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Comparison of the transpiration part of two sources evapotranspiration model and the measurements of sap flow in the estimation of the transpiration of sweet cherry orchards

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ABSTRACT

The transpiration part of the coupled Shuttleworth–Wallace model was compared to the data measured using the heat balance sap flow method on sweet cherry trees planted in Hungary. The model was validated under various weather conditions. Appropriate consistency was found between the transpiration part of two source, the output of the Shuttleworh–Wallace evapotranspiration model and the measured sap flow data. Although the model underestimates transpiration on cloudy and rainy days as well as on high vapour pressure deficit days, it is suitable for quantifying the water loss of intensive sweet cherry orchards.

In our experience, the model evaluation is reliable, but it is necessary to be aware of a 0.5 mm (10%) daily sum difference depending on weather conditions, as well as of a 10–30 min shift in favour of the modelled values. Investigation of the sensitivity of the model by changing the input data for the leaf area index and minimal stomatal resistance showed that a 20% decrease or increase in the above mentioned input data did not lead to any significant deviation, although wider fluctuation produced a notable variance in the result. Our investigation provides data on high density sweet cherry orchards under continental climatic conditions for which little information has been published.

1. Introduction

An adequate water supply plays an important role in cherry growing. The crucial point is to estimate the precise amount of orchard evapotranspiration. Complex models, such as the Shuttleworth–Wallace (SW) two source coupled model (Ortega-Farias et al., 2007) could provide a useful tool for estimating the water use of the orchard. This model has been adapted to different fruit species, but so far it has not been applied to high density cherry orchards. The model requires verification by direct water usage measurements.

In recent decades, the SW model has often been applied to estimate the actual evapotranspiration of various crops (Fisher et al., 2005; Gardiol et al., 2003; Kato et al., 2004; Zhou et al., 2006).

Ortega-Farias et al. (2007) used the SW model to estimate the latent heat flux of irrigated vineyard (*Vitis vinifera*) and compared the SW outputs with the data derived from the eddy-covariance measurements. They reported the largest difference between the measurement and output of the model under dry air conditions. According to their investigation of model sensitivity, the greatest difference in the model's output is produced by the variation in leaf area index (*LAI*) and the average stomatal resistance (as inputs in the model), while changing the aerodynamic resistance did not cause any significant deviation in the result. Anadranistakis et al. (2000) and Kato et al. (2004) have also applied the coupled SW model to the evaluation of the evapotranspration of sorghum (*Sorghum vulgare Pers.*), corn (*Zea mays*), wheat (*Triticum genus*) and, cotton (*Gossypium hirsutum*). Calculation of the latent heat flux using the SW model was used for semiarid areas by Stannard (1993) and for sub-artic regions by Lafleur and Rouse (1990).

As regards plantation with fragmented canopy (vineyard), Brenner and Incoll (1997), Domingo et al. (1999) and Were et al. (2008) estimated the water requirement. In their model, the total evapotranspiration of the orchard surface was the sum of the evaporation of the inter row space, the grape transpiration and the evaporation in the rows (Poblete-Echeverri and Ortega-Farias, 2009). The model was validated by the eddy-covariance

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measurements. They found that the model underestimated the results after rainy weather on sunny days.

Dryer weather conditions are predicted by the global climatic models for the Mediterranean region and the frequency of the extreme weather events grown in the Carpathian-Basin, which results in increased irrigation costs. Further on, the cherry growing areas of the two large cherry producing countries (Turkey and Iran) of the world are located under dry continental climate (Dehghanisanij et al., 2007; Burak and Senih, 2010) with similar predicted climate changes.

In Hungary, estimations of potential and actual evapotranspiration have been mainly made for field crops (Dunkel, 1995, 2000; Dunkel and Szenyán, 2000; Szász, 1995, 1999).

We have chosen sweet cherry in our work as subjects for sap flow (SF) measurement and testing of the transpiration model, because if its growing importance in Carpathian-Basin. Planting of intensive sweet cherry orchards is more and more popular in Hungary but the temporal distribution of their water uptake and water usage is mostly unknown. The irrigation demand is growing in intensive orchards planted recently, because of the market requirements in fruit size. The high density (1000–3000 tree ha^{-1}) plantation and the optimal canopy and leaf area formation (Hrotkó, 2010) require accurate irrigation. In Hungary 232 ha of sweet cherry was irrigated in 2011. In the continental climate in Hungary the irrigation of cherry orchards was not usual, so data on water requirements of high density cherries are not available.

In our study, we compare the outputs of the transpiration part of the two source SW model with the data measured for sweet cherry trees using the heat balance sap flow method. The structure of high density sweet cherry orchard is similar to those with fragmented canopy, where the SW model had already been used and verified.

