WOOD RESEARCH
64 (2): 2019
205-212

ABOVEGROUND BIOMASS BASIC DENSITY OF SOFTWOODS TREE SPECIES

Rudolf Petráš, Julian Mecko, Danica Krupová, Marián Slamka
National Forest Centre – Forest Research Institute in Zvolen
Zvolen, Slovak Republic

Andrej Pažitný
Pulp and Paper Research Institute
Bratislava, Slovak Republic

(Received November 2018)

ABSTRACT

Experimental material was obtained from 43 trees of four tree species, namely pine, fir, larch and spruce from the territory of Slovakia. Wood and bark samples were taken from the discs in three locations on a stem and from small-wood, branches coming from tree crowns. The volume of fresh samples was measured in calibrated graduated cylinders with a precision of 1 ml; a dry matter was measured with a precision of 0.01 g. The statistically significant effect has been shown in tree species, fractions of biomass and locations on the tree using a special software based on ANOVA. The average basic density of wood for all species ranges from 373 to 508 $kg \cdot m^{-3}$. For bark it is 333-551 $kg \cdot m^{-3}$ and for small-wood outside bark it reaches 406-535 $kg \cdot m^{-3}$. The fir and larch have the lowest and highest values for wood density; pine and fir for bark density and pine and spruce species for small-wood density.

KEYWORDS: Basic density, biomass, wood, bark, small-wood, softwoods.

INTRODUCTION

Wood is permanently the main object in tree biomass production, but not the only object of interest as it recently shows. Bark and leaves are naturally attached to the wood. Their composition on trees is changing mainly by the type of tree species, the environment in which the trees grow, but also by their age. From aboveground biomass of trees, wood and bark are the most important materials for economic use and their amount is mostly stated in volume in m^3. However, it appears that for a broader and more objective assessment of biomass production, for example for the calorific value content or comparison with other plant communities it is necessary to quantify biomass more general, also in terms of weight. In order not to determine forest biomass production in units of weight again, it is sufficient to recalculate its known volume in m^3 per weight. For such a procedure, it is necessary to know its density by individual fractions expressed in volumes. Although the density is generally expressed as the ratio between weight and volume of the particular component, in practice the basic density is applied:

$$\rho_b = \frac{m_0}{V_s} \tag{1}$$

where: ρ_b – the basic density ($kg \cdot m^{-3}$),
m_0 – the dry mass (kg),
V_s – the saturated volume (m^3).

