TRANSPIRATION AND BIOMASS INCREMENT IN SHORT ROTATION POPLAR COPPICE

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ABSTRACT

This paper deals with interaction between amount of water lost by tree transpiration and aboveground biomass increment in poplar based short rotation coppice in conditions of Czech-Moravian highlands. Stem sap-flow measured on 8 poplar trees by Granier heat dissipation method was put in relation with biomass increments measured both with automated dendrometers so with manual measurements with caliper gauge. Transpiration totals ranged between 28.3–175.6 liters per tree in executed period 3.8.–31.8.2011. Above-ground biomass increments in this period varied between 30.07–519.28 g per tree and mean value of water use efficiency of all monitored trees reached 2.76 g.kg^{-1}. Mean diurnal sap-flow total of all sampled trees was 3.25 liters. Results show that it is possible to establish relationship between transpiration totals and biomass increments (coefficient of determination $R^2 = 0.90$) and also relationship between transpiration totals and stem diameter ($R^2 = 0.81$). These results (especially after obtaining experimental data from spring growth conditions) can be further used for calculations of biomass increments and transpiration as scaling factors from tree level to whole stand level.

Key words: sap-flow, transpiration, biomass increment, poplar, short rotation coppice

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INTRODUCTION

Short rotation coppice (SRC) generally means any high-yielding fast-growing woody species managed under coppice system grown for biomass production on arable land. Trees are usually coppiced every three to six years depending on genotype of the clone used, weather conditions and management practices, which influence survival rate and final vigor of the stand. In last decades SRC plantation based on poplar (Populus spp.) and willow (Salix spp.) are increasingly being grown in Europe as a sustainable source of bioenergy. The largest areas of SRC are situated in Scandinavia (Sweden 12 500 ha) (Dimitriou et al, 2011), Germany, UK, Italy, Belgium and France (Slater et al., 2001). Highest potential of SRC consists in vigorous juvenile growth and rapid biomass accumulation, reaching under conditions of the Czech-Moravian highland mean annual increment close to 14 tons of dry matter per hectare (Trnka et al., 2008). Beside its productive function the SRC could potentially provide other ecosystem services as e.g. increasing biodiversity, cooling landscape by transpiration, increasing carbon content in soil, utilizing municipal wastewater for irrigation/fertilization etc. In the early screening and breeding efforts on energy crops the main focus was on aspects such as potential productivity, disease and frost resistance, coppicing and resprouting ability (Hall & Hanna, 1995; Zsuffa, 1995). However, more recently it has been acknowledged that water will very often under practical conditions be the most important yield-limiting factor (e.g. Lindroth & Båth, 1999). The urge to determine relationship between water flux and biomass increment of plants led to the expression water use efficiency (WUE), which is a ratio between **biomass growth** (total dry matter produced) and the **water lost by transpiration** (de Wit, 1958). WUE of majority of energy plants vary between 0.3 – 14.2 g kg^{-1} (Jørgensen a Shelde, 2001). Biomass growth is usually estimated on the basis of dendrometric measurements, which can be practically performed only on the above-ground part. Therefore, WUE is mostly estimated for above-ground biomass production (Ciencialla, 1995). Diurnal transpiration of particular tree can be derived from the stem sap flow (Sellami, 2003). There are several methods for measuring sap-flow generally based on the analysis of how much of the heat applied to the conductive xylem is removed by the passing water flow in the stem. Granier (1985) developed a dual-probe sap flow measuring system, which is now commonly known as the Granier or thermal dissipation probe (TDP) method. This method is used for sap-flow measurements in this study.

This paper provides first processed data regarding sap-flow rates of poplar based SRC frequently planted in Czech Republic. Interconnection of above-ground biomass increments (ABi) measured in parallel with water loss through transpiration allows to prove their mutal relationship and brings better understanding of soil-plant-atmosphere water fluxes in SRC.

MATERIALS AND METHODS

In April 2001, a high density experimental field plantation of poplar clone J-105 (P. *nigra* x P. *maximowiczii*) with the total area of 4 ha was established in locality Domanínek, near Bystřice nad Pernštějnem (Czech Republic, Czech-Moravian highland, 49°521'N, 16°235'E, altitude 530 m, rain-fed area with mean annual precipitation 587.8 mm, mean annual temperature 6.6 °C). The plantation was established on agricultural land previously seeded predominantly with cereals and potatoes. Hardwood cuttings were planted in a double row design with inter-row distances of 2.6 m and spacing of 0.7 m within rows accommodating density of 10,000 trees/ha. Soil conditions at the location are representative to the wider region with deep luvic cambisol influenced by gleyic processes and with limited amount of stones in the profile. The site itself is situated on a mild slope of 3° with an eastern aspect and is generally subject to cool and relatively wet temperate climate typical for this part of Central Europe with mingling of continental and maritime influences. Although the area does not provide optimal conditions for SRC based on Populus sp. clones, the site itself is highly suitable for planting due to deep soil profile (Trnka et al., 2008).

