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BIOMASS PRODUCTIVITY AND WATER USE RELATION IN SHORT ROTATION POPLAR COPPICE (*POPULUS NIGRA X P. MAXIMOWICZII*) IN THE CONDITIONS OF CZECH MORAVIAN HIGHLANDS

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Abstract

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The plantations of short rotation coppice (SRC) usually based on poplar or willow species are promising source of biomass for energy use. To contribute to decision-making process where to establish the plantations we evaluated the water consumption and its relation to biomass yields of poplar hybrid clone J-105 (*Populus nigra x P. maximowiczii*) in representative conditions for Czech-Moravian Highlands. Water availability is usually considered as one of the main constraints of profitable SRC culture and therefore we focused on analyzing of the linkage between the aboveground biomass increments and the total stand actual evapotranspiration (ET_a) and on water use efficiency of production (WUE_P). During the seasons 2008 and 2009 the total stand ET_a measured by Bowen ratio energy balance system constructed above poplar canopy and the stem diameter increments of randomly chosen sample trees were examined. The stem diameters were subsequently converted to total aboveground biomass (AB) by allometric equation obtained by destructive analysis at the beginning of 2010. The biomass volume and its increment of particular trees were subsequently converted to the whole canopy growth and correlated with the ET_a values. Our results revealed that there was a statistically significant relation between water lost and biomass growth with coefficients of determination r^2 0.96 and 0.51 in 2008 and 2009 respectively. By using multiple linear regression analysis additionally accounting for effect of precipitation events and thermal time (sums of effective temperatures above +5 °C) the AB growth was explained from 98 and 87% in 2008 and 2009, respectively. Therefore for further analysis the multiple linear regression model was applied. The dynamic of seasonal WUE_P (expressed as gram of AB dry matter per thousand grams of water) reached up to 6.2 and 6.8 g kg^{-1} with means 3.13 and 3.54 g kg^{-1} in both executed years respectively. These values are situated in higher range comparing to the other broadleaved tree species of temperate climate zone and suggest that economically profitable plantation (defined by yield at least in the range of 10–12 Mg ha^{-1} year^{-1} of dry matter content) will consume more than 450–500 mm per growing season and thus will demand a locality with higher and adequately temporally distributed amount of precipitation especially in rain fed areas such as the discussed Czech-Moravian Highlands.

short rotation coppice, biomass increment, water consumption, water use efficiency

The term short rotation coppice (SRC) is generally used for any high-yielding woody species managed in a coppice system usually grown especially for energy use on arable land. Typically, these crops are harvested on a 3–7 years long rotation and remain viable for 15–30 years. The SRC plantations in the conditions of middle Europe are usually based on poplar or willow species and have been seen recently as a promising source of bio-energy. The replacement of fossil fuel with biomass in the generation of energy and heat has recently been an important strategy promote by the European Union (EU) to mitigate effect of climate change an enhance the security of the supply and diversification of energy sources (IEA, 2003). Moreover, biomass and in particular energy crops have attracted attention as a promising renewable and local energy source which could help the EU reduce its dependency on external energy sources, i.e., the main oil-exporting and gas- exporting countries (EU commission, 2005, Gasol *et al.*, 2007). Within the biomass option, SRC plantations feature several environmental advantages. Of all the raw materials, such as winter rape oil, sugarcane, sorghum, soy and palm oil, wood chips show the best performance as biofuel with respect to the total environmental impact and greenhouse gas emissions (Scharlemann and Laurance, 2008). Only biofuels produced from waste materials show a better performance (Lasch *et al.*, 2009). Furthermore, the life cycle assessment for poplar SRC plantations in Germany (Rödl, 2008) confirms the very low CO_2 emissions resulting from energy production using biomass from SRC. It produces just 0.015 kg CO_2-equivalent per kWh generated electricity. At the other extreme, lignite-fired power plants discharge 1.1 kg CO_2-equivalent per kWh. In accordance with the results of many research papers, SRCs has additionally positive impacts on their surround; e.g. on water cycle, carbon cycle, biodiversity, liveliness of the countryside, and also beside the energetic independence also higher employment rate (Isebrands and Karnosky, 2001). Despite these facts, the areas of SRC plantations in the Czech Republic are still low compared with the neighbouring countries (Weger *et al.*, 2009), however, higher popularity of SRCs and resolve to plant them has been recorded during a few of last years. For successful establishing and choosing suitable sites, it is necessary to understand well the growth requirements of particular species for the planned plantation. According to empirical and modelled results, the water availability of the locality constitutes one of the main constraint for SRC grown on arable land (Braatne *et al.*, 1992; Cienciala and Lindroth, 1995; Lindroth and Båth, 1999; Deckmyn *et al.*, 2004; Fischer *et al.*, 2010). As a convenient characteristic assessing how the water use is coupled with the biomass yields, so called water-use efficiency (WUE) was proposed. There are many ways describing WUE depending on the scientific disciplines and different measuring methods and approach. Firstly, WUE can be described as a ratio of CO_2 uptake and transpiration in the process of photosynthesis (Polster, 1950; Bierhuizen and Slatyer, 1965; Holmgren, 1965; Tanner and Sinclair, 1983). In this case we are talking about so called water-use efficiency of photosynthesis (WUE_{Ph}) or sometimes referred to as WUE_I – instantaneous WUE because of the time resolution (Bierhuizen and Slatyer, 1965; Zur and Jones 1984; Baldocchi *et al.*, 1987; Denmead *et al.*, 1993; Lindroth *et al.*, 1994; Cienciala and Lindroth, 1995; Larcher, 2003). For ecological, agricultural and forestry purpose, however, the ratio of dry matter production to water consumption over longer period is more informative than temporary gas exchange ratios. Hellriegel (1883) and Maximow (1923) are considered to be among the first who carried out calculations on the relationship between increase in dry matter and water requirement. By dividing the biomass productivity, expressed as organic dry matter, with the water lost by transpiration or whole evapotranspiration, water-use efficiency of productivity (WUE_P) or long term WUE (WUE_L) is obtained (de Wit, 1958; Lindroth *et al.*, 1994; Cienciala and Lindroth, 1995; Linderson *et al.*, 2007; Forrester *et al.*, 2010). Sometimes the reciprocal transpiration, evapotranspiration or assimilation ratio is used describing the water use per unit of growth (Jones and Mansfield, 1972; Masle *et al.*, 1992). To estimate the WUE of whole ecosystem geoscientist and ecologist commonly use the ratio of the main ecosystem fluxes such as gross primary production (GPP) gross ecosystem production (GEP), or net primary (ecosystem) production (NPP, NEP) to the water losses by evapotranspiration and thus $WUE_{GPP(GEP,NPP,NEP)}$ is obtained (Law *et al.*, 2002; Reichstein *et al.*, 2002). Depending on which method is used, factors such diurnal variation in root and soil respiration, relative carbon allocation to roots and shoots, turnover of fine roots and leaves have influence in resulting WUE (Lindroth *et al.*, 1994; Dickmann *et al.*, 2001).

