Seasoning Poplar (*Populus maximowiczii × Populus nigra ´Max 4-5´)* Wood Using Evapotranspiration

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This study focused on the use of evapotranspiration as a means of drying wood. This principle is based on the fact that tree species with outstanding sprouting capacities are able to leaf after being felled and are physiologically active until they have enough water. The course of wood drying (the stems and branches) was examined in relation to their subsequent foliage creation and ongoing evapotranspiration, and how those factors related to other factors (temperature and precipitation). As for stems, the drying process proved to be more effective in samples with buds and less effective in samples without buds. As for branches, the samples with buds had a slightly higher weight in the long-term average, but during the sprouting season their drying was more efficient. These findings may help achieve more efficient handling of the timber from fast-growing species in relation to their processing and storage.

Keywords: Wood drying/timber seasoning; Energy coppices; Poplar

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INTRODUCTION

Issues surrounding the use of fossil fuel have brought great focus on alternative energy sources. One of them is woody biomass, which is relatively accessible due to short rotation coppice (SRC) plantations. Another advantage of burning wood mass is its zero CO_2 balance.

In order to be used as fuel, biomass must reach a close to optimum state in terms of energy usability, *i.e.*, it must provide thermal energy. A dry wood substance has an average calorific value potential between 16.7 MJ/kg and 18.4 MJ/kg, *i.e.* 4.65 ÷ 5.11 kWh/kg (Bartolazzi 2005). The calorific value is fundamentally affected by moisture, which is between 50% and 60% of absolute moisture content during the harvest (Mitchell 1995). For efficient energy use, it is necessary to reduce the moisture content (Cafourek *et al.* 2016). In a short rotation, the wood is usually immediately chipped. Unless the wood is rapidly dried or used within a few days, this method of storage results in the degradation of the fuel (Mitchell *et al.* 1999). Storing the wood chips in piles increases the temperature of the chips through anaerobic microbial processes that reduce the fuel quality. These exothermic reactions may even lead to spontaneous ignition. For optimal combustion, it is necessary to achieve an absolute moisture content of at least 10% to 15%. This moisture level is particularly important in the case of smaller power stations (Brammer and Bridgwater 2002).

Most of today's modern combustion devices are equipped with drying systems. There are several methods of drying, which differ in energy demand, time, and temperature. Drying may take several weeks if warm air is used, or a few minutes if exhaust gases are used (Worley 2011). To reduce the costs, the moisture level of the mass entering the dryer should be as low as possible. This is achieved by natural drying, which does have the above-mentioned risks given that it is a lengthy process.

An important factor of the storage is climate, upon which other technical measures also depend. An Italian study (Manzone 2015) mentioned the possibility of covering piles of wood chips with breathable fleece fabric, white or black plastic sheeting, or a storage area under the roof. The results show that impervious plastic film can be used for short-term storage, as it prevents rapid temperature increase but does not decrease the moisture level of the chips. A more suitable method of storage in a drier southern climate is storage under a roof. It is not clear how such storage may work in a different climate. In the United Kingdom, for example, storage under the roof caused approximately 20% loss of mass (Mitchell *et al.* 1988) for willow, which is similar to poplar, in comparison with losses between 5% and 10% in Manzone’s studies in Italy (2015).

In the energy processing of wood mass, sawdust and its conglomerates in the form of pellets are also being used in addition to wood chips. Their drying process had specific requirements, and several studies addressed the details (Chen *et al.* 2012; Gebreegziabher *et al*. 2013; Monedero *et al*. 2015).

Much has been written about wood chips, including storage methods, the suitable size of chips, and their drying methods. However, little attention has been paid to the storage of logs, despite the fact that their storage results in a smaller loss of dry matter at approximately 2% per year. This small loss is also due to better air circulation within logs than in wood chips. Drying logs is a natural and standard process and is thus more cost-efficient compared to the relatively high technical demands of drying wood chips, which includes the risk of spontaneous ignition (Ferrero *et al*. 2009).