In 2011 the examined poplar plantation was in the 3rd year of 2nd rotation. In mid June 2011 four automatic dendrometers (DRL 26) (EMS Brno, Czech Republic) were placed on randomly chosen poplar tress within 50 m^2 research plot. In late July 8 pcs of sap-flow measurement sensors (Granier) (UP GmbH, Cottbus, Germany) were purchased. The measurement method relies on the fact, that the sap flow is deducted from the thermal difference between a probe continuously heated at a constant power and a reference probe, using an empirical relationship determined in laboratory conditions. The measuring element consists of two cylindrical probes (2 cm long and 2 mm in diameter). Each of them contains a copper-constantant thermocouple. Those probes are radially inserted in the sapwood of the trunk at o distance of approximately 15 cm from each other. The upper probe is heated at a constant power (0.2 W) and the lower probe is considered as temperature reference. The two thermocouples are mounted in opposition so the temperature difference between the two probes can be measured. In early August four trees with DRL 26’s were supplemented with 4 Graniers. Remaining 4 Graniers were installed on other 4 trees within the same plot. The sap-flow of 8 different poplar trees was continuously monitored in 10 min. measuring step for 1 month period (VIII). Sap flow was calculated according recommended equation: $\mathbf{v = 0.199*[(\Delta T_{max}/\Delta T) - 1]^{1.231}}$, [kg m^{-2} s^{-1}], where $\Delta T_{max} \geq \Delta T$ is the temperature difference for zero sap flow and is approximated by the maximum ΔT at nighttime. In addition, the temporal changes in DBH were measured either in 1 hour step (4 trees monitored automatically by DRL 26’s) or 2 week step (4 trees measured manually by digital caliper gauge). The initial DBH ranged between 27.1 – 59.39 mm. The values of DBH [mm] increment were subsequently converted through the allometric equation: $\mathbf{y = 0{,}204x^{2{,}172}}$, ($R^2 = 0.99$) to increment of biomass [kg]. This equation describing relationship between DBH and weight originated from destructive sampling carried out in early spring 2011. Initial ABi contents were subtracted from final biomass contents and thus the ABI of particular tree and for whole period was obtained. Furthermore, the ABi of each tree was divided by sap flow totals and thus WUE was obtained.

RESULTS AND DISCUSSION

During monitored period 3. 8. – 31. 8. 2011 the stem sap flow and above-ground biomass increments of 8 poplar trees were measured. Tab. 1 summarizes all data collected and calculated.

Tab. 1 Summary of data collected and calculated.

Period 3. 8. - 31. 8. 2011					
Tree no.	Final DBH [mm]	Sap-flow totals [kg]	Diurnal average sapflow totals [kg day^{-1}]	Biomass increment [kg]	WUE [g kg^{-1}]
#1	60.56	116.70	4.02	0.42	3.64
#2	55.95	118.15	4.07	0.33	2.77
#3	31.69	41.21	1.42	0.07	1.70
#4	28.91	28.34	0.98	0.07	2.56
#5	55.34	175.61	6.06	0.52	2.96
#6	50.95	133.01	4.59	0.42	3.18
#7	52.66	109.04	3.76	0.47	4.33
#8	27.31	31.96	1.10	0.03	0.94

The initial DBH of poplar trees ranged between 27.1 – 59.39 mm, the final DBH varied between 27.31 – 60.56 mm. After 29 day (3. 8. – 31. 8. 2011) the mean DBH increment of all trees reached 0.95 mm, which represents mean above-ground biomass increment 292.41 g per tree. Maximal increment was observed by tree #5 – 519.28 g, the lowest increment had tree #8 – 30.07 g per period 3. 8. – 31. 8. 2011. The amount of water lost by transpiration depended on the particular tree DBH, as expected. Transpiration totals ranged varied 28.34 – 175.61 liters per tree and period. Average diurnal sap flow totals for particular trees reached from 0.98 liters (tree #4, DBH 28.34 mm) to 6.06 liters (tree #5, DBH 55.34 mm). WUE ranged from 4.33 to 0.94 and mean value of WUE of all monitored trees reached 2.76 g kg^{-1} (VIII 2011), which is in good agreement with values described in Fischer et al. 2010.