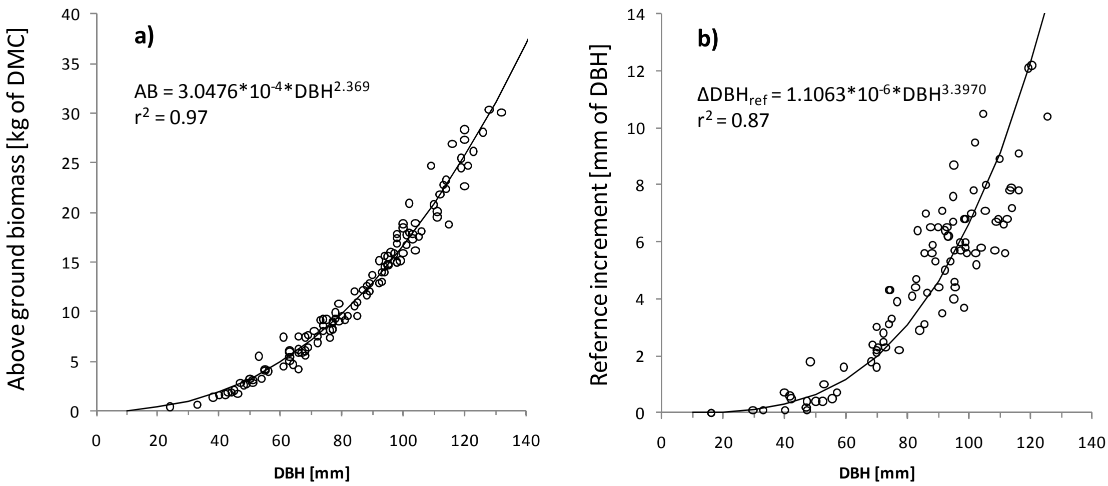
Generally, the average WUE_P of most coniferous and broadleaved trees of temperate zone range between 3–5 g of dry biomass per kg of transpirated water (Larcher, 2003). The research on WUE_P of three different poplar clones (Beaupré, Trichobel and Ghoy) growing in weighting pots placed in greenhouse indicated relatively constant values varying from 3.5–4.4 g of dry biomass per kg of water despite strongly fluctuated soil moisture during the season leading to marked variation in root-to-shoot ratios (Souch and Stephens, 1998). However, Guidi *et al.* (2008) demonstrated great influence of fertilization on WUE_P where the effect of fertilizers increased WUE_P from 0.43 to 2.14 and from 0.68 to 2.4 g of dry biomass per kg of evapotranspirated water, respectively for willows and poplars used as a vegetation filter. Lindroth *et al.* (1994) investigated WUE_P of fertilized and irrigated high-density willow stand and they found relatively high values of mean seasonal WUE_P reaching to 4.1 and 5.5 g of dry biomass per kg of transpirated water for two consecutive years. Later study by Lindroth and Cienciala (1996) found even higher mean seasonal values of WUE_P reaching to 6.3 of dry biomass per kg of transpirated water which they associated with high foliar nitrogen concentrations.

