Selected properties of European beech (*Fagus sylvatica* L.)

V. Gryc, H. Vavrčík, Š. Gomola

Faculty of Forestry and Wood Technology, Mendel University of Agriculture and Forestry in Brno, Brno, Czech Republic

ABSTRACT: The paper deals with the variability of tree-ring width, with the density and swelling (volumetric swelling and swelling in individual anatomical directions) of wood from two different locations. Further, the variability of the explored properties along the stem radius is researched. The ring analyses show that the ring width decreases along the stem radius from the pith to the stem outer perimeter. Location 2 (a lower altitudinal vegetation zone) had on average wider rings (a statistically insignificant difference), higher density and higher volumetric swelling of wood in comparison with location 1 (a statistically significant difference). The relation between volumetric swelling and wood density has been confirmed. The results show that the wood density and its volumetric swelling change along the stem radius. With the increasing wood density the volumetric swelling also increases. The average density of beech wood from both locations is 752 kg/m^3 with moisture content of 12%.

Keywords: beech wood; ring width; density; swelling

The European beech (*Fagus sylvatica* L.) is one of the most important deciduous commercial tree species not only in the Czech Republic but also in the other countries of Central Europe. In 2005 the area representation was 6.7% of the total area of the Czech and Moravian forests (Forest and Forest Management Report of the Czech Republic 2006).

Wood is a significant renewable raw material and many industrial fields, besides forestry and wood industry, depend on it. In contrast to other industrial raw materials, wood has the advantage to be renewable. It is important to remember that wood is a natural material with a very variable structure and properties. Its structure and properties are determined during the tree growth (Gryc, Horáček 2004).

Beech wood is from the category of deciduous wood species with diffuse-porous wood structure, i.e. there are only microvessels (dimensions of 8–45–85 µm; Wagenführ 2000) which are placed in the wood as separate ones or in radial groups. The number and the size of the vessels decrease from early-wood to late-wood. The basic tissue of the beech wood is mainly formed by libriform fibres. Homogeneous rays are of two sizes: the wide rays (multilayered) are placed in regular intervals (0.5 to 1 mm), the narrow and very narrow rays are irregularly scattered (Grosser 1977; Wagenführ 2000).

Wood density, which significantly affects most physical and mechanical wood properties, can be considered as the basic indicator of wood quality. The average wood density of beech ranges around 720 kg/m^3 with the moisture content of 12% (Kollmann 1951; Lexa et al. 1952; Trendelenburg 1955; Cividini 1969; Janota, Kurjatko 1978; Alden 1995; Požgaj et al. 1997; Wagenführ 2000; Bectaş et al. 2002; Frühwald et al. 2003; Blass et al. 2005; Mišíková 2006; Popović et al. 2006). The beech wood density decreases along the stem radius (from the centre to the peripheral parts) and with the altitude (Govorčin et al. 2003).

When the wood moisture content changes within the range of bound water content, the wood is sub-

Supported by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. MSM 6215648902.

ject to dimensional changes. The changes in the wood moisture content above the hygroscopicity limits (change in free water content) have no significant effect on the changes in dimensions. The shrinkage and swelling (the release or the absorption of bound water) are localized in the cell wall where parting (the process of swelling) or closing (the process of shrinkage) of fibrils in the fibrillar structure occurs. In linear swelling and shrinkage, the anisotropic character is demonstrated by different values in individual directions. The change in dimensions is the smallest in the longitudinal direction – 0.1–0.4%. In the transversal direction the wood swells and shrinks more, in the radial direction it is by 3–6%, in the tangential direction by 6–12%. The swelling in individual anatomical directions can be expressed by the following ratio: $\alpha t{:}\alpha r{:}\alpha l$ = 20:10:1 (Niemz 1993; Požgaj et al. 1993; Niemz, Sonderegger 2003).

The present paper deals with the variability of ring width, with the density and swelling of beech wood in dependence on the locations of different altitudinal vegetation zones. Another aim was to examine the ring width, density distribution and wood swelling along the stem radius.

MATERIAL AND METHODS

Two locations were chosen for sampling. Both of them are in the cadastral area of the Rajnochovice village. They are contained within Natural Forest Area 41 – the Hostýn-Vsetín Highlands and the Javorník Highlands – and within the supra-regional biocentre Kelečský Javorník.