In Europe, there are two ways of storing logs for energy purposes that are both based on different methods of yarding. In northern countries, the typical length of logs ranges between 2 m and 6 m (Erber *et al*. 2012, 2014; Lin and Pan 2013); in southern countries, the length is between 1 m and 2 m (Zimbalatti and Proto 2009; Magagnotti *et al.* 2012; Manzone 2015). Shorter logs allow for storage on pallets and stacking under sheds, while longer logs are typically stored in stacks. However, storage requires a large area. Moreover, if stored on an unpaved surface, the stacks can become overgrown by weeds, which enhances the conditions for mass degradation. Manzone (2015) concluded that in southern European countries with a dry climate, after 60 days of drying timber in stacks, regardless of the thickness and height of the stack, the moisture reduction was less than 20%. Barontini *et al*. (2014) found that after wood chips were stored for 180 days in climatic conditions similar to those in Manzone’s experiment (2015), the moisture level of wood chips was approximately 30% and the dry matter loss was between 6% and 27%.

Souček *et al*. (2008) designed and monitored the progress of energy wood biomass drying in the oven. They achieved good drying within a short time, but at the price of considerable energy demands (Souček *et al.* 2008). Sladký (2004) examined the economic aspect of drying, and found that because of the need to use dryers for final moisture reduction and other costs, poplar fuel cannot compete with brown coal without financial support from the state.

This study sought to achieve the more efficient drying of poplar logs stored on a bare surface using evapotranspiration. This experiment followed previous experiments (Klvac *et al.* 2014) in which a few stem samples were left for foliage in the same way, and the results indicate decreasing wood moisture using evapotranspiration.

EXPERIMENTAL

Materials

Forty poplars were used for the research (*Populus maximowiczii* × *P. nigra* 'Max 4-5'). The samples were taken from a lot in Vráž, near Písek, in the South Bohemian region of the Czech Republic. The coordinates of the lot were 49° 39' 39'' N, 14° 11' 71'' E. The area of the plantation was 0.6 ha. In this area, 3-year-old bare-root plants of Japanese poplars (mix of clones *Max 4-5*) were planted. The stem diameter (measured on the butt) varied between 4.8 and 5.4 cm with an average of 5.2 cm, and the branch diameter ranged between 0.5 and 1.8 cm; the average was 0.9 cm. The altitude of the location was 435 m, and the average annual rainfall was 565 mm. The soil was claylike with an average production potential according to the Czech system of farming land classification called BPEJ. The altitude of the location where the samples were dried and weighed was 380 m, the slope of the terrain was up to 1%, and the grass covers the surface up to 10 cm.

Methods

The fieldwork in Vráž was performed on March 22, 2015 before the 2015 growing season started. The plantation was established in the spring of 2012. The plants were grown from the spring of 2011 to the autumn of 2011, when they were removed, trimmed, and then replanted in the soil. They were not treated during their growth period. The planting density was 8000 pcs/ha, and they were planted in a rectangular spacing (1.8 m x 0.6 m). Before the 2015 growing season, 40 three-year-old specimens of poplar (*Populus maximowiczii* x *P. nigra 'Max 4-5'*) were cut down. The samples were selected at random, but always at least 10 m from the edge to exclude the impact of factors affecting the edges.

A handsaw (Fiskars Oyj Abp, Helsinki, Finland) was used for the felling of the trees, and pruning shears were used for debranching. Felling was performed as close to the ground as possible, and the branches were cut as close to the trunk as possible. An upper part of the stem (terminal) up to a diameter of 1.5 cm was added to the branches. Branches were bundled and labelled immediately after shearing. The stem and bundle were always given the same number to avoid confusion. The samples were then stored in a covered van to prevent devaluation during transport, and then they were transported to a site near České Budějovice. After the transport, the buds were removed from the stems and branches of 20 sample plants. The samples were then placed on wooden supports and periodically weighed every five days.

Fig. 1. Poplar stems on supports

For weighing, a digital suspension scale HDB 10K10 Kern (Kern, Balingen, Germany) with an accuracy of 10 g was used. Calibration was performed before weighing. The climatic factors were recorded by the Davis Vantage Pro 2 (Davis Instruments Corp., Hayward, California, USA) weather station at the nearest climatological station (České Budějovice). To test the influence of climatic factors, the daily precipitation totals and average daily temperatures were used. The precipitation was measured with a tipping bucket rain gauge with a resolution of 0.2 mm and an accuracy of ± 4%. The gauge recorded temperatures at a resolution of 0.1 °C from -40 °C to +65 °C with an accuracy of ± 0.5 °C.

