Original scientific paper

Effects of Short-Term Storage Method on Moisture Loss and Weight Change in Beech Timber

Arkadiusz Tomczak, Grzegorz Grodziński, Marcin Jakubowski, Tomasz Jelonek, Witold Grzywiński

Abstract

Timber harvested from fresh-felled trees has high moisture content and relatively high mass. During storage, the timber dries out and its weight decreases with the loss of moisture. The main objective of this study was to determine how the method and conditions of short-storage in summer affect weight changes and moisture loss in beech timber (not used for fuel). The study was carried out in a stand located in the north-eastern part of the range of beech. The age of the studied stand was 47 years. A total of 60 model trees were selected and divided into two groups. In the first group, 30 whole trees (WT) were left in the stand after felling. In the second group, 30 trees (CT) were delimbed and crosscut, and trunk sections (logs) were obtained (2.5 m). The timber (CT) was stored in a pile, and the weight of each log was measured daily. After 14 days, the trees from the first group, which had been left in the stand (WT), were delimbed and the trunks were cut into 2.5 m sections and weighed. It was assumed that timber intended for mechanical processing is stored in the forest for a short period of time, unlike energy wood. Therefore, the period of storage was not longer than two weeks. A more effective method of drying is to leave whole trees after felling, called transpirational drying. The timber stored in a pile (CT) lost moisture more slowly than the timber from trees that had been left whole after felling (WT). Comparing the weights of the logs stored in a pile, on days after harvesting, a statistically significant difference was found only between the first and the last day. It can be concluded that two weeks is the minimum period of storage in a pile (CT) required to obtain a significant degree of weight change and moisture loss.

Keywords: transpirational drying, storage conditions, summer, beech stand

1. Introduction

During summer, timber is susceptible to the harmful effects of insect pests and discolouring fungi. Its storage close to the place of felling should, therefore, last for as short a time as possible. In Poland, it is accepted that, in the summer season, timber should be transported as soon as possible after felling, and the maximum interim storage time should not exceed two weeks. Timber harvested from fresh-felled trees has high moisture content and relatively high mass. During storage the timber dries out and its weight decreases with the loss of moisture. This is particularly important in the case of relatively large transportation distances. The greater weight (moisture) of the timber will cause higher costs and environmental load (CO_2 emissions) (Acuna et al. 2012, Busenius et al. 2015, Sosa et al. 2015, Kanzian et al. 2016, Bennamoun et al. 2017).

The initial moisture content (MC) depends on tree species, wood structure and season (Wullschleger et al. 1996, Ciganas and Raila 2010, Hultnäs et al. 2013). Drying, in turn, is affected by atmospheric conditions, type of material and time of storage (Kokkola 1993, Filbakk et al. 2011, Erber et al. 2014, Visser et al. 2014, Routa et al. 2015, Anisimov et al. 2017, Erber et al. 2017). Beech has diffuse-porous wood and does not have heartwood. Helińska-Raczkowska (1996) analysed MC in birch, a species with similar wood structure to beech. She found that MC decreases as the basic wood density increases. Lower-density wood is more porous and is, therefore, able to store more water. This relationship may explain the high green density of timber obtained from the top parts of trunks of fresh-felled trees. In most trees, the basic density or over-dry density of wood in the bottom of the trunk is greater than in the top part. In pine, oak and birch, the weight of 1 m^3 of timber with smaller diameters is higher than in the case of timber with larger diameters (Tomczak et al. 2015, Tomczak and Jelonek 2015, Tomczak et al. 2016). Differences also result from changes in the share of the bark in the volume of timber. The bark on the bottom of the trunk of pine, oak and birch is thick and heavily cracked, while it is usually thin at in the top part of the trunk. Therefore, the share of bark in the total volume is large at the bottom of the trunk and small at the top part. Quite differently, beech has a relatively thin bark along the whole trunk. Dudzińska (2004) reported that the proportion of bark in the volume of trunk in young stands was 3.8% and 14.6% in mature stands.