Location No. 1 – stand 102 B 06

The total area of the stand is 11.4 ha. The area is a 12.5° (27%) slope oriented towards the north or north-west. The average altitude is 560 m above sea level. The forest is structured into groups. The dominant tree species is European beech (*Fagus sylvatica*) – 55%, there is a smaller proportion of Norway spruce (*Picea abies*) – 40%, an admixed tree species is ash (*Fraxinus excelsior*), disseminated tree species are sycamore (*Acer pseudoplatanus*) and European alder (*Alnus glutinosa*). The prevailing forest type is 5B1.

Location No. 2 – stand 201 C 09

The total area of the stand is 5.29 ha. The forest grows on a slope of 7.5° (16%) on average oriented towards the north, structured by gullies. The average altitude is 460 m above sea level. The forest is structured into groups with a significant dominance of European beech (*Fagus sylvatica*) – 53%, a smaller proportion of Norway spruce (*Picea abies*) – 45%, an admixed tree species is European alder (*Alnus glutinosa*), which depends on the stream flowing in one of the gullies. The disseminated tree species here are sycamore (*Acer pseudoplatanus*), oak (*Quercus* sp.), small-leaved lime (*Tilia cordata*) and ash (*Fraxinus excelsior*). The area is in the 3rd altitudinal vegetation zone, the prevailing forest type is 3B8.

30 trees were chosen in each of the locations. Before felling, the northern part of the stem was marked. A log about 30 cm long was taken out of each stem (at the height of 0.5 m). The transverse cuts were used to measure ring width values using a stereo magnifying glass Nikon SMZ 660 with a special test desk TimeTable.

The section was used to make a central block with an N-S orientation. Then, sample pieces of 20 × 20 × 30 mm were made out of the block. The pieces were marked by letters in an ascending order (A, B, C,…) in the direction from the stem periphery to the centre (i.e. the samples marked A were the closest to the cambium); then the pieces were marked with two digits. The first digit means the rank of the piece in the direction of rings, the second digit shows the rank of the piece in the direction of the stem axe.

Wood density was examined in compliance with ČSN 49 0108 norm. The density was found out for the moisture content of 12%. The swelling (volumetric swelling and swelling in individual anatomical directions) was examined in compliance with ČSN 49 0126 norm. The maximum linear and volumetric wood swelling was found out.

RESULTS

Ring analysis

The ring analysis showed that the found average age of trees from both locations was considerably different from the age of the forest stated in the forest management book. For location 1 – forest 102 B 06, the age of the forest is 57 years according to the Forest Management Plan, whereas the average age of the measured trees was 83 years. For location 2 – forest 201 C 09, the age according to the Forest Management Plan is 88 years but the real average age of the measured trees was 75 years. Therefore, we can say there are mistakes in the Forest Management Plan and these are also manifested in typological mapping (e.g. continuous character of the 3rd and the 5th vegetation zones). The average ring width in location 1 was 1.86 mm. The average ring width

Table 1. The descriptive statistics of the average ring width in the locations

	Mean (mm)	Minimum (mm)	Maximum (mm)	Standard deviation (mm)	Coefficient of variation (%)
Location 1	1.86	0.45	3.13	0.55	29.56
Location 2	2.07	0.91	4.02	0.78	37.48

Table 2. The descriptive statistics of wood density (w = 12%)

	N	Mean (kg/m³)	Minimum (kg/m³)	Maximum (kg/m³)	Standard deviation (kg/m³)	Coefficient of variation (%)
Location 1	289	736.56	670.15	841.16	26.98	3.66
Location 2	300	768.51	664.27	912.15	52.04	6.77

in location 2 was 2.07 mm (see Table 1 and Fig. 1). Statistical examination did not show any statistical differences in the mean value of ring width between the researched rings.

Wood density

The average wood density found out in location 1 was 737 kg/m^3. In location 2 it was 767 kg/m^3. The descriptive statistics of the wood density in both locations is shown in Table 2. Statistical examination rejected the zero hypothesis of the influence of individual locations on the wood density ($P < 0.05$). It means there is a statistically significant difference in the wood density between the two locations. Fig. 2 shows the variability of wood density along the stem radius. It is obvious that the wood density slightly increases in the direction from the cambium (A) to the stem centre (H). We can also see that the wood density variability in individual sections is higher in the second location than in the first location. Statistical examination did not show any statistical difference in the mean value of wood density between the northern and the southern parts of the stem (valid for both locations; $P > 0.05$).