Evaluation and calculation

Due to the different weights of the various samples, further analysis referred to the relative sample weight related to the initial state, according to Eq. 1,

$$M_i = \frac{m_i}{m_0} \tag{1}$$

where, m_{i} is the total weight (kg) of samples on the i-th day of measurement, m_0 is the absolute weight (kg) at the beginning of the measurement, and M_i is the relative weight. A linear relationship was assumed between the relative weight of samples and conditions of drying.

The factors affecting the drying process depended on the relative weight of wood, and were modeled using Eq. 2

$$M_i = \beta_0 + \beta_1 x_{1,i} + \beta_2 x_{2,i} + \beta_3 x_{3,i} + \beta_4 x_{4,i} + \beta_5 x_{5,i} + \varepsilon_i, \tag{2}$$

where x_1 is the number of days from the beginning of the drying, x_2 and x_3 are the amounts of rainfall (mm) and temperature (°C), respectively, one day before measuring the weight, x_4 is the sprouting indication, x_5 is an indication of the buds' appearance (at least 90% of buds was breaking), β_j are the respective regression coefficients, and ε_{i} are residues.

The relative weight differences of the variants with and without buds on individual days were compared using Welch's test. This was a modified two-sample Student´s t-test that did not assume equal variances; it did, however, keep the normal distribution assumption. The test statistic is as follows:

$$T = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}, \tag{3}$$

where $\overline{X}_1$ is the arithmetic average of the first sample, s_1^2 is the variance, and n_1 is the size of the first set (number of samples). The symbols $\overline{X}_2$, s_2^2, and n_2 mark the same values in the second sample. The degrees of freedom are given according to Eq. 4,

$$v = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{s_1^4}{n_1^2(n_1+1)} + \frac{s_2^4}{n_2^2(n_2+1)}} - 2, \tag{4}$$

where $n_1 + 1$ is the number of degrees of freedom for the first estimate of the variance, and $n_2 + 1$ for the second variance estimate.

RESULTS AND DISCUSSION

Table 1 lists the average sample weight at the beginning and end of the experiment.

Table 1. Average Sample Weight

	Stems		Branches	
	Buds	No buds	Buds	No buds
Weight average (initial/final)(kg)	1.250/0.520	1.240/0.540	0.996/0.425	0.949/0.416

The average values of the initial and final weights of the samples show that the weight decrease was more pronounced in samples with buds.

Relationship between Relative Weight and the Variables Influencing the Drying Process During the Whole Period

The proposed model (see Eq. 2) explained a large part of the data variability, namely the coefficient of determination was over 90%. Tables 2 and 3 provide estimates for the parameters of Model 2 and a statistical analysis.

Table 2. The Influence of Selected Factors on Stem Weight Loss

	Estimate	Std. Error	Pr (> |t|)
(Intercept)	1.468E+00	8.547E-03	<2e-16
Day	-4.594E-03	7.823E-05	<2e-16
Precipitation	2.319E-04	5.142E-04	0.6521
Temperature	-1.320E-03	5.334E-04	0.0135
Budbreak	-5.615E-02	3.326E-03	<2e-16
Buds	-3.272E-02	3.060E-03	<2e-16

Residual standard error: 0.04539; Multiple R-squared: 0.9247; F-statistic: 2146 on 5 and 874 D, p-value: < 2.2e - 16

Table 2 shows that the samples with buds showed a significantly lower average relative weight during the experiment (approximately 0.0327 kilograms). The influence of the sprouting time was also demonstrated, though the influence of the temperature and precipitation on weight decrease was not shown.

Table 3 shows that the branches with buds showed a significantly higher average relative weight during the experiment (approximately 0.0177 kg), and also demonstrates the effect of the sprouting period. As with the stem samples, there was no evidence that temperature or precipitation influenced the weight.

