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Evaluation of fruit tree transpiration with heat flux sensor

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Summary: One of the biggest professional challenges of the following years is to develop the water resource management for apple trees. In order to know the water consumption of plants, some traditional and modern methods could useful. In our research the sap flow measurement of the plants were carried out. We have analyzed the transpiration properties of the trees in the investigation period. In order to compare the transpiration of the trees, the leaf areas were scanned and evaluated. Beside these measurements, soil water properties were determined by tensiometers, thus it makes possible to observe the soil-plant-atmosphere system.

Keywords: *sap flow, transpiration, leaf area*

Introduction

In Hungary, fruit plantations cover 1.5% of the whole agricultural area, from which apple is cultivated on one of the largest areas. The total area of apple orchards is more than 32 000 hectares (FAOSTAT, 2014). The data of the Central Statistics Office shows that 33% of the apple plantations can be irrigated, but only c.a. 26.5% is irrigated (KSH, 2014).

Horticulture is a water demanding sector, mainly during times of drought periods. So the high quality fruit-growing is difficult without proper irrigation. Furthermore in some horticultural farms there are no irrigation applied, or its techniques are improper. There are several experiments are carried out around the world to develop methods of irrigation, which draw different technology combination for the water and energy saving micro-irrigation. In order to determine the irrigation water requirement of the fruit trees, the water demand of trees is needed to be known. Some instruments and techniques are available to measure water use of plants, like lysimeters (Pruitt & Angus 1960; González-Talice et al., 2012), porometers (Proctor, 2011) and nowadays there are great perspectives in the remote sensing to evaluate water stress conditions of the vegetation (Suárez et al., 2010). The inducing factors of plants' sap flow are the sun and climatic conditions, resulting water potential gradient. Water transport in xylem of plants could be measured by special instruments (Cohen et al., 1981). One of the most effective ways to measure water consumption of fruit trees is the heat pulse method, which spread in the practice. The sensors measure the temperature of the sap and based on the flowing sap the transpiration is estimated by the instrument. There are some methods, which use this principle (Juhász, 2012). Heat pulse method could be applied in herbaceous (Baker & van Bavel 1987) and woody plants (Steinberg et al., 1990) too. During the development of herbaceous plants, it needs modify the heater unit.

Beside the transpiration of trees, leaf area is an important factor, thus the water use of plants could be compared. The transpiration of plants are determined by the leaf area. Transpiration is taking place through the stomas of the lower epidermis (Boyer, 1985), which is used for gas exchange. In the case of different apple varieties, the number of stomas can be different: 200–450 pores/m^2 (Cowart, 1935; Slack, 1974). Cowart (1935) determined hat less stoma can be found in the leaves of lower position of the canopy. The extent of transpiration depends on several physical factors as well as the opening or the closing of the stomas (Jackson, 2003).

In our study, sap flow of two apple trees was examined to conclude the transpiration of investigated trees. To compare the transpiration properties of the apple trees, those leaf areas were defined beside the sap flow measurement. Furthermore, the soil moisture content and climatic data were measured to analyze the soil-plant-atmosphere relationship.

Materials and methods

In this study the transpiration properties and the response to heat stress of two apple trees were measured by the Sap Flow2 System. Apple trees, with same variety (*Húsvéti rozmaring*) on MM106 semi-dwarfing rootstock were selected. The investigation period was from 16th of June to 20th of July 2013.

The sensors with the heating strip were fit on smooth part of the trunks under the canopy (*Figure 1*). Sensors were covered by insulation rings, which provided the protection of the heater units against radiation, rain and extreme ambient changes. Around the foam insulation, aluminum top shields were used to reduce the effects of moisture, but provide the appropriate ventilation.