The proportion of bark is an important indicator of quality in the production and combustion of both wood chips and pellets. The bark also reduces the drying out of logs. Röser et al. (2011) carried out experiments in different parts of Europe, comparing the natural drying of wood to be used for bioenergy. The study covered several species of conifers and broadleaved trees. It was found that broad-leaved trees dried out more effectively when debarked. For example, the rate of drying of debarked broad-leaved trees was approximately 30 g/kg per month higher than in the case of logs with bark. Generally, many studies have analysed various methods of preparing and storing timber intended for fuel (Nordfjell and Liss 2000, Nurmi and Hillebrand 2007, Pettersson and Nordfjell 2007, Afzal et al. 2010, Filbakk et al. 2011, Krigstin and Wetzel 2016). Another study of interest with regard to moisture loss is that of Saralecos et al. (2014). Their results showed that moisture loss rate increased as the size of the trunk decreased. They also observed a higher moisture loss rate in the top parts of trunks, which were not delimbed after felling, compared to logs that were delimbed.

The aim of this study was to determine how the method and conditions of storage in summer affect weight changes and moisture loss in beech timber, not intended to be used for fuel. Our hypothesis is that the form in which wood is stored has an impact on the moisture loss rate (and consequently timber weight loss). More specifically, trunks with intact crown, which are subject to transpirational drying, are expected to lose more moisture than delimbed trunks. Moisture loss depends largely on the temperature and relative humidity of the air and on rainfall. Therefore, we analysed how the beech timber reacts to changes in atmospheric conditions in summer. In particular, we investigated how the relation of weight to volume changed over a period of two weeks. We assumed that timber intended for mechanical processing is stored in the forest for only a short period of time. Nevertheless, a significant change in weight and moisture content was expected.

2. Materials and methods

2.1 Experimental setup

The study was carried out in a stand located in the north-eastern part of the range of beech (N 53° 20′ 56.526″, E 16° 13′ 26.229″). In the region managed by the Świerczyna Forest District, common beech (*Fagus sylvatica* L.) is the second dominant species after Scots pine (*Pinus sylvestris* L.). It forms compact stands with high breeding quality, from which valuable timber is harvested. It also often occurs as an additional species and in the second layer of pine stands. The age of the studied stand was 47 years and it covered an area of 5.03 ha. Within the stand, two homogeneous areas could be identified for the selection of model trees. These were selected based on their diameter at breast height (DBH) out of all trees designated for commercial thinning. Each tree was marked with a number for unique identification. The DBH values for all trees were measured using a caliper, to an accuracy of 0.1 cm. A total of 60 model trees were selected and divided into two groups (Table 1). In the first group, 30 whole trees (WT) were left in the stand after felling. In the second group, 30 trees (CT) were delimbed, and trunk sections (logs) were obtained (2.5 m in length, minimum diameter of 7 cm in bark). The timber (CT) was stored in a pile. At the same location, the weather station to measure temperature, humidity and rainfall were set up. Air temperature was measured to an accuracy of 1°C, humidity – 1%, rainfall – 0.01 l/m^2. The experiment was carried out between 6^{th} July and 20^{th} July 2015. The weight of each log was measured once every day, between 4 p.m. and 6 p.m. Each log was weighed using a crane scale (Steinberg Systems SBS-KW-300AB), with maximum capacity of 300 kg. Weight was measured to an accuracy of 0.1 kg. After 14 days, the trees from the first group, which had been left in the stand (WT), were delimbed, and the trunks were cut into 2.5 m sections and weighed.