The wood density term has the highest frequency in published sources so far and most authors associate it with its mechanical properties. Niemz and Sonderegger (2003) deduced such connection from literature materials for 103 trees. Soft deciduous species have the lowest basic density, followed by softwoods and then hardwood deciduous species. Požgaj et al. (1997) declare for spruce, fir and poplar the value of 370 $kg \cdot m^{-3}$, for pine 440 $kg \cdot m^{-3}$, for beech 560 $kg \cdot m^{-3}$ and for locust tree with hornbeam 600-650 $kg \cdot m^{-3}$. Trendelenburg states for softwoods species the basic density of 370-470 $kg \cdot m^{-3}$ and for hardwood deciduous species the density of 510-570 $kg \cdot m^{-3}$ (Šmelko et al. 1992). Similar values are also stated by Knigge and Schulz (Pretzsch (2009)). Thus, the poplar reaches the value of 377 $kg \cdot m^{-3}$; softwoods species approximately 380-490 $kg \cdot m^{-3}$, hardwood deciduous species 520-560 $kg \cdot m^{-3}$ and locust tree up to 650 $kg \cdot m^{-3}$. Several authors state that the wood density varies not only by tree species but also with the vertical or radial location on the stem and in the tree crown. The wood density is also affected by the annual rings width, the proportion of early and late wood, the tree age and the site on which the tree grows. Požgaj et al. (1997) and Husch et al. (2003) state also the certain location on the tree. Matovič and Šlezingerová (1992) state that the density of branches outside bark is significantly higher than the density of stem wood. Wood coming from spruce branches has basic density of up to 570 $kg \cdot m^{-3}$; then 506 $kg \cdot m^{-3}$ reaches branches wood outside bark; 354 $kg \cdot m^{-3}$ branches bark, and 406 $kg \cdot m^{-3}$ stem wood. Klašnja and Kopitovič (1992) examined the density of the locust tree species in Serbia. It varies from 533 to 639 $kg \cdot m^{-3}$, with an average of 599 $kg \cdot m^{-3}$ and no effect of its provenance has been demonstrated. Petty et al. (1990) examined the wood density of the stem for Norway spruce and Sitka spruce, depending on the width of annual rings, and authors state that Sitka has slightly higher values. Munoz and Anta (2010) derived the wood density for the Maritime pine in Spain in the range of 307-527 $kg \cdot m^{-3}$, with average of 408 $kg \cdot m^{-3}$. Wimmer (1991) states, by his example of pine in Austria, that the wood density is significantly affected by the proportion of early and late wood. Repola (2006) gives the models for wood density according to relative height on the stem in Finland. The values for pine are in the range of 410-435 $kg \cdot m^{-3}$, for spruce 385-386 $kg \cdot m^{-3}$ and for birch 475-478 $kg \cdot m^{-3}$. Vavrčík and Gryc (2012) state that the wood density of English oak for South Moravia is 584 $kg \cdot m^{-3}$ and that of Sessile oak is 673 $kg \cdot m^{-3}$. Koman and Feher (2015) report values of 568, 586 and 627 $kg \cdot m^{-3}$ for wood of beech, Sessile oak and Turkey oak in Hungary.

For more accurate conversions of whole tree biomass from volume to weight units, it is necessary to know this biomass density by their basic fractions. Specifically, it is intended for the density of thick wood, its bark and small-wood (thin wood outside bark < 7 cm). More comprehensive research of forest biomass density for the purpose of its production question was started by Petráš et al. (2010) and Petráš et al. (2013) in Slovakia, in connection with the research on the calorific value production of poplar clones stands. According to the results of this research, wood of the Robusta clone has basic density of 400-450 kg·m^{-3} and I-214 clone of about 50 kg·m^{-3} less. The bark density has lower values, approximately 370 kg·m^{-3}, but in the crown sections the density of wood and bark is approximately the same. Under this research, additional research with the same focus continues for other economically important tree species.

The aim of this presented work is to derive basic density of basic fractions of the aboveground tree dendromass (wood, bark and small-wood) for four softwoods species. Furthermore, it is the estimation of this density variability for spruce, fir, pine and larch and comparing these values among the tree species.

MATERIAL AND METHODS

Experimental material for spruce, fir, pine and larch was obtained from 43 cut trees (Tab. 1). Trees were selected from various areas of western, central and eastern Slovakia with an altitude of approximately 165-1070 m. The quality of sites on which trees grew is expressed by the site index ranging from 24 to 42. This site index reflects the mean height of the stand at the age of 100 years. Selected trees were characterized by their diameter dbh (cm), height h (m) and age. Most of them have parameters of mature trees.

Tab. 1: Characteristics of cut trees by tree species, diameter breast height, height, tree age, site index and altitudes of forest stands.

Species	Number of trees	dbh (cm)	h (m)	Age (years)	Site index	Altitude (m)
Spruce	12	20-62	23-38	35-105	26-42	435-1070
Fir	11	23-75	22-39	35-153	24-40	390-950
Pine	10	25-51	24-30	75-108	24-30	165-940
Larch	10	26-56	24-35	40-100	28-40	275-1070
Overview	43	20-75	22-39	35-153	24-42	165-1070

Four wood samples outside bark were cut from each tree. The first three samples were the discs cut by a radial cut from the stem. For the first sample, a disc from the foot of the stem was cut; for the second one from the middle part of the stem (approximately below the tree crown) and the third one came from the crown part of the stem. All three samples from the stem were separated into wood and bark. Since there was not a large volume of bark from the cut discs, another bark had to be peeled from that part of the stem, where discs were cut. The fourth sample represented small-wood, i.e. branches wood outside bark thinner than 7 cm. This sample consisted of 20-25 cm long cuttings from branches selected from the middle part of the crown. Wood and bark remained together on this sample. Of all 43 trees, a total of 301 samples were taken; 129 for wood, 129 for bark, and 43 samples for small-wood.