Wood swelling

Because wood is an anisotropic hygroscopic material, the dimensional changes (wood swelling) were researched in all the anatomical directions (radial, tangential and longitudinal). The descriptive statistics of volumetric swelling and swelling in the individual anatomical directions is presented in Table 3. The results show that wood swells the least in the longitudinal direction. The average values of swelling in the direction along fibres were 0.49 % in location 1 and 0.59% in location 2. The coefficient of variation for the longitudinal wood swelling is very high, which can be explained by small dimensional changes that cannot be measured precisely. No change in the value of the longitudinal swelling along the stem radius was observed. In the transversal plane, wood swelled less in the radial direction and

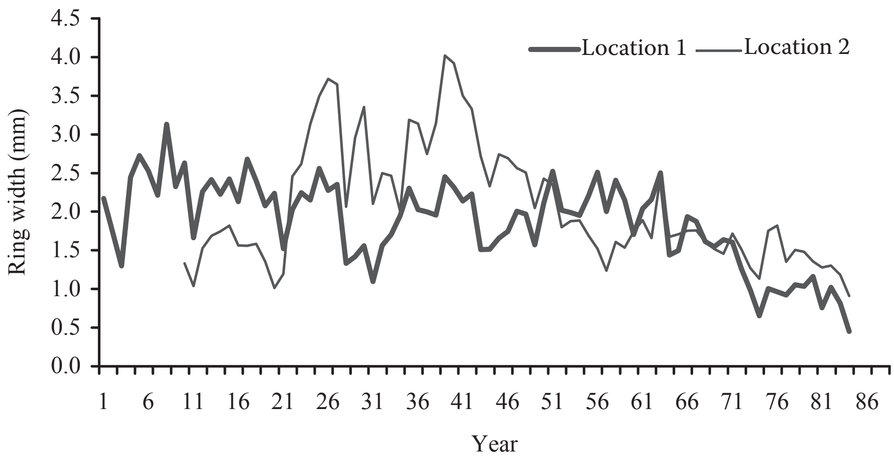

Fig. 1. A comparison of the average curve of ring widths in the locations

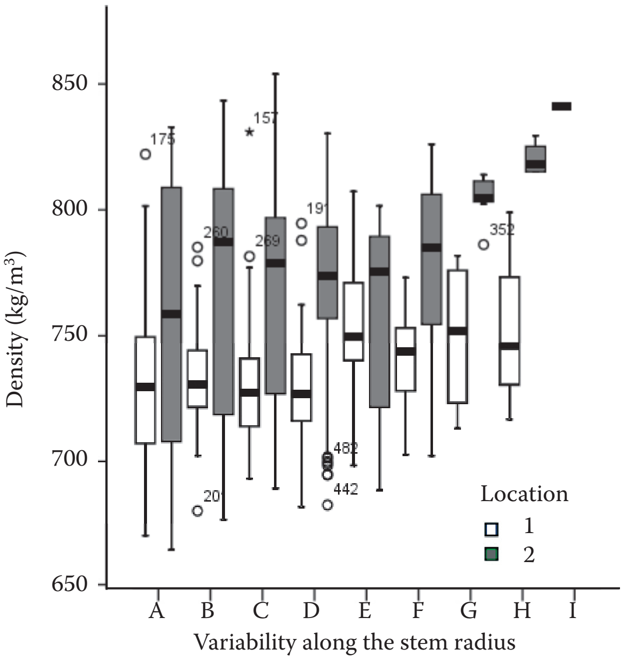

Fig. 2. A box plot – the variability of wood density along the stem radius for individual locations