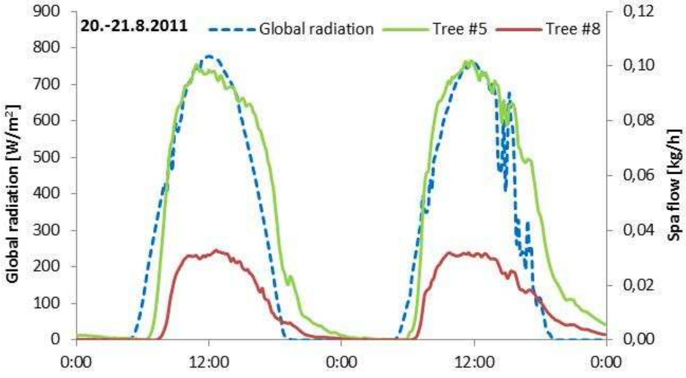

Fig. 1 Comparison of daily course of sap flow between tree #5 (DBH = 55.34 mm) and tree #8 (DBH = 27.31 mm).

In Fig. 1 is depicted daily course of sap flow of two contrasting trees. Tree #5 (final DBH = 55.34 mm) shows highest transpiration rate (21. 8. 2011 reached 10.16 liters in 24h), on the contrary the tree #8 (final DBH = 27.31 mm) showed lowest transpiration rate (21. 8. 2011 reached 6.1 liters in 24h) compared with all sampled trees.

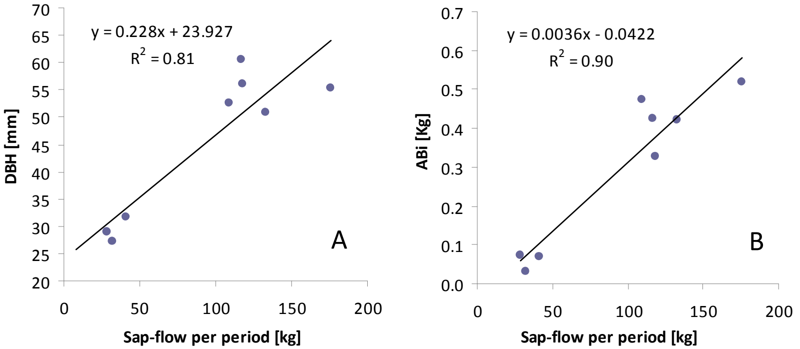

Fig. 2 A illustrates the relationship between DBH of particular tree and its sap flow. B illustrates the relationship between tree sap flow and above-ground biomass increment.

In figure 2 A is depicted relatively close relationship between DBH and transpiration totals for particular trees and period, with coefficient of determination $R^2 = 0.81$. However the “skill” of the linear function is significantly helped by the existence of two distinct group of points with trees having low DBH showing low Sap-flow values and similarly for high DBH. The trees from classes between 30 and 60 mm in diameter will be sampled during the next season. Part of the unexplained variability is due to the influence of soil moisture variability and mutual competition between trees and simultaneously between particular shoots on each stump which were not (yet) considered in this first study. Additional data regarding tree height, soil moisture variability or number of shoots growing from particular stump would provide more accurate results. Figure 2 B depicts similar linkage between transpiration totals and biomass increment. There is almost linear dependence ($R^2 = 0.90$) between an amount of water lost by transpiration and biomass increment, which confirms our initial presumption. As in the case of DBH the robustness of the relationship between Sap-flow and biomass increment have to be increased by additional measurements but the study has proved the concept and selected method.

CONCLUSIONS

Authors have found promising relationship between total amount of water lost by transpiration and above-ground biomass increment with coefficient of determination $R^2 = 0.90$. It was also showed, that the amount of water lost by transpiration is directly linked with DBH of particular tree. This relationship shows coefficient of determination $R^2 = 0.81$. The mean water use efficiency of sampled trees in August 2011 reached 2.76 g kg^{-1}, mean diurnal water loss is 3.25 kg per tree and the mean above-ground biomass increment reached 292.41 g per tree. These results (after obtaining additional experimental data) can be further used as scaling factors for calculations biomass increments and transpiration from tree level to whole stand level.

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