Table 1 Description of model trees and obtained logs

Storage method	Number of trees	Mean DBH cm	Mean height m	Number of logs	Volume of logs with bark, m^3	Mean diameter of logs at the top end, cm	Mean diameter of logs at the butt end, cm
CT	30	13.1	17.6	116	4.10	10.6	12.6
WT	30	13.1	17.7	98	4.18	11.6	13.8

CT – timber storage in the pile, WT – whole trees storage in the stand after felling

A total of 116 (CT) and 98 (WT) logs were obtained (Table 1). The diameters at the ends of the logs were measured to an accuracy of 0.1 cm. The measurements were performed twice: over bark and under bark. The volume of each log was determined by Smalian's formula:

$$V = ((d_1 + d_2) / 2) \times l \qquad (1)$$

Where:

- V volume;
- d_1 cross-sectional area of the section at the butt end
- d_2 cross-sectional area at the top end
- l log length.

2.2 Data analysis

The data were subjected to statistical analysis for the purpose of comparison of weight changes and moisture loss. In the first step, the Lilliefors test for normality was carried out. The result led to the rejection of the hypothesis that the data was normally distributed. For this reason, the data between independent groups were compared by means of the non-parametric Kolmogorov–Smirnov test (weight between CT and WT). Comparison of data between dependent groups was performed using the Wilcoxon test (MC between start and end of the experiment). For comparing more than two groups, the Kruskal–Wallis test was used. If the null hypothesis was rejected, a post hoc Dunn's multiple comparison test of mean ranks was performed for all samples. A correlation matrix was developed for the studied features, using Spearman's rho. A significance level of α=0.05 was employed. All calculations were performed using the Statistica 12PL application (StatSoft Inc.).

3. Results

3.1 Storage conditions

According to our measurements, the mean air temperature in the place and time of storage was 18° C, which is similar to the mean summer temperatures recorded by meteorological stations in north-west Poland in July 2015 and in previous years (Wójcik and Miętus 2014, Owczarek and Filipiak 2016). Rainfall occurred on the 3rd, 4th, 5th, 8th, 9th and 14th day of storage and analogous fluctuation in the air humidity were observed (Fig. 1). During the experiment (14 days), the total precipitation amounted to 22.5 mm. For comparison, in July, the average monthly precipitation in the region was 71.5 mm; Gdańsk meteorological station, eastern part of the region, data from 1880–2008 (Filipiak 2001) and 72.3 mm; meteorological station Szczecin, western part of the region; data from 1861 to 1999 (Kirschenstein 2007). Average air humidity was 69.1%, while it was 76.0% on days with precipitation.

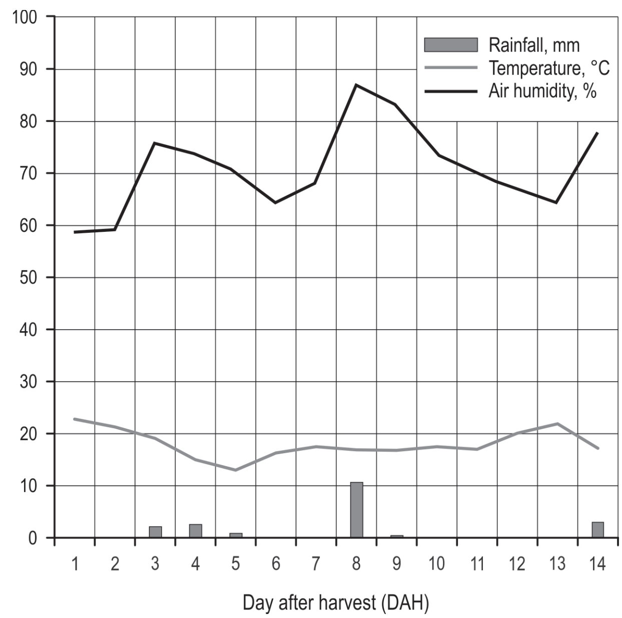

Fig. 1 Measurement of temperature, air humidity and precipitation between 6th and 20th of July 2015

3.2 Weight change and moisture loss

Fourteen days after harvesting (14 DAH), the weight of the WT group was lower than CT. The Kolmogorov–Smirnov test showed a significant difference between WT and CT (p-value <0.025). The timber