The volume of fresh samples was measured 1-2 days after their removal. This volume was measured in calibrated cylinders, 2000 ml graduated with an accuracy of 1 ml. The large discs taken from stems were cut in a radial direction to smaller triangular sections before their measurement. Volume of wood of the samples examined was in the range of 975-1608 ml; of bark 705-1335 ml and for small-wood it varied from 705 to 1302 ml. All samples were then dried at 103 ± 2°C to a constant weight. The weight was determined to the nearest 0.01 g. Values in the range of 355-981 g were found at wood; 281-704 g at bark and 363-710 g at small-wood. The basic density of each sample was calculated according to the Eq. 1. Its variability has been investigated and the most important factors that affect it were identified.

The ANOVA generalized analysis of variance (more factors and variables) by means of QC-Expert computer software (Kupka 2013) was used. The ANOVA based on principle of addition of variances of known reasons (factors or variables) σ_i^2 and unknown ones (random) cause $\sigma^2_{residual}$ to the total variance σ^2_{total} :

$$\sigma_{total}^2 = \sum\sigma_i^2 + \sigma_{residual}^2 \quad (2)$$

In the analysis of variance were used as reasons of 3 factors (species, biomass fraction and location on tree):

- Species with 4 levels – spruce, fir, pine, larch,
- Biomass fraction with 3 levels – wood, bark, small-wood,
- Location on the tree with 4 levels – 3 locations on the stem (foot, middle of stem, middle of crown) and 1 location of small-wood.

The additional 4 reasons (site index, age, diameter and height of tree) were numerical variables. The total analysis resulted in the analysis of variance, where the total effect of all the factors and variables on the biomass density was assessed. In addition, the analysis of variance according to single factors and variables was performed as well. The differences between the average values at single levels were tested by Student's t-test.

RESULTS AND DISCUSSION

The effect of seven predictors (impact of three factors and four variables on the number of 301 of density values) was analysed by ANOVA. We can state (Tab. 2) that their overall effect on the density of biomass is statistically significant, p-value is less than the chosen significance level p=0.05.

Tab. 2: The overall test if the predictors have any effect on the basic density.

Source of the Variability	Degrees of freedom	Sum of squares	Mean square	F-statistic	p-value
Total variability	300	2286317	7621	-	-
Explained variability	4	710762	-	1.43	9.28E-04
Residual variability	296	1575556	5323	-	-

The ANOVA was also applied to determine effect of the concrete predictors on the biomass density (Tab. 3). The statistically significant effect, p-value is less than the chosen significance level p=0.05, was shown only at three factors. All four variables do not have statistically significant effect on biomass density.

Tab. 3: The amount of variance explained by the predictors (factors and variables) at the basic density.

Predictors (factors and variables)	Parameter	Sum of squares	F-statistic	p-value
Location on the tree	-	272856	13.42	3.12E-08
Biomass fraction	-	254413	18.66	2.34E-08
Species	-	365228	18.82	3.36E-11
Site index	1.745557	12544	1.65	0.199
Age	0.520280	26109	3.47	0.064
Diameter breast height	-0.797600	13229	1.75	0.187
Height	-0.720960	6451	0.85	0.358

The average densities and their standard deviations were calculated for single levels of all the three factors (Fig. 1). Their variability is relatively wide. The average values of density are in the range of about 320-560 kg·m^{-3} and variation coefficients of about 4-15%. Wood has lower variability and bark higher one.