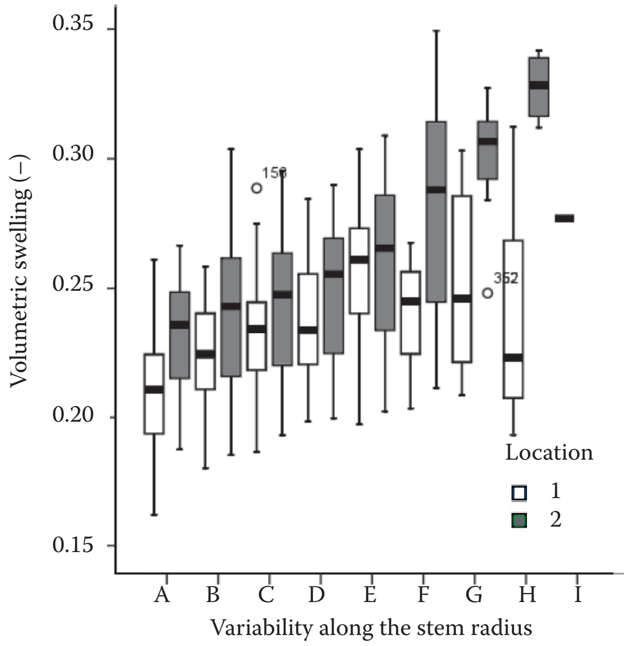

Fig. 3. A box plot – the variability of wood volumetric swelling along the stem radius for individual locations

the measured values are 6.98% for location 1 and 7.61% for location 2. The coefficient of variation for the radial direction is 26% in both locations. The wood changed dimensions most in the tangential direction. The value of the average tangential swelling was 14.8% in location 1 and 15.5% in location 2.

The volumetric swelling, which is a sum of all dimensions in all anatomical directions, is 23.47% in location 1 and 25.02% in location 2. Statistical examination rejected the zero hypothesis of the influence of the individual locations on the volume wood swelling ($P < 0.05$). It means there is a statistically significant difference in the wood volumetric swelling between the two locations. Fig. 3 clearly shows the variability of the volumetric swelling along the stem radius. The volumetric swelling of wood increases along the stem radius in the direction from the cambium (A) to the central parts of the stem (H) – (see Fig. 3). This very graph also shows the higher variability of the values measured in the second location. The same tendencies can also be seen in the wood volumetric swelling along the stem radius in the northern and the southern parts of the stem. Statistical examination did not show any statistical difference in the mean value of volumetric swelling between the northern and the southern parts of the stem (valid for both locations; $P > 0.05$).

Fig. 4 shows the relationship between the density and the volumetric swelling. First, the measured data from both locations were put in relation. The

Table 3. The descriptive statistics of volumetric swelling and of swelling in individual anatomical directions in the locations (in %)

	Direction	*N*	Mean	Minimum	Maximum	Standard deviation	Coefficient of variation
Location 1	R	301	6.98	4.10	13.16	1.83	26.22
Location 2		290	7.61	2.41	17.53	2.04	26.77
Location 1	T	301	14.80	9.52	20.25	2.12	14.29
Location 2		290	15.49	2.77	20.88	2.49	16.06
Location 1	L	301	0.49	0.03	2.14	0.33	60.59
Location 2		290	0.59	0.21	2.18	0.38	64.09
Location 1	V	301	23.47	16.23	33.20	3.53	15.06
Location 2		290	25.02	9.11	34.94	3.54	14.15

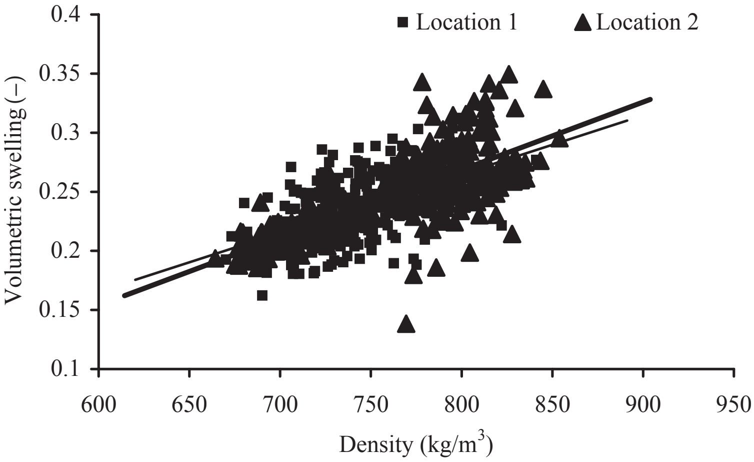

Fig. 4. The effect of wood density on the volumetric swelling of beech

degree of the tightness of this relationship, expressed by the coefficient of determination (R^2 = 0.484), is medium-high. The model explains about 50% of the total spread. Because the data from the two locations were different as the previous results show, the linear correlation model was created separately for location 1 and location 2. The resulting graphs and the coefficients of determination show that the dependence of the coefficient of the volumetric swelling on the wood density is lower (R^2 = 0.255) in location 1 than in location 2 (R^2 = 0.522). The found functions with the coefficients of determination are presented in Table 4. To evaluate the relationship of the density and the volumetric swelling these two physical properties were put in relation and the data were interlaid with a trend curve using a simple linear correlation.