The main aim of this paper is to provide first analysis of the water and biomass relation of SRC species frequently planted in the Czech Republic. It is done by using the long term WUE_P based on stand aboveground biomass increment and water lost by evapotranspiration. The main hypothesis that there is existing relationship described by WUE_P is extended by including possible influence of weather conditions and seasonal variation of WUE_P on the biomass yield estimation.

MATERIALS AND METHODS

In April 2002 a high-density experimental field plantation for verification of the performance of poplar clone J-105 (*Populus nigra x P. maximowiczii*) with the total area of 4 ha was established in Domanínek (Czech Republic, 49° 32´ N, 16° 15´ E and altitude 530 m a.s.l.). The plantation was established on agricultural land previously cropped predominantly for cereals and potatoes. No irrigation, fertilization and herbicide treatments were applied during the whole experiment. Hardwood cuttings were planted in a double row design with inter-row distances of 2.5 m and spacing of 0.7 m within rows accommodating a theoretical density of 9,200 trees/ha. Soil conditions at the location are representative of the wider region with deep luvic Cambisol influenced by gleyic processes and with a 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 continental and maritime influences. Although the area in general does not provide prime 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 May 2008, 14 m high mast with system for estimating actual evapotranspiration (ET_a) by measuring Bowen ratio and radiation balance (EMS Brno, Czech Republic) was placed in the centre of the poplar plantation. At the same place below ground, three sensors EC-20 (Decagon Devices, USA) for measuring volumetric water content of soil and six gypsum blocks (EMS Brno, Czech Republic) to measure soil water potential were accommodated in the depths 0.1 m, 0.3 m and 0.9 m. All sensors were connected to datalogger ModuLog 3029 (EMS Brno, Czech Republic) and measuring step was adjusted to measure each 2 minutes and to store the averages each 10 minutes. At the same time, the tipping bucket rain gauge MetOne 370 (MetOne Instruments, USA) was placed next to the poplar plantation. For estimating biomass increment and its reaction to soil water availability an array of 15 mechanical – DB 20 and 3 automatic dendrometers – DRL 26 (EMS Brno, Czech Republic) were used. These measurements were updated by adding another 15 DB 20 and 1 DRL 26 dendrometers at start of the season 2009. The DBs and DRLs were fixed to trunks at the breast height and read in a week period while the DRL 26 dataloggers were adjusted to hourly measuring step. The dendrometers used are designed for long-term registration of tree trunk circumference via stainless tape that encircles the tree trunk. The values of increment are very useful because they could be subsequently converted through the allometric equation to increment of biomass (e.g. Cienciala *et al.*, 2005; Al Afas *et al.*, 2008; Fajman *et al.*, 2009). Moreover, in summer 2009 the plantation inventory took place and diameters at breast height (DBH) of 702 trees were measured with calliper at the area of cca 800 m^2 around the mast with Bowen ratio measuring system. Finally, destructive measurements of 40 randomly chosen trees, where the dendrometers were placed and another randomly selected 80 trees, were carried out during the harvesting at the beginning of 2010 – the end of first eight years long rotation period. This procedure followed the same methodology as described by Fajman *et al.* (2009). Figure 1 a) depicts the allometric relationship between DBH and the dry matter content (DMC) of aboveground biomass (AB) without leaves which was described by common biometric power function $AB = a * DBH^b$ parameterized with $a = 3.0476 * 10^{-4}$ and $b = 2.369$ ($r^2 = 0.97$, n = 120). Furthermore, DBH of 100 randomly chosen trees from all of the diameter and height classes were measured with calliper at the start of June 2009 and after that again during the summer inventory at the end of July 2009. Based on this results power function describing the linkage of stem diameter and the reference increment was determined in form of $\Delta DBH_{ref} = a * DBH^b$ with parameter $a = 1.1063 * 10^{-6}$ and $b = 3.3970$ ($r^2 = 0.87$, n = 100). This function shown at Figure 1 b) was applied on the known DBH of all 702 trees from above mentioned inventory and thus their reference DBH increments were obtained. At the same time the function was applied on the sampled trees where the DBH increment was measured regularly with dendrometers and by dividing the real by the calculated (reference) increments, the scaling coefficient was obtained. It means, that for each record from one dendrometer there is one scaling coefficient making possible to convert reference increment from all the trees to the real change in DBH. Although, there where totally 40 dendrometers, there were only 15 of them with uninterrupted data series for both of the consecutive years. Due to the homogenity and comparability of both years, only these 15 measured trees were used for up-scaling. For each of these 15 sampled trees, one scaling coefficient was obtained resulting in 15 slightly different increment of all 702 tress. This is especially due to the fact, that the relationship at Figure 1 b) is not completely tight (r^2 0.83). The mean of 15 variants of calculated increment of 702 trees at defined area were finally up-scaled to the whole stand, assuming that the 702 trees is sufficient to provide representative view on social distribution of the whole stand. These all stem increments were subsequently converted by using the allometric equation given at Figure 1 a) to the biomass increment (DMC) per area of 1 m^2.