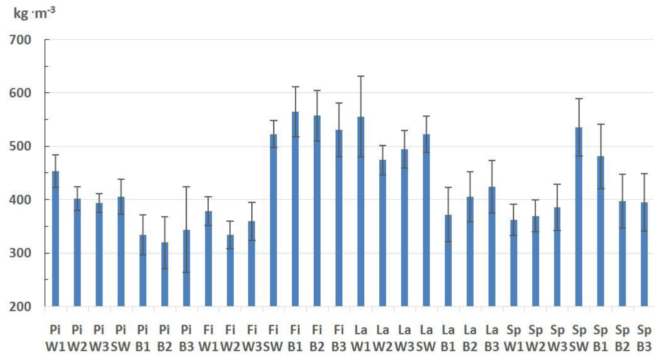

Fig. 1: The basic density of the elementary biomass fractions of species and location on tree (Pi – Pine, Fi – Fir, La – Larch, Sp – Spruce, W – wood, SW – small-wood, B – bark, 1 – on tree foot, 2 – at middle of stem, 3 – at middle of crown).

The concrete differences among all average densities on single levels were tested by Student's t-test ($p < 0.05$). The test confirmed equivalent basic density for several fractions. Mostly these were the biomass fractions from three locations on the stem. After that, those fractions were merged into new, larger sets according to fractions and tree species. This procedure created new sets for each tree species. Pine has two sets, so for wood with small-wood and bark separately; fir has two sets, for wood and small-wood outside bark; larch has similarly to pine wood with small-wood and bark sets. It is only the spruce where three sets were created, i.e. for wood, small-wood and bark. Also, for these new sets, mean densities and their standard deviations (Fig. 2) were calculated.

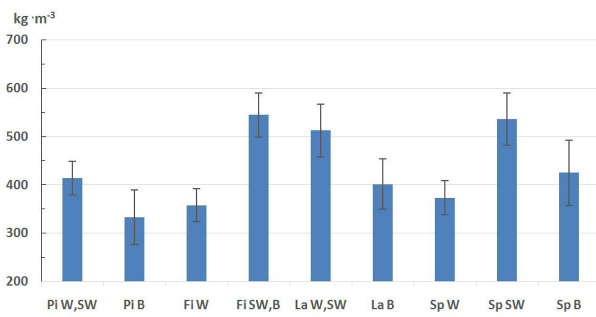

Fig. 2: The basic density of the biomass fractions of species (Pi – Pine, Fi – Fir, La – Larch, Sp – Spruce, W – wood, SW – small-wood, B – bark).

Their variability is relatively wide. The average values of density are in the range of about 330-540 kg·m^{-3} and variation coefficients of about 8-12%. Wood has lower variability and bark higher one. Small-wood fractions from fir, larch and spruce, but also larch wood and fir bark have the highest density, approximately 510-540 kg·m^{-3}. All other fractions have lower density by about 100 kg·m^{-3}. According to Student's t-test, a major part of statistically significant differences among the sets is found in these two groups.

In forestry, biomass production is mainly expressed by the volume (m^3) of wood, bark and small-wood, especially for each tree species. Mean basic densities (kg·m^{-3}) of mentioned fractions and species (Fig. 3) were calculated for the effective conversion of biomass production between volumes to weight units. The lowest wood density of 358-373 kg·m^{-3} is found at heartwood-free species such as fir and spruce. Heartwood species such as pine and larch follow with the density of 417-508 kg·m^{-3}. Small-wood is practically branches wood outside bark. Apart from the pine, its density is higher than that of wood. It is virtually identical (523-535 kg·m^{-3}) for fir, larch and spruce. Pine small-wood has lower density by approximately 100 kg·m^{-3} compared to other tree species.