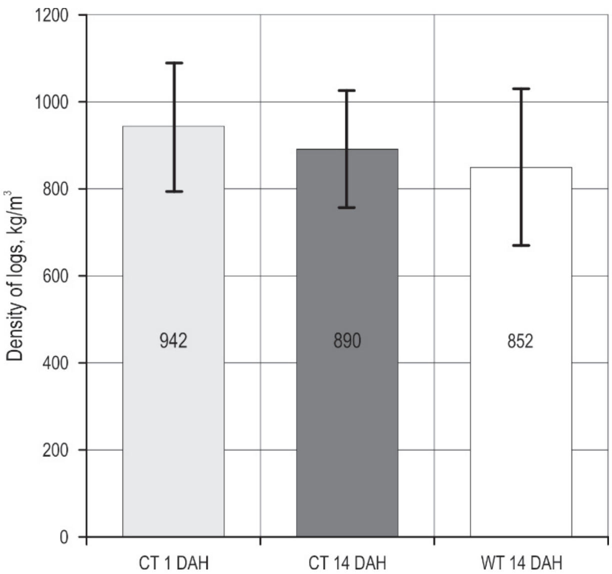

Fig. 2 Differences between weight (1 m^3) of logs obtained from fresh-felled trees (CT 1 DAH), stored in the pile (CT 14 DAH) and whole trees stored in the stand (WT 14 DAH)

stored in a pile (CT) lost moisture more slowly than the timber from trees that had been left intact after felling (WT). The average mass of 1 m^3 of logs from fresh-felled trees (CT) was 942 kg. During the storage period, the mass of 1 m^3 of CT logs decreased to 890 kg and that of WT logs to 852 kg. The average green density of CT at 1 DAH was significantly higher than CT at 14 DAH (p-value <0.01). Similarly, the green density of CT at 1 DAH (control) was significantly higher than that of WT at 14 DAH (p-value <0.005) (Fig. 2).

The weight of the logs stored in a pile (CT) decreased by 4 kg per m^3 and day, on average. The largest reduction was observed between 1 and 2 DAH. Generally, large weight loss was observed at the start of the storage period and following rainfall. After the first 24 hours of storage, the weight of 1 m^3 of logs dropped by approximately 10 kg. After rainfall, for example at 6 and 10 DAH, the weight dropped by approximately 5–6 kg per m^3. The largest amount of rainfall was recorded at 8 DAH. On that day and the next, the weight increased. The increase at 8 DAH was very small, but at 9 DAH the weight of timber increased by 0.7 kg per 1 m^3 (Table 2). Comparing the green density of the logs on particular days of storage, a significant difference was observed only between 1 DAH and 14 DAH (p-value = 0.0054). The fact that the median values were larger than the arithmetic means shows that there were more logs with higher green density, that is, with smaller volume and weight (Table 2). Logs with smaller volume, and hence smaller weight, exhibit

Table 2 Green density and weight changes per 1 m^3 logs stored in the pile (CT) (n=116) – grey marked lines present days with rain

DAH	Green density kg/m^3	SD	VC	Min	Max	Median	Change kg/m^3*	Change %*	Change kg/m^3**	Change %**
1	942	146	15.5	620	1315	977	–	–	–	–
2	932	143	15.3	615	1285	967	–9.86	–1.05	–9.9	–1.0
3	925	141	15.2	611	1262	961	–6.86	–0.74	–16.7	–1.8
4	921	140	15.2	609	1255	959	–3.79	–0.41	–20.5	–2.2
5	918	139	15.2	607	1251	955	–2.91	–0.32	–23.4	–2.5
6	913	139	15.2	604	1247	949	–5.15	–0.56	–28.6	–3.0
7	909	138	15.2	602	1239	945	–4.49	–0.49	–33.0	–3.5
8	909	138	15.2	600	1239	944	+0.05	+0.01	–33.0	–3.5
9	910	138	15.2	600	1239	945	+0.72	+0.08	–32.3	–3.4
10	904	137	15.2	598	1232	940	–5.68	–0.62	–38.0	–4.0
11	899	136	15.2	594	1224	935	–5.00	–0.55	–43.0	–4.6
12	896	136	15.1	594	1217	932	–2.95	–0.33	–45.9	–4.9
13	892	135	15.1	593	1205	927	–4.32	–0.48	–50.2	–5.3
14	890	134	15.1	591	1205	925	–1.81	–0.20	–52.0	–5.5