Table 3. Influence of Selected Factors on Branch Weight Loss

	Estimate	Std. Error	Pr(>|t|)
(Intercept)	1.459E+00	9.645E-03	< 2e-16
Day	-5.020E-03	8.829E-05	< 2e-16
Precipitation	5.062E-04	5.803E-04	0.383
Temperature	6.030E-04	6.020E-04	0.317
Budbreak	-6.853E-02	3.754E-03	< 2e-16
Buds	1.770E-02	3.453E-03	3.68e-07

Residual standard error: 0.0512; Multiple R-squared: 0.9119; F-statistic: 1809 on 5 and 874 DF, p-value: < 2.2e-16

During the experiment, the samples of stems with buds showed a significantly lower average relative weight, and the branch samples showed an opposite trend. These results were explained by the ratio of the weight of the buds and the leaves to the total weight of the sample. In this ratio, the branches, when compared with the stems, significantly shifted in favor of the weight of the leaves and the buds. Due to vertical and horizontal precipitation, the quantity of water absorbed by the branches was comparatively higher (compared with the stems). This fact was probably the decisive factor that explained the changes of the relative weight of the branches during the experiment. The results also confirmed significant effects of the sprouting period; during this period the drying was more efficient, which confirmed the assumption that evapotranspiration accelerated the drying process. As for the stem samples, those with buds where foliage developed lost moisture faster than the stem samples without buds, which also confirmed the original assumption that evapotranspiration accelerated the drying process. The result was only statistically relevant for the aggregate period (Eq. 2), where branches with buds had a higher relative weight than the branches without buds for the aggregate period. However, at the end of the experiment after the leaves dried, the relative weight of the branches dropped, which confirmed that evapotranspiration accelerated the drying process.

Relationship between the Weight of the Samples With and Without Buds in Respective Days

Table 4 shows the results of ANOVA evaluating the effect of Branch Difference and Stem Difference on the monitored characteristics.

Based on the significance level "P", it was judged to be a significant and insignificant effect on the monitored characteristics.

Table 4 shows the differences between the relative weight of samples with and without buds for each day for both the stems and the branches. The second column shows the importance levels of the respective Welch test. To keep the level of significance at 0.05 while evaluating the results for the whole duration of the experiment, the Bonferroni correction was used. The criterion for the statistical significance of the differences in separate days was 0.0024. Statistically significant differences are marked green in Table 4.

Table 4. Differences between the Relative Weight of Samples With and Without Buds

Measurement	Branches		Stem	
	Difference	p-value	Difference	p-value
1	-0.005	0.4412	-0.013	0.2804
2	0.015	0.1136	-0.023	0.0405
3	0.024	0.0625	-0.035	0.0047
4	0.033	0.0141	-0.021	0.1370
5	0.058	0.0002	-0.019	0.2101
6	0.046	0.0016	-0.033	0.0225
7	0.037	0.0168	-0.049	0.0012
8	0.069	0.0005	-0.056	0.0002
9	0.057	0.0024	-0.039	0.0052
10	0.046	0.0100	-0.040	0.0031
11	0.040	0.0069	-0.040	0.0051
12	0.032	0.0139	-0.045	0.0014
13	0.015	0.1749	-0.039	0.0042
14	0.006	0.5438	-0.042	0.0016
15	0.004	0.6307	-0.043	0.0011
16	0.003	0.6960	-0.044	0.0023
17	0.003	0.7515	-0.032	0.0231
18	-0.031	0.0109	-0.019	0.1509
19	-0.024	0.0058	-0.032	0.0258
20	-0.023	0.0188	-0.040	0.0020
21	-0.016	0.2439	-0.017	0.1886

Figure 2 describes the course of the changes in the relative weight of branches and stems during the experiment. As for the stems, a lower relative weight of samples with buds was evident during the whole experiment. For the branches it was usually the opposite, but at the end of the experiment the relative weight was reduced even in the samples with buds.

Figure 3 shows, in the case of the branches, a long period in which the samples with buds had a higher relative weight than the samples without buds. However, there was a change over time, and, at the end of the period, the relative weight of the samples with buds was lower (significantly when concerning samples individually). This change was possibly caused by the leaves drying at the end of the monitored period, when the weight of the samples considerably decreased.