DISCUSSION

The paper has dealt with the variability of ring width, with the density and wood swelling of European beech (*Fagus sylvatica* L.) from two different locations and also with the variability of these properties along the stem radius. The ring width depends on the internal and external factors (Trendelenburg 1955; Bouriaud et al. 2004). The ring width in the researched locations ranged between 0.453 and 4.021 mm, which falls within the range of values presented by Požgaj et al. (1997) and Govorčin et al. (2003). Statistical examination did not show any difference in the average ring width between the locations although the locations were in different altitudinal vegetation zones (location 1 – 5B1; location 2 – 3B8). The average ring width decreases with the increasing altitude (Govorčin et al. 2003). The difference in altitude between the two researched locations is 100 m. This could explain the minimum difference in the average ring width between the researched locations. Also in our case, the average ring width was higher in location 2, which is at a lower altitude. Further, a gradual decrease in the ring width was observed along the stem radius (location 1). In location 2 the ring width increased in the first 25 years, it reached the maximum and then the average ring width decreased with the age. Therefore, we can agree with the results presented by Govorčin et al. (2003), who showed the variability of the beech ring width caused by age. Their conclusion is that the ring width of beech decreases until the age of 100 and then we can see a growing trend, i.e. increments of the ring width.

Wood density is a basic physical quantity which also affects other physical and mechanical wood properties. In contrast to other materials, the wood density is considerably dependent on the wood structure (ring width, the proportion and the radius of macro- and micro-vessels), the position in the stem, the location of the tree and the moisture con-

Table 4. The chart of the resultant functions and the coefficient of determination for volumetric swelling in dependence on the wood volume

	Function	R^2	Coefficients	
			a	*b*
Location 1 + 2	$y = ax + b$	0.484	0.0005454	–0.1682
Location 1	$y = ax + b$	0.255	0.0004971	–0.1327
Location 2	$y = ax + b$	0.522	0.0005706	–0.1883

tent (Lexa et al. 1952; Trendeleburg 1955; Niemz 1993; Požgaj et al. 1997; Bouriand et al. 2004). Bouriand et al. (2004) examined the variability of wood density within a tree ring. They found out that wood density ranged between 200 and 850 kg/m^3 and that wood density increased continually from the beginning to the end of a ring. The authors claimed the average wood density of beech to be 764 ± 43 kg/m^3 with moisture content of 11%. Nepveu (2001) also found out that the wood density of beech (a collection of 60 trees, aged 70–100 years) decreased with the increasing age (counted from the pith). A similar trend, i.e. a decrease in the wood density with age (the first 90 years), was reported by Govorčin et al. (2003). Their research shows that the beech wood density is constant in the following years. The same trend was also observed in the chosen sample trees used for this study. However, as only trees up to 80 years of age were used, it was not possible to observe the wood density from the aspect of a longer period.

The observed average wood density is slightly higher than the values determined for beech (*Fagus sylvatica* L.) wood density by other authors (Kollmann 1951; Lexa et al. 1952; Cividini 1969; Požgaj et al. 1997; Wagenführ 2000; Frühwald et al. 2003). The differences can be explained by the conditions of the locations or by the variability along the stem radius. Govorčin et al. (2003) stated that the beech wood density decreased with the increasing altitude. This has been proved in our measurements, when location 2 (lower altitude) showed statistically higher density than location 1.

Further, the average density of the researched European beech (752.5 kg/m^3) is higher in comparison with the density of American beech (*Fagus grandifolia*), whose average density is 721 kg/m^3 (Alden 1995).

Wood as a hygroscopic and porous material can absorb or release water in dependence on the surrounding conditions. When absorbing or releasing moisture under the limits of hygroscopicity, wood shrinks or swells. The anisotropic properties of wood are demonstrated by different swelling and shrinking in individual anatomical directions.

In practice the longitudinal change in dimensions is often neglected as swelling and shrinkage are very small in the longitudinal directions. However, we cannot neglect the dimensional changes in the transversal plane where swelling and shrinking are considerably higher (Niemz 1993; Požgaj et al. 1997; Simpson, Tenwolde 1999). European beech (*Fagus sylvatica* L.) wood is the wood of the species that are subject to dimensional changes (swelling and shrinkage) to a considerable extent when compared with other types of wood.