*changes compared to the previous day; **changes compared to the first day after harvest

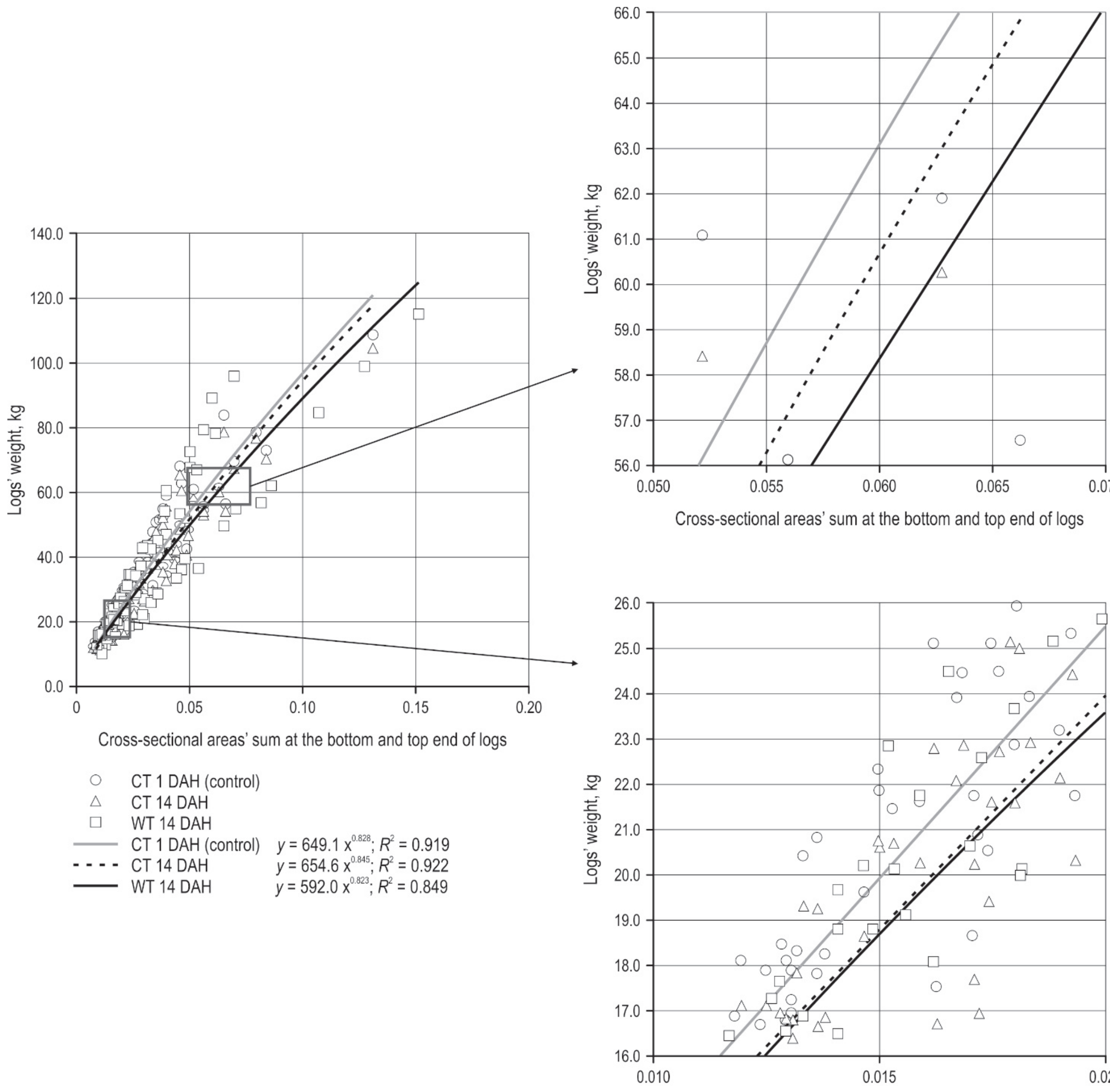

Fig. 3 Relationship between the sum of cross-sectional area and log weight depending on time and storage method

higher green density. The sections with smaller volume were naturally obtained from the top parts of trees. Considering the variability of wood density (oven dry or basic) along the trunk length (high dry density at the bottom, low dry density at the top part), the moisture content in the upper parts is expected to be higher than at the base.

Moisture loss is dependent on many factors. For example, drying out is restricted by bark. In this experiment, the logs were obtained so that the bark was not damaged. Thus, moisture could leak only through the area of the cross-section (top or bottom). Logs with smaller area of the cross-section lost moisture (weight) more rapidly than those with larger area. For example, in the case of a sum of cross-sectional area at the bottom end of the log of 0.015 m^2 (thinner logs), the difference between CT at 1 DAH and CT at 14 DAH was calculated at approximately 1 kg, while in the case of a sum of cross-sectional area of 0.06 m^2 (thicker logs), the difference was approximately 2 kg. If it was 1 kg per

0.015 m^2, it would result in about 67 kg per m^2. If it was 2 kg per 0.06 m^2, it would result in about 33.3 kg per m^2. An even greater weight loss was observed when comparing the control data (CT at 1 DAH) with the data for WT at 14 DAH. Analogous analysis showed that, for logs with the sum of cross-sectional areas at the bottom and top end of 0.06 m^2, the difference was around 5 kg. This is about 83.3 kg per m^2 (Fig. 3).