The sapflow measured by heat balance method could be considered as the Tr part of the total evapotranspiration (Alarcón et al., 2000, 2005; Cabibela et al., 1997; Santos et al., 2007; Juhász et al., 2013b). As we do not have equipment for measuring the evapotranspiration separately of the interrow space (evaporation plus Tr of interrow vegetation) we use models to estimate this part of TET, which consider the crop covering rate. The two source evapotranspiration models (Shuttleworth and Wallace, 1985, Dolman, 1993) estimate the evaporation and transpiration part of the whole area based on the vegetation covering rate, taking into account the tree's transpiration and the evaporation from the inter row and from the rowspace (Dolman, 1993; Blyth, 1995; Brenner and Incoll, 1997; Blyth et al., 1999; Domingo et al., 1999). For fragmented canopies like in our case the SW model is supposed to use (Wallace, 1995). In the last ten years SW model has been widely applied to estimate the total evapotranspiration (Gardiol et al., 2003; Kato et al., 2004; Fisher et al., 2005; Zhou et al., 2006).

We test the deviation of results calculated by transpiration part of SW model to the measured SF data under different weather conditions. Model output variability is caused partly by the uncertainty of the input data and parameters. Model sensitivity investigation has been frequently done to reduce this variability and to make more precise estimation. In our study the evaluation of the transpiration could improve by the clarification of the plant (leaf area index) and resistance parameters (particularly of the stomatal resistance).

2. Materials and methods

2.1. Site conditions

The investigations were carried out in Hungary, in Soroksár at the Station of the Experimental Farm of Corvinus University Budapest on sweet cherry orchard. The cultivar is 'Rita', ripening early, on 22–28 May. The experimental orchard was planted in spring 2004 with 4.0 m × 2.0 m spacing and 1250 tree ha^{-1} density. Row orientation is N–S, while in the alleyway the natural vegetation (grass and weed species) was mown. The trees are trained to Hungarian spindle (Hrotkó et al., 2007); their height was around five metres and the trees were headed at 4 m on 16 July 2009. The orchard was rain fed, and also received additional irrigation by dripping system.

The Soroksár station (47°38′ N; 19°14′ E, 103 m above the sea level) is located in Central Hungary, South-East of Budapest and, belongs climatically to the continental Great Hungarian Plain. The average annual temperature is 11.3 °C, while total sunshine is 2079 h. Average annual rainfall is about 550 mm mainly falling in May and June. The soil type is light sandy; lime content is around 2.5%, soil organic matter is low (0.8–0.9%), pH is 7.7 and the Arany-type cohesion index (KA) (Dobos et al., 2010; Joori, 2002) is 24 (low).

2.2. Measurement of SF and meteorological parameters

The SF measurements were carried out using Dynamax Flow 32 equipment with Dynagage SF gauges (Dynamax Inc., Houston, TX, USA) developed from the designs published by Sakuratani (1981, 1984), Baker and Van Bavel (1987) and Steinberg et al. (1990) applying the heat balance method. In general, the installation of the gauges was in accordance with the procedures recommended by the manufacturer (Dynamax, 1990). Measurements were made using SGB50-ws, SGB70-ws and SGB100-ws gauges accordingly to the trunk's diameters. Followed the proposal of the Dynamax Guideline the trunk gages were used complianced with the tree's size. The leaf area index and the covered surface fraction were measured and calculated by our team in the investigated orchard. *LAI* was measured by using Accupar 80 (Decagon) equipment. Canopy covering was calculated as a fraction by dividing the projected canopy area by the plantation area (8 m^2).

SF was measured from 1 May to 31 August each year (2008, 2009, 2010, 2011). Our data originates from 43 different sample days in 2008, 43 in 2009, 12 in 2010, 76 in 2011, giving a total of 174 sample days in the research.

Seven sample trees were chosen for the SF investigations to represent all of the vigour of the rootstocks: two of them on GiSelA 6, others on mahaleb seedlings. The trunk cross section area of the trees on GiSelA 6 in 2011 was 67 and 78 mm, while those on mahaleb seedlings ranged from 95 to 130 mm. The *LAI* of investigated trees on mahaleb seedling ranged from 5.1 (May) to 7.5 (June), while those on GiselA 6 were 3.2 and 5.2 respectively. According to the Manual (Dynamax, 1990) the sensors should be set up on smooth trunk without any furrows, cleaned with soft sandpaper from all injuries. In order to avoid gumming of injured trunks we did not apply rubbing but choose trees only with smooth trunk.

By the investigation carried out in orchards it has to be taken into account that the transpiration of an individual tree is affected by the neighbouring trees competitions for water, the root development of the individual tree and the soil water capacity and heterogeneity.

Since the sensors were placed on the trunk under the canopy, the shade effect of the canopy protected them from overheating. We created 'plate' such as an umbrel protecting the sensors against dew and rain runoff along the trunk. This 'plate' was fixed by isolating foam. Even if we applied loose tailored plate, it occurred that the plate injured the swelling trunk, choped the bark. To avoid this injuries we used only plastic foil for isolation against the runoff water.

Even if the investigation were carried out during four years vegetation period (2008, 2009, 2010, 2011), in each year from 1st April to 31st August, we have got data from 174 days only, because of unexpected technical and other issues (dilapidation: cables chewed by