The bark represents a particular fraction, because here are the highest differences among the species. Values of pine are only 333 kg·m^{-3} and that of fir up to 551 kg·m^{-3}. According to Požgaj et al. (1997), the cause is in their different structure, a proportion of feloderm and suberoderm, inorganic substances and mechanical (sclerenchymatic) tissues. In these tissues, the proportion of mechanical cells (sclereids) is a decisive factor. Then, pine should have the lowest density because it does not have sclereids. Larch and spruce follow with 10-20% proportion and then fir with 30-60% proportion of sclereids. We can state with satisfaction that the quoted findings correspond to ours.

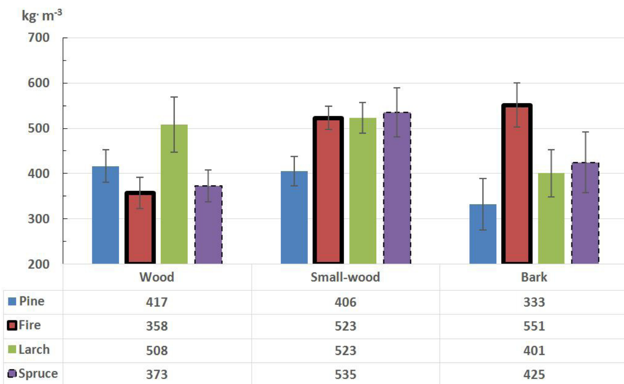

Fig. 3: The basic density of the biomass fractions of species.

Our results are fairly consistent with the previously published findings for all fractions. They reach approximately middle values of their range. This applies especially to the density of spruce wood, where the vast majority of results is available. Požgaj et al. (1997), Repola (2006), Petty et al. (1990), Matovič and Šlezingerová (1992) and Gryc et al. (2011) report this density in a relatively wide range of 300-430 kg·m^{-3}. At the same time, they emphasize that wood density is affected not only by growth conditions, but also by its macro- and microscopic structure, such as the width of annual rings, the structure and thickness of conductive tissues, the thickness of their wall, and the like. In pine and larch cases the higher density of wood reflects the presence of core wood. Požgaj et al. (1997), Munoz and Anta (2010) and Repola (2006) declare that the mean density of pine wood is 408-440 kg·m^{-3}. Fabisiak et al. (2003) state that the wood density of 30-year larch stands is 450-460 kg·m^{-3}. However, it is assumed that with the increasing age the proportion of heartwood in larch stems will increase and hence its density too. Chmelař (1992), Matovič and Šlezingerová (1992) and Gryc et al. (2011) state that the density of spruce wood from branches inside bark is 550-580 kg·m^{-3} and outside bark is 480-515 kg·m^{-3}.

CONCLUSIONS

For an objective assessment of the production of forest stands, it is necessary to know the weight of produced biomass in addition to the volume. Thus, it is necessary to know the biomass density to conduct a conversion between volumes to weight units. Based on experimental analysis of 301 samples from 43 trees from the territory of Slovakia the basic density was determined for a group of selected softwoods (pine, fir, larch and spruce). Mean wood density of all species ranges from 373 to 508 kg·m^{-3}; values of 333-551 kg·m^{-3} can be found at bark and 406-535 kg·m^{-3} at small-wood. The fir and larch have the lowest and highest values for wood density; pine and fir for bark density and pine and spruce species for small-wood density.

Special software based on ANOVA confirmed that overall effect of seven predictors (wood species and placement in a tree) is statically significant on the density values reached.

ACKNOWLEDGEMENT

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-16-0344.