This is an interesting phenomenon, since the whole trees did not lose moisture through cross-sectional areas. In this case, moisture was lost through transpiration. After a tree is felled, the leaves continue to transpire, but there is no moisture uptake, and so the relative water content in the trunk decreases (Barrs 1968). However, the changes in water content are not uniform in different parts of the trunk.

4. Discussion

The trunks of living trees contain a large quantity of water, which is essential for the organism to function. Timber from fresh-felled trees, therefore, has a high moisture content and high green density. Moisture loss leads to changes in the weight and green density of wood. The rate of change in moisture depends on many factors. Moisture loss is largely dependent on the atmospheric conditions at the place and time of storage (Persson et al. 2002, Hultnäs et al. 2013, Erber et al. 2014, Routa et al. 2015, Erber et al. 2016, Anisimov et al. 2017). Particularly significant is the air humidity, which increases at times of rainfall (Afzal et al. 2010). Wood is a hygroscopic material, capable of absorbing and releasing water in the form of vapour. In heavy rainfall, moisture loss stops completely (the weight remains unchanged), or the weight of logs may increase, as occurred on days eight and nine of the experiment. In spite of the rainfall and periods of elevated air humidity, the weight of both the logs stored in a pile and those stored in the form of whole trees showed a decrease. There is only a low level of light (semi-darkness) inside a beech stand, even in summer, and particularly in younger stands. Such conditions reduce the drying of timber, and it would certainly affect the final results. However, such conditions are common, and hence reflect the actual potential of moisture loss during a short period of storage.