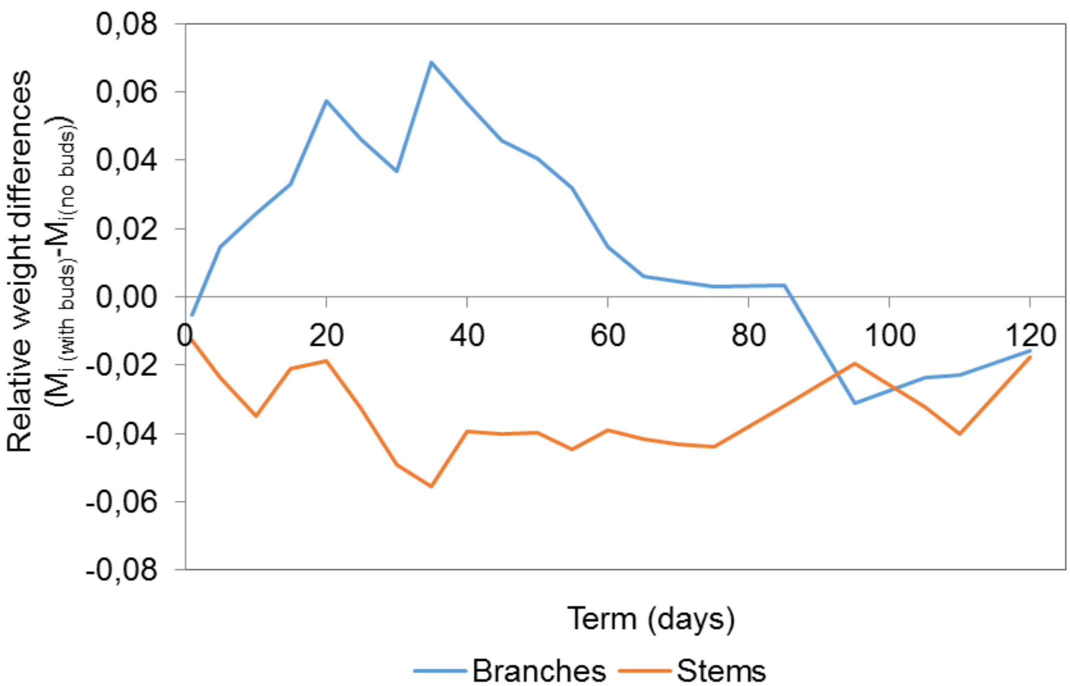

Fig. 2. Differences in the relative weight of branches (with and without buds) and stems (with and without buds) during the experiment