The swelling in the longitudinal direction was the lowest (around 0.5%) in both locations, which was caused by the minimum deflection of fibrils from the longitudinal axe of the cell (the fibril angle is 10–15° in the secondary layer of the cell wall of anatomical elements). In the transverse plane wood swelled more in the tangential direction than in the radial direction. The values of swelling are higher than the values presented in used literature (Kollmann 1951; Lexa et al. 1952; Wagenführ 2000), which is caused by the higher density of the samples. The effect of wood density on the volumetric swelling of wood was statistically confirmed (see Fig. 4). The increase in the volumetric swelling of wood with the increasing density was reported by Trendelenburg (1955), Nečesaný (1959), Niemz (1993), Požgaj et al. (1997). The increase in the wood volumetric swelling is related not only to the increasing proportion of cell walls but also it is positively correlated with the content of cellulose in wood where water molecules can get bound (Nečesaný, Morárová 1959).

The results show that the wood swelling in individual anatomical directions and also the volumetric swelling were higher in location 2 (a lower altitude). It means that our results of measurement correspond to the results published by Govorčin et al. (2003) – i.e. there is a decrease in tangential swelling with increasing altitude. A decrease in radial swelling with increasing altitude is probably related to a decrease in wood density with increasing altitude. The variability along the stem radius can be put in relation with the wood density, which also changed along the stem radius.

To conclude, the results showed that wood as a natural material has highly variable properties. Wood density varies not only between locations but also within a stem. The anisotropic character of wood is demonstrated bye different swelling of wood in the individual anatomical directions. Therefore, it is necessary to take into account this knowledge when processing and using wood for specific purposes.

References

ALDEN H.A., 1995. Hardwoods of North America. General Technical Report FPL-GTR-83, Madison, WI. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 136.

BECTAŞ I., GÜLLER C., BAŞTÜRK M.A., 2002. Principal mechanical properties of eastern beech wood (*Fagus orientalis* Lipsky) naturally grown in Andirin Northeastern Mediterranean Region of Turkey. Turkish Journal of Agriculture and Forestry, *26*: 147–154.

BLAß H.J., DENZLER J., FRESE M., GLOS P., LINSENMANN P., 2005. Biegefestigkeit von Brettschichholz aus Buche. Band 1 der Reihe Karlsruher Berichte zum Ingenieurholzbau. Karlsruhe, Universität Karlsruhe: 137.

BOURIAND O., BRÉDA N., LE MOGUÉDEC G., NEPVEU G., 2004. Modelling variability of wood density in beech as affected by ring age, radial growth and climate. Trees, *18*: 294–276.

CIVIDINI R., 1969. Studio Tecnologico sulFaggio dell'Appennino Toscano. Roma, C.N.R., Instituto del Legno, *22*: 1–38.

FRÜHWALD A., RESSEL J.B., BERNASCONI A., 2003. Hochwertiges Brettschnichtholz aus Buchenholz. Hamburg, Abschulssbericht: 181.

GOVORČIN S., SINKOVIĆ T., TRAJKOVIĆ J., DESPOT R., 2003. Bukovina. Zagreb, Obična bukva u Hrvatskoj: 652–669.

GROSSER D., 1977. Die Hölzer Mitteleuropas. Ein mikrophotografischer Lehratlas. Berlin, Heidelberg, Springer-Verlag: 208.

GRYC V., HORÁČEK P., 2004. Influence of Forestry Practices on Wood Quality – Review. In: BUCHTA I., KAŇOVÁ D., STEJSKAL R., ŠIMKOVÁ P. (eds), MendelNet 2004. Proceedings of International Postgraduate Students' Conference. Brno, MZLU v Brně: 45–50.

JANOTA I., KURJATKO S., 1978. Promenlivosť hustoty bukového dreva. Drevársky výskum, *23*: 25–40.

KOLLMANN F., 1951. Technologie des Holzes und der Holzwerkstoffe. 1. Aufgabe. Berlin, Springer-Verlag: 870.

LEXA J., NEČESANÝ V., PACLT J., TESAŘOVÁ M., ŠTOFKO J., 1952. Mechanické a fyzikálne vlastnosti dreva. Bratislava, Práca – vydavateľstvo ROH: 432.