Garret (1985) evaluated the average moisture loss for many species of conifers and broad-leaved trees over a wide range of diameters and reported the decrease of 4% of the moisture content within two weeks in the summer period. In the present study, the logs stored in a pile (CT) lost approximately 6% of their mass, while those left in the stand (WT) lost approximately 10%. The differences were statistically significant (p-value <0.05). It can be concluded that a more effective method of drying is to leave whole trees after felling. This phenomenon, called transpirational drying, is a basic method of drying out timber and method for increasing the energy content of woody feedstocks (Cutshall et al. 2013, Civitarese et al. 2015). A review of a number of studies on transpirational drying was published by Stokes et al. (1993). They show that drying by this route takes place especially over the first two weeks. Comparing the weights of the trunk sections stored in a pile on days after harvesting, a statistically significant difference was found only between the first and the last day. It can be concluded that two weeks is the minimum period of storage required to obtain a significant degree of weight change and moisture loss. Nonetheless, the specific atmospheric conditions during the period of our experiment must be taken into account.

Beech is diffuse-porous wood. The weight differences obtained between the first and last day of storage were statistically significant. A similar result was obtained by Patterson and Post (1980) for paper birch, another diffuse-porous species (*Betula papyrifera* Marsh). However, they found no significant difference for northern red oak (*Quercus rubra* L.), a ring-porous species. The authors noted an increasing gradient in the moisture content from bole to crown. Similarly, in our experiment, logs with smaller volume and weight were found to have higher green density. These logs were obtained from the top part of trees, where wood is less dense than at the base of the trunk. Low-density wood is more porous, and therefore has a greater capacity to hold water, which results in a higher moisture content and in a higher green density in this part of the trunk.

In our study, logs cut from the top parts of trees lost weight (moisture) more rapidly than those with larger diameters (taken from the bottom of the trunk). A review of the literature shows that many authors have segregated logs on the basis of diameter (Garret 1985, Stokes et al. 1987, Spinelli et al. 2011, Assirelli et al. 2013, Saralecos et al. 2014), as this is one of the factors affecting drying (Kokkola 1993, Visser et al. 2014, Tomczak et al. 2016, Anisimov et al. 2017) or not affecting drying (Manzone 2015). Logs of smaller diameter have smaller cross-sectional areas, through which moisture may be lost. This is an interesting phenomenon, since the undelimbed beech trees did not take up water after felling, but continued to lose it in the same way as living trees, through evaporation from the surface of the leaves. The evaporated water is replaced by water stored in the wood, causing a rapid outflow of moisture.

The drying of wood prior to use has many advantages. These include lower transport costs, greater energy value of fuel, and increased efficiency of heating systems. In Poland, transport costs are becoming relatively higher, as timber harvesting is increasing. In the past decade, the total quantity of timber harvested has increased by several million cubic metres. There is also social pressure to use natural and renewable energy sources. The development of principles and methods for the storage of timber will eventually lead to a reduction in economic losses and increased efficiency in the supply chain of bioenergy (Erber et al. 2016, Krigstin and Wetzel 2016, Bennamoun et al. 2017).

5. Conclusions

To leave trees intact in the stand after felling is a more effective method of drying, known as transpirational drying. The timber stored in a pile (CT) lost moisture more slowly than the timber from trees that had been left whole after felling (WT). Comparing the weights of the logs stored in a pile on days after harvesting, a statistically significant difference was only found between the first and the last day. It can be concluded that two weeks is the minimum period of storage required to obtain a significant degree of weight change and moisture loss.

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Author's addresses:

Arkadiusz Tomczak, PhD. *
e-mail: arkadiusz.tomczak@up.poznan.pl
Grzegorz Grodziński. Eng.
e-mail: grodzinski.grzegorz@gmail.com
Marcin Jakubowski, PhD.
e-mail: marcin.jakubowski@up.poznan.pl
Tomasz Jelonek, PhD.
e-mail: tomasz.jelonek@up.poznan.pl
Assoc. prof. Witold Grzywiński, PhD.
e-mail: witold.grzywinski@up.poznan.pl
Department of Forest Utilisation
Faculty of Forestry
Poznań University of Life Sciences
Wojska Polskiego 71A St.
60-625 Poznań
POLAND

* Corresponding author