným kmeňom sú zastúpené 26,95 % a stromy s nekvalitným kmeňom 0,78 %.

Z hľadiska kvality koruny vytvára borovica čierna v nezmiešanej 100-ročnej kmeňovine najviac koruny stredne veľké (91,09 %), stredne husté (75,39 %) a pravidelné (96,09 %). Nadúrovňové a úrovňové stromy majú kmene najlepšej kvality a koruny stredne veľké, stredne husté a pravidelné.

Porast dosahuje kruhovú základňu 51,75 m^2/ha, objemovú zásobu hrubiny 571,56 m^3/ha a zásobu nadzemnej dendromasy 348,76 t/ha, index listovej plochy 21,85 ha/ha, pričom najvyšší podiel pripadá na 2. stromovú triedu (41,35 m^2/ha, 449,92 m^3/ha, 271,16 t/ha, 17,31 ha/ha). Na indexe listovej plochy sa najvyšším podielom (50,40 %) zúčastňujú ihlice 2. ročníka (11,07 ha/ha).

Pri dendrochronologickej analýze 15 vzorníkov borovice čiernej sa šírky letokruhov u všetkých vzorníkov pohybovali od 0,12 do 5,82 mm. Priemerná šírka letokruhov je od 0,96 do 1,92 mm. Priemerná senzitivita letokruhových kriviek je 0,318. Redukcia hrúbkového prírastku sa zistila v rokoch 1927–1929, 1931–1933, 1942–1944, 1960–1963, 1967–1968, 1986–1993. Zotavenie nasledovalo v rokoch 1934–1937, 1964–1966, 1977–1980, 1983–1986 a 1994–1997.

V dôsledku poškodenia hubou *Sphaeropsis sapinea* (Fr.) Dyko et Sutton syn. *Diplodia pinea* (Desm.) Kicks. bolo vyschnutých 264 ks/ha borovice čiernej, najviac z 2. a 3. stromovej triedy (128, resp. 124 ks/ha). Vyrúbané stromy mali kruhovú základňu 7,99 m^2/ha, zásobu objemu 84,48 m^3/ha.

Vplyv priemerných mesačných teplôt v sledovanom období 1923–2002 na hrúbkový rast borovice čiernej nebol tak výrazný ako jeho závislosť na mesačnom úhrne zrážok, a to najmä zrážok vo vegetačnom období. Korelačný koeficient nadobudol hodnotu 0,61 medzi priemernou indexovou krivkou borovice čiernej a sumou mesačného úhrnu zrážok v tzv. teplom polroku (apríl až september) v priebehu obdobia hrúbkového rastu. Dopad sucha mohol mať nepriaznivý vplyv na oslabenie vitality borovice čiernej, minimálne šírky letokruhov v rokoch chudobných na atmosférické zrážky sú toho dôkazom (1968, 1993, 2000). Ďalšie výskumy závislostí letokruhových kriviek borovice čiernej a klimatických faktorov v posledných desaťročiach jej rastu pred vypuknutím poškodenia pomôžu nájsť hlbšie súvislosti dopadov klimatických extrémov posledných rokov. Dodnes nie je známy presný podiel jednotlivých faktorov vonkajšieho prostredia, ktoré sa prejavili ako stresory poškodenia borovice čiernej. Klimatické faktory ako aj klimatické extrémy posledných rokov je potrebné považovať predbežne za primárne príčiny oslabenia vitality borovice čiernej, ktoré synergicky pôsobia na rozšírenie poškodenia tejto dreviny hubou *Sphaeropsis sapinea* (Fr.) Dyko et Sutton syn. *Diplodia pinea* (Desm.) Kicks.

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