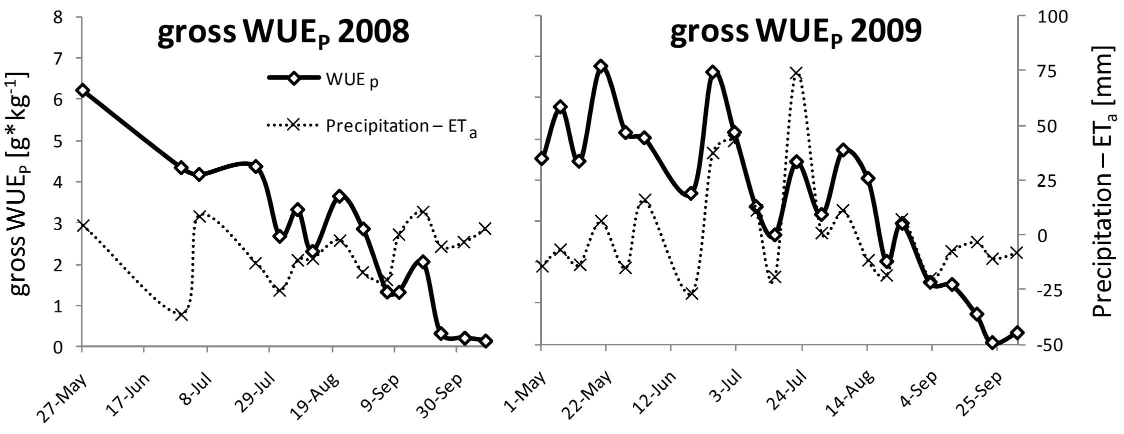
1: *Allometrically defined relations a) between DBH [mm] and the AB without leaves [kg of DMC]; b) between DBH [mm] and ΔDBH_{ref} [mm of DBH]*

Furthermore, the AB increment per 1 m^2 of the area was divided by the amount of ET_a [mm] integrated to the periods corresponding to dendrometers readings and thus the long term WUE_P was obtained. Because in this work, the WUE is defined only from part of above ground biomass (stems and branches – the growth of leaves and roots is not considered) which is divided by ET_a (not only transpiration), the term gross WUE_P is used in order to point out the differences against typical view on WUE.

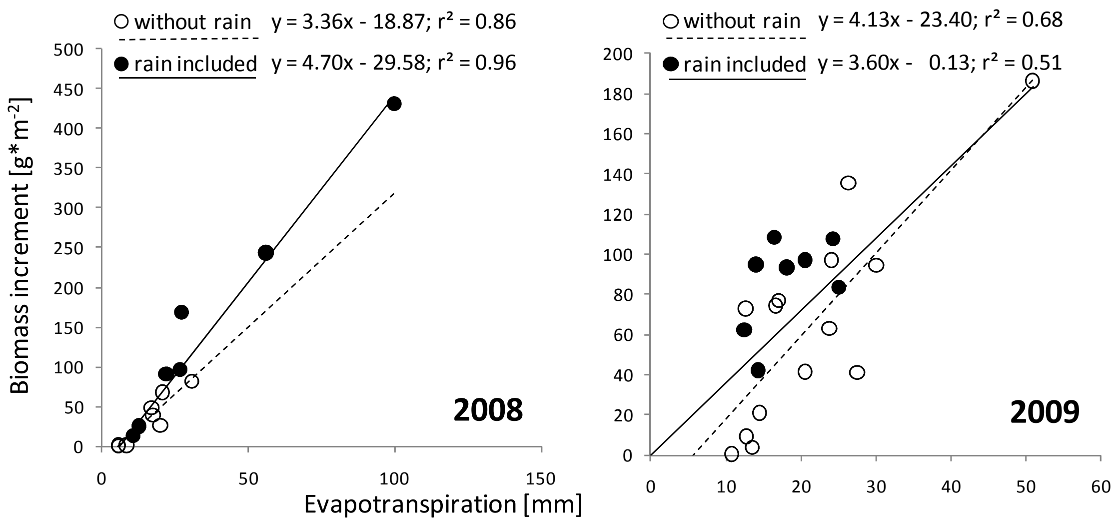
RESULTS

Figure 2 depicts the seasonal patterns of gross WUE_P with means 3.13 and 3.54 $g*kg^{-1}$ in 2008 and 2009, respectively. Apparently, there are systematically higher values during the second investigated season which also showed higher variability. Except the seasonal decreasing trend from spring toward the end of summer in both of executed years, the linkage with the dynamic of precipitation totals is obvious (especially on the peaks of WUE_P). Due to the discontinuous character of precipitation dynamic, the differences between precipitation and the ET_a were used to depict this relationship.