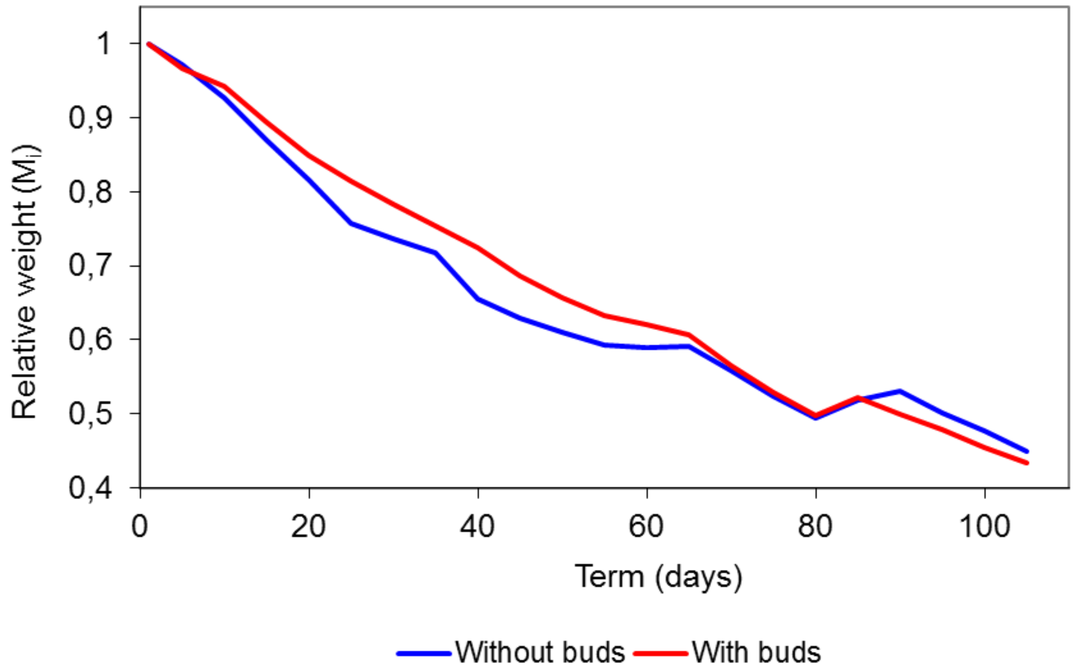

Fig. 3. Development of the average relative weight of branches

As for the stems, the relative weight of the samples with buds was lower during the entire period, mostly statistically significant (Fig. 4).

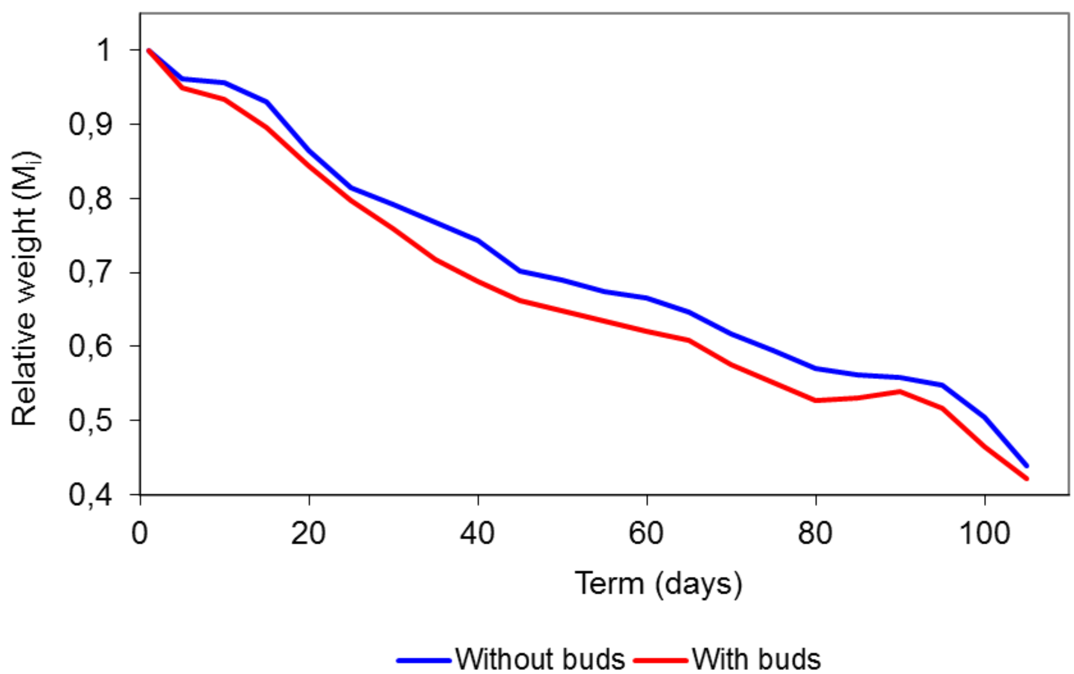

Fig. 4. Development of the average relative weight of stems

The use of evapotranspiration possibly brings the opportunity to accelerate the drying process of wood stems (Fig. 4), but it is necessary to investigate the influence of other factors (*e.g.* precipitation interception) that may play a crucial role in the drying process.

CONCLUSIONS

1. Samples with buds showed an overall significantly lower average relative weight (M_i) during the experiment in the stem samples (approximately with M_i = 0.0327). The branches were inversely related, and the relative weight was higher with M_i = 0.0177 during the experiment.
2. Each day the relative weight of the stems with buds was lower, and most of the days were statistically significant. As for branches, the relative weight was mostly inversed, though at the end of the experiment the relative weight of the branches with buds was abruptly lower (due to dry leaves) than the samples without buds, but not significantly.
3. As for the stems and branches, no correlation was established between the amount of precipitation, temperature, and relative weight.
4. The results also confirmed a significant influence of the sprouting period. During the sprouting, the drying was significantly more efficient.

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