REFERENCES

1. Fabisiak, E., Drogoszewski, B., Kocjan, H., Marcinkowska, A., Molinski, W., Roszyk, E., 2003: Selected physical properties of larch wood (*Larix decidua* Mill.) from plantation. Annals of Warsaw Agricultural University – SGGW, Forestry and Wood Technology 53: 90-95.
2. Gryc, V., Horáček, P., Šlezingerová, J., Vavrčík, H., 2011: Basic density of spruce wood with bark, and bark of branches in locations in the Czech Republic. Wood Research 56(1): 23-32.
3. Husch, B., Beers, T.W., Kershaw, J.A., 2003: Forest Mensuration. John Wiley & Sons. New Jersey, 443 pp.
4. Chmelař, T., 1992: Variabilita konvenční hustoty dřeva větví smrku v závislosti na poloze větví v korune. (Variability of the conventional wood density of spruce (*Picea abies* (L.) Karst.) branches in dependence on the position of branches in crown). Lesnictví – Forestry 38(2): 127-135.
5. Klašnja, B., Kopitovič, Š., 1992: Some properties of *Robinia* wood obtained from trees grown in provenance field experiments. Drevársky výskum 134: 1-8.
6. Koman, S., Feher, S., 2015: Basic density of hardwoods depending on age and site. Wood Research 60(6): 907-912.
7. Kupka, K., 2013: QC-Expert 3.3. Uživatelský manual. (User's manual). TryloByte, Ltd. Pardubice, 318 pp.
8. Matovič, A., Šlezingerová, J., 1992: Konvenční hustota dřeva větví smrku obecného (*Picea abies* Karst.), (Basic density of branchwood in Norway spruce (*Picea abies* /L./ Karst.). In: Les, drevo, ekológia, Sekcia 4. Štruktúra a vlastnosti dreva v technologickom využití. Technická univerzita, Zvolen, Pp 53-59.

9. Munoz, G.R., Anta, M.B., 2010: Physical properties of thinning wood in Maritime pine (*Pinus pinaster* Ait.): case study. European Journal of Forest Research 129(6): 1037-1045.
10. Niemz, P., Sonderegger, W., 2003: Untersuchungen zur Korrelationausgewählter Holzeigenschaften untereinander und mit der Rohdichte unter Verwendung von 103 Holzarten. Schweizerische Zeitschriftfür Forstwesen 154(12): 489-493.
11. Petráš, R., Mecko, J., Neuschlová, E., 2010: Density of basic components of above-ground biomass of poplar clones. Wood Research 55(4): 113-122.
12. Petráš, R., Mecko, J., Oszlányi, J., Petrášová, V., Jamnická, G., 2013: Landscape of Danube inland-delta and its potential of poplar bioenergy production. Biomass and Bioenergy 55: 68-72.
13. Petty, J.A., Macmillan, D.C., Steward, C.M., 1990: Variation of density and growth ring width in stems of Sitka and Norway spruce. Forestry 63(1): 39-49.
14. Požgaj, A., Chovanec, D., Kurjatko, S., Babiak, M., 1997: Štruktúra a vlastnosti dreva. (Structure and properties of wood). Príroda. Bratislava, 485 pp.
15. Pretzsch, H., 2009: Forest dynamics, growth and yield. Springer. Berlin Heidelberg, 664 pp.
16. Repola, J., 2006: Models for vertical wood density of Scots pine, Norway spruce and birch stems, and their application to determine average wood density. Silva fennica 40(4): 673-685.
17. Šmelko, Š., Wenk, G., Antanaitis, V., 1992: Rast, štruktúra a produkcia lesa. (Forest growth, structure and production). Príroda, Bratislava, 342 pp.
18. Vavrčík, H., Gryc, V., 2012: Analysis of the annual ring structure and wood density relations in English oak and Sessile oak. Wood Research 57(4): 573-580.
19. Wimmer, R., 1991: Beziehungen zwischen Jahrring parametern und Rohdichte von Kiefernholz. Holzforschung und Holzverwertung 43(4): 79-82.

*Rudolf Petráš, Julian Mecko, Danica Krupová, Marián Slamka
National Forest Centre – Forest Research Institute in Zvolen
T. G. Masaryka 22
960 92 Zvolen
Slovak Republic
*Corresponding author: petras@nlcsk.org

Andrej Pažitný
Pulp and Paper Research Institute
Dúbravská Cesta 14
841 04 Bratislava
Slovak Republic