At the next figure 3, the water lost and change of allometrically defined biomass are correlated. The values are additionally differentiated into the two groups considering the influence of precipitation. The first group "without rain" is comprised only from values for periods of no precipitation events with totals higher than 10 mm. Conversely, the second group "rain included" was created by adding the periods in which precipitation amounts higher than 10 mm were recorded and thus contains all of the measured values. Taking into account all the values, there is narrower relationship in the year 2008 with the coefficient of determination 0.96 compared to lower 0.51 in 2009. On the other hand, the correlation in 2009 was more often based on



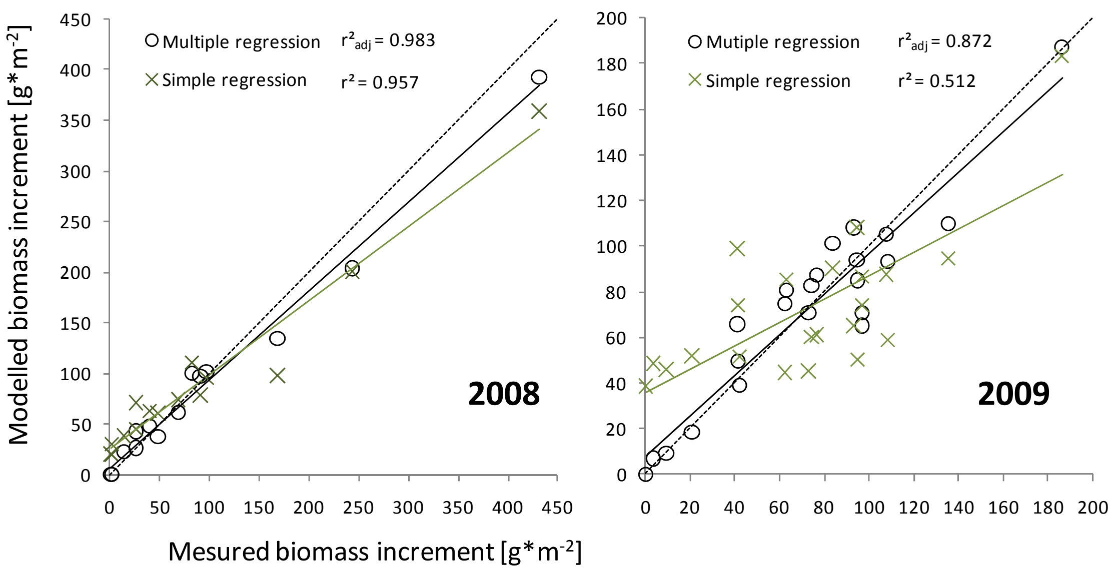
2: *The seasonal patterns of gross water use efficiency as the ratio of total evapotranspiration [mm] and allometrically defined aboveground biomass [g*m⁻² of DMC] increments compared with the differences in totals of precipitation and actual evapotranspiration [mm]. All values are integrated usually in weekly time-step, except the beginning of 2008, and the curves are smoothed by cubic spline fit.*



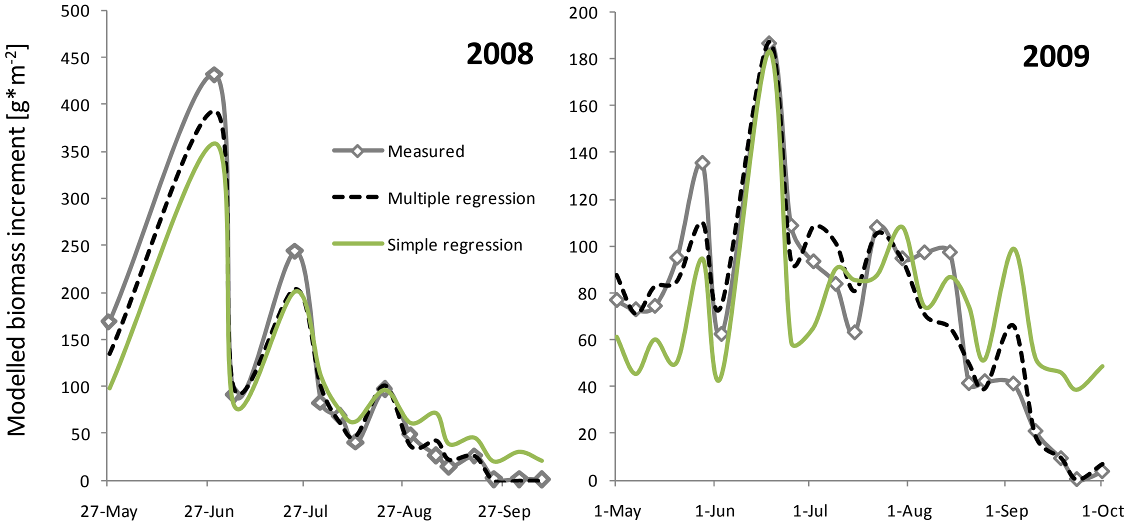
3: *The relationships between the total evapotranspiration [mm] and aboveground biomass increments [g*m⁻² of DMC] during two consecutive seasons2008 and 2009. The black filled circles depict the periods with precipitation amounts higher than 10 mm, in contrast the empty circles represent the periods with precipitation amounts lower than 10mm. All values are integrated usually in weekly time-step, except the beginning of 2008 which results in higher values during this period.*