MIŠÍKOVÁ O., 2006. The hardness and density of beech wood from necrotic wounds and opposite wood. Proceedings of the 5th International Symposium Wood Structure of Properties '06. Zvolen, Arbora Publishers: 309–311.

NEČESANÝ V., 1959. Objemové změny bukového dřeva. I. část. Vliv základních fysikálních vlastností na nasycení a objemové bobtnání dřeva. Drevársky výskum, *4*: 13–26.

NEČESANÝ V., MORÁROVÁ E., 1959. Objemové zmeny bukového dreva. II. časť. Vplyv obsahu celulózy na nasýtenie blán a objemové napúčanie dreva. Drevársky výskum, *4*: 27–38.

NEPVEU G., 2001. Effet de la conservation en foręt sans exploitation sur l'altération de chablis de hętre (*Fagus sylvatica* L.). Convention ONF/INRA/AFOCEL BP 009. Nancy, Champenoux, INRA-CRF.

NIEMZ P., 1993. Physik der Holzes und der Holzwerkstoffe. Stuttgart, DRW-Verlag Weinbrenner: 243.

NIEMZ P., SONDEREGGER W., 2003. Untersuchungen zur Korrelation ausgewählter Holzeigenschaften untereinander mit der Rohdichte unter Verwendung von 103 Holzarten. Schweizerische Zeitschrift für Forstwesen, *154*: 489–493.

POPOVIĆ Z., ŠOŠKIĆ B., MIRIĆ M., 2006. Effect of moisture and temperature on some mechanical properties of beechwood. Proceedings of the 5th International Symposium Wood Structure of Properties '06. Zvolen, Arbora Publishers: 349–354.

POŽGAJ A., CHOVANEC D., KURJATKO S., BABIAK M., 1997. Štruktúra a vlastnosti dreva. Bratislava, Príroda: 486.

SIMPSON W., TENWOLDE A., 1999. Physical Properties and Moisture Relations of Wood, Wood handbook – Wood as an engineering material. General Technical Report FPL-GTR-113, Madison, WI. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 463.

TRENDELENBURG R., 1955. Das Holz als Rohstoff. 2. Aufgabe. München, Carl Hanser Verlag: 541.

WAGENFÜHR R., 2000. Holzatlas. Leipzig, Fachbuchverlag Lepzig: 707.

Zpráva o stavu lesa a lesního hospodářství České republiky, 2006. Praha, Ministerstvo zemědělství ČR.

ČSN 49 0126. Drevo, 1976. Metóda zisťovania radiálneho a tangenciálneho napučania. Praha, Vydavatelství Úřadu pro normalizaci a měření: 6.

ČSN 49 0108. Drevo, 1980. Zisťovanie hustoty pri fyzikálnych a mechanických skúškach. Praha, Vydavatelství Úřadu pro normalizaci a měření: 8.

Received for publication June 12, 2008
Accepted after corrections July 1, 2008

Vybrané vlastnosti dřeva buku lesního (*Fagus sylvatica* L.)

ABSTRAKT: Práce se zabývá variabilitou šířky letokruhu, hustotou a celkovým bobtnáním dřeva (objemového, v jednotlivých anatomických směrech) ze dvou rozdílných lokalit. Dále byla sledována variabilita zkoumaných vlastností po poloměru kmene. Z letokruhové analýzy vyplývá, že šířka letokruhu se snižuje po poloměru kmene od dřeně k obvodu kmene. Lokalita 2 (nižší vegetační stupeň) měla v průměru širší letokruhy (statisticky nevýznamný rozdíl), vyšší hustotu a objemové bobtnání dřeva proti lokalitě 1 (statisticky významný rozdíl). Byl potvrzen vztah mezi objemovým bobtnáním a hustotou dřeva. Z výsledků vyplývá, že hustota dřeva i objemové bobtnání dřeva se mění po poloměru kmene. Se zvyšující se hustotou dřeva se objemové bobtnání zvyšuje. Průměrná hustota dřeva buku z obou lokalit je 752 kg/m^3 při vlhkosti dřeva 12 %.

Klíčová slova: buk; šířka letokruhu; hustota; bobtnání

Corresponding author:

Ing. Vladimír Gryc, Ph.D., Mendelova zemědělská a lesnická univerzita v Brně, Lesnická a dřevařská fakulta, Lesnická 37, 613 00 Brno, Česká republika
tel.: + 420 545 134 548, fax: + 420 545 134 049, e-mail: gryc@mendelu.cz