shorter time span between individual integrations and thus the other factors like the root-shoot carbon allocation and the stem shrinking and swelling linked with the precipitation affected more the estimated biomass increment. Looking at the slopes of both regression lines, note it is approximately 19% higher in 2009 compared with the 2008 for the variant without precipitation events whereas it is 30% lower in the case including all the values. This underlines the effect of precipitation on gross $WUE_{P,}$ which has to be taken into account.

On the basis of patterns of gross WUE_P depicted at figure 2 and 3 we used a multiple linear regression model by adding the precipitation and cumulated effective mean air temperature as other independent variables, which explained the variability more satisfactorily (Fig 4 and 5). The reasonable and statistically best resulted was the separation of the precipitation again simply into the two categories: amounts lower and higher than 10 mm. Further, the characteristic temporal variability of seasonal gross WUE_P patterns caused by phenology of mobile carbon allocation was simply expressed as indirect proportionality to sums of effective temperatures defined by the common threshold 5° C. The final



4: *The comparison of measured biomass increment [g*m⁻² of DMC] with simple and multiple linear regression models based on water lost and aboveground biomass increment relationship. All values are integrated usually in weekly time-step, except the beginning of 2008 which results in higher values during this period.*



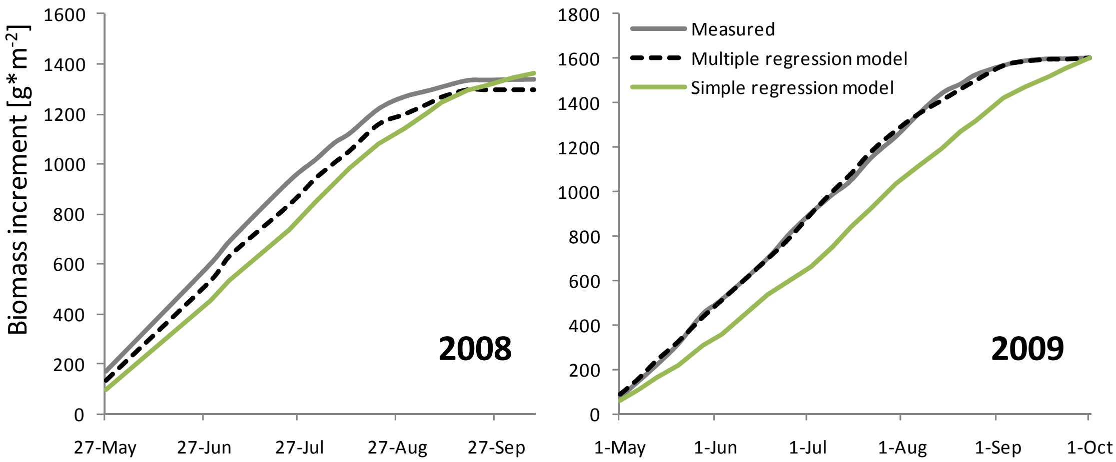
5: *The seasonal patterns comparing the measured biomass increment [g*m^{-2} of DMC] with simple and multiple linear regression models based on water lost and aboveground biomass increment relationship. All values are integrated usually in weekly time-step (except the beginning of 2008) which is depicted by diamond points at the grey line expressing measured values. All curves are smoothed by cubic spline fit.*

form of multiple regression model created from the data of the season 2009 with r^2_{adj} 0.872 is as follows:

$$AB = 38.2192 + 3.4123 \times ET_a + 13.3144 \times P - 0.04202 \times T_{cum},$$

where AB is in kg of DMC, ET_a in mm, P describes number of days with precipitation amounts higher than 10 mm and T_{cum} is the cumulative mean diurnal temperature [°C] above 5 °C. This empirical model was subsequently compared with the first simple linear model as well as with the measured biomass increments (Fig. 4). Furthermore, the model was tested on the data from previous year 2008 yielding higher coefficient of determination compared to the simple linear function.

The comparison of two linear regression functions with the measured data revealed that the simple linear model overestimated within the range of low values but conversely underestimated the higher values. This is especially more evident in the case of the year 2009. The multiple linear function fitted quite well in both of the executed year but the underestimation during the 2008 turned the scale down whereas in 2009 the under/overestimation ratio was quite balanced. For the simple linear function the root mean square error (RMSE) was equal to 9.6 and 26.9 g*m^2; the mean bias error (MBE) was equal to –1.6 and –7.4 g*m^2 of AB in 2008 and 2009, respectively. Multiple linear regression model yielded RMSE 23.8 and 14.5 g*m^2 and MBE



6: *Cumulative comparison of measured biomass increment [g*m^{-2} of DMC] with simple and multiple linear regression models based on water lost and aboveground biomass increment relationship*

4.8 and –0.2 g*m² of AB for both consecutive years 2008 and 2009.

Figure 6 depicts the same comparison of modelled and measured AB increments, this time expressed in cumulative way. Quite authentic course of AB increment was modelled by multiple linear function also for comparative year 2008. On the other hand, the simple linear model shows the most problematic periods for estimating the biomass increments at the beginnings and the ends of the seasons when the antinomy of WUE is significant.

DISCUSSION

Gross WUE_P based on synchronous measuring of AB increment and the canopy ET_a showed high seasonal variability in both of the evaluated years. The seasonal patterns were typical with the highest rates of gross WUE_P at beginning of the season and with the decreasing at the end of summer. Lindroth *et al.* (1994) described the similar seasonal trends of WUE_P in willow SRC in Sweden, where the last most marked fall of WUE_P was linked with reducing LAI (leaf area index) at the end of summer. Our results confirmed this coherency with LAI dynamic since the pronounced decline of gross WUE_P was observed around the mid August, when the period of LAI culmination in the investigated poplars culture was recorded. Further, Lindroth *et al.* (1994) explained the maximal peaks in WUE_P, which was defined as the ratio of AB increment and transpiration, as an effect of rainy weather and thus with considerably amounts of evaporation of intercepted water and thus lower transpiration rates. However in our research which took into account with the gross WUE_P based on total evapotranspiration, the maxima were also found during the rainy events. This is also in contradiction with results of Grelle *et al.* (1997) maintaining that precipitation days and the days after, lower the WUE_{GPP} due to enhanced surface evaporation of water that has never been part of the plant metabolism. The higher gross WUE_P as a consequence of precipitation could be explained by a few reasons. Firstly, by using the long-term water use efficiency based on AB increment and not on CO_2 uptake and transpiration ratio, the relative carbon allocation to roots or AB can play important role (Höll, 1985; Lindroth *et al.*, 1994; Dickmann *et al.*, 2001; Hoch *et al.*, 2003). During the period with reduced soil water availability, the assimilated carbohydrates are directed away from shoots and towards root growth. After alleviated of such conditions by replenish the soil water status with rains or irrigation, the temporary carbon allocation toward the roots is compensated by a later increase in shoot growth (Hsiao and Acevado, 1974; Kramer, 1983; Lindroth *et al.*, 1994; Barbaroux *et al.*, 2003). The similar effect caused by mobile carbon pools influences also the seasonal variation with high WUE_P in the spring characteristic with so called spring flush (strong upward translocation of non-structural carbohydrates produced in assimilation during the end of previous season), and conversely with the drop to zero at the end of season linked with downward accumulation (Teskey and Hinckley, 1981; Deans and Ford, 1986; Dickman *et al.*, 2001; Barbaroux *et al.*, 2003; Lacointe *et al.*, 2004). Here is noteworthy that the high accumulation of root reserves has great significance to coppicing. Secondly, growth is the biological phenomenon of increase in size with time. Growth involves the formation, differentiation and expansion of new cells, tissues or organs. The sudden increase in tree diameter often observed after rain is not necessary due to growth but reflects the saturation of shrunk xylem and other stem tissues with water after previous drier period (Herzog *et al.*, 1995; Offenthaler *et al.*, 2001). Moreover, e.g. Hsiao and Acevado (1974), Hinckley and Lassoie (1981), Barbaroux and Breda (2002), Steppe *et al.* (2006), Zweifel *et al.* (2006) explain that during drier periods when the stem water deficit occurs, new cells which are still created do not immediately expand, but a release of the low pressure conditions in the cambium suddenly enlarges the already existing cells to their mature sizes. This means that, within a certain period of time and for a range of water deficit, growth is not inhibited but just delayed. Within this context, the term WUE is very disputable and using gross WUE_P (either based on total evapotranspiration or just on pure transpiration) seems to be more reasonable and correct. On the other hand, research of WUE_{GPP} based on measuring the fluxes of CO_2 and ET_a by eddy covariance method across European forest ecosystems as described in Kuglitsch *et al.* (2008) provided that WUE_{GPP} increased with a rising monthly precipitation sum and rising average monthly temperatures. The higher productivity during these periods can be result of an increase of diffuse radiation that might stimulate assimilation (Alton *et al.*, 2007; Knohl and Baldocchi, 2008) and particularly low vapour pressure deficit under warm and humid conditions resulting in open stomata and thus higher CO_2 uptake to water lost ratio (Kuglitsch *et al.*, 2008).

Comparing the both of executed years, there was notably higher gross WUE_P during 2009. Similar situation was described also by Lindroth *et al.* (1994) where the authors explained the contrast in the consecutive seasons by different age of culture and with this linked different root-to-shoot ratio. The decreasing root-to-shoot ratio with ontogenically aging is well known phenomenon in SRC and also other tree species culture (Ovington, 1957; Reynolds and D'Antonio, 1996; Coleman *et al.*, 2004) and could provide an interpretation of higher AB increment during 2009. The heterogeneity in carbon allocation during the particular ontogenetic phases and also during the particular parts of the season causes difficulties to predict the yields with some simplified method based on evapotranspiration and biomass relation, but on the other hand such information could provide some general and gross estimation of the SRC production. By including the influence of precipitation and the decreasing seasonal trend of WUE_P expressed as a phenological factor, more precise method has been proposed in this work. Nevertheless, this is a simplified empirical relationship which could be valid presumably only for SRC grown on arable land with similar fertility, water holding capacity and other soil properties in the comparable condition of Czech-Moravian highland. Modelling the seasonal and yearly dynamic of root-to-shoot allocation could be key point to improve such approach.

Finally, considering that resulted values of gross WUE_P with means 3.13 and 3.54 g*kg^{-1} in 2008 and 2009 respectively are calculated from total evapotranspiration which is in SRC usually around 30% higher than pure transpiration, the WUE of poplars is comparable and rather higher than other broadleaved tree species of temperate climate zone. The estimated economically profitable yields range at least from 10 to 12 Mg ha^{-1} year^{-1} of DMC which, according to our calculations, will consume more than 450–500 mm per growing season. Therefore, it is assumed that a locality with higher and adequately temporally distributed amount of precipitation is necessary prerequisite for right site selection, especially in rain fed areas such as the discussed Czech-Moravian Highlands.

CONCLUSION

The gross WUE_P for poplar SRC was characterized by high variability in both of the investigated years 2008 and 2009 with means 3.13 and 3.54 g*kg^{-1}, respectively. These values are situated in higher range comparing to the other broadleaved tree species of temperate zone and suggest that for well economically profiting biomass yields more than 450–500 mm of water per growing season will be consumed by the SRC plantation.

The relationship between AB increment and ET_a was investigated with considering that other factors like especially rains (resulting in change of soil water potential and stem water potential) and also the phenology of mobile carbon pool are influencing the AB increment and volume.

The final multiple linear regression equation yielded satisfactory results for both of the analysed seasons.

Since the gross WUE_P is strongly influenced by seasonal and ontological variation caused by mentioned changing of allocation of non-structural carbohydrates, the modeling approach has to be updated by more sophisticated and dynamic including of this process to fit better the real seasonal and yearly patterns of gross WUE_P.

SUMMARY

Water-use efficiency of production (WUE_P) is commonly used tool across many scientific disciplines, evaluating the water economy related to the growth at plant, culture or whole ecosystem scale. The main idea of WUE_P is the linkage between biomass production and water consumption since photosynthesis carbon fixation and transpiration are often limited by stomatal conductance at the leaf level. To contribute to the discussion about the potential yields of the plantations grown as short rotation coppice (SRC) on arable land for energy use in condition of Czech-Moravian Highland and with considering that the water availability is one of the main constraint, we examined the gross WUE_P of recently most planted hybrid poplar clone J-105 (*Populus nigra x p. maximowiczii*). Gross WUE_P patterns during the seasons 2008 and 2009 were obtained by simultaneous measuring of actual evapotranspiration (ET_a) by Bowen ratio energy balance method and the aboveground biomass (AB) increment allometrically derived from change of stem circumferences of sampled trees subsequently up-scaled to the whole stand. AB expressed in kg of dry matter content per square meter were correlated with the ET_a (in mm) providing statistically significant relationship with r^2 0.96 and 0.51 for 2008 and 2009, respectively. With separating the values into the two groups depending on the intensity of precipitation, evident positive linkage between AB growth and occurring of precipitation events was observed. Moreover, as another factor appreciably influencing the AB changes, the thermal time (sums of effective temperatures above +5 °C) was recognized. Based on this, the multiple linear regression model was proposed with ET_a, precipitation higher than 10 mm, and thermal time as independent variable, explaining the AB growth from 98 and 87% in 2008 and 2009 respectively. The dynamic of seasonal WUE_P reached up to 6.2 and 6.8 g kg^{-1} with means 3.13 and 3.54 g kg^{-1} in both executed years, respectively. These values are comparable and rather higher than other broadleaved tree species of temperate climate zone and refer to very effective water economy. According to our first results, we estimated that economically profitable plantation (defined by yield at least in the range of 10–12 Mg ha^{-1} year^{-1} of dry matter content) will consume more than 450–500 mm of water per growing season and thus will demand a locality with higher and adequately temporally distributed amount of precipitation especially in rain fed areas such as the discussed Czech-Moravian Highlands.

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