The loggers collected data with a power down mode so that power was saved at night and the stem is preserved from

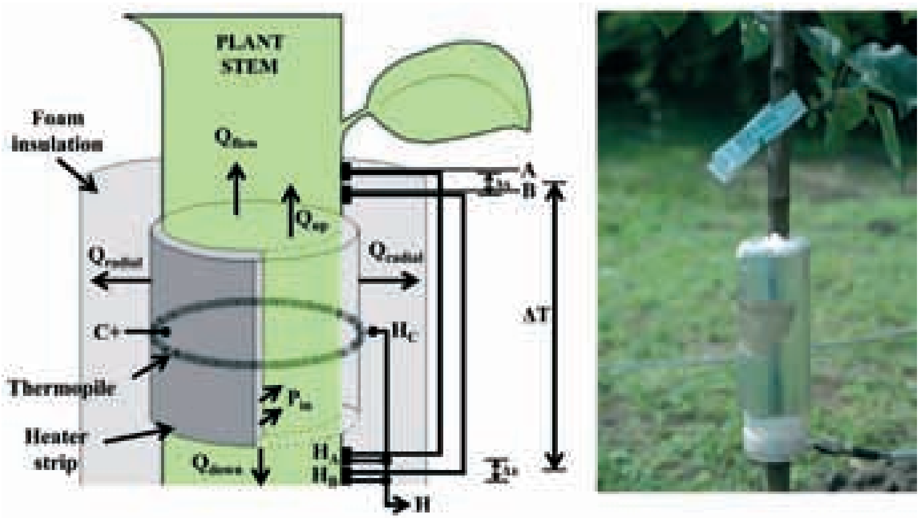

Figure 1. Stem gage schematics (van Bavel, 1993), and the photo documentation from the installation of the whole gage unit

overheating. During the power down mode and at the transitions to power on, the sap flow was not computed to maintain the accumulated flow accurately during this unbalanced transition.

Sap flow can be computed and saved in grams per hour or per day by a formula using the heat applied to the stem, the radial energy from the stem, and temperature differences of sap above and below the strip heater.

The so called stem heat balance (SHB) theory requires a steady state and a constant energy input from the heater strip inside the gage body (van Bavel, 1993). In order to provide the constant energy input, the SapFlow2 data logger was connected with a PC. The fixed amount of heat (Q_h) is equivalent to the power input to the stem from the heater (P_{in}). Radial (Q_r) and vertical (Q_v) heat loss appear in this heat balance system. Based on the P_{in}, Q_v and Q_r the flow rate per unit of time (F) is calculated by the following equation:

$$F = \frac{P_{in} - Q_v - Q_r}{c_p \cdot \Delta T}$$

where c_p is the heat capacity of the water (4.186 J/g·C), and ´T is the temperature increase of the sap.

In order to compare the sap flow of the fruit trees, the leaf area of the trees were determined. The leaves were collected at the end of the vegetation period, in order to prevent the canopy form physical injuries during the vegetation period. Scanning of the leaves was carried out in the laboratory of the Institute of Water- and Environmental Management of the Faculty of Agricultural and Food Sciences and Environmental Management of the University of Debrecen. The leaf areas were measured by Area Meter 100 (ADC AM 100) leaf area scanner developed by the Analytical Development Company. After scanning, the data were stored in the memory of the AM 100, then they were downloaded to a computer. The scanner measures not only the surface area of the leaves with different sizes, but also of the leaves damaged by pests. After each scanning the length and width of the leaf, the average and total area and the number of the leaves were displayed and stored.

Results

Daily dynamic changes of the sap flow in the case of two fruit trees were monitored by the Dynamax SapFlow logger system. Collection of sap flow data was carried out between 7:30 A.M. and 8:30 P.M. Dynamics of sap flow of the investigated trees was similar, which represented a strong linear correlation (r=0.79). The daily pattern of transpiration represented a bellshaped curve. Sunshine and air temperature were lower at the early-morning hours, then the dynamics of sap flow was increased, reaching a peak. In the afternoon the temperature was decreased, thus the water usage of trees was reduced as well.

The sap flow of the fruit trees during the period with higher water use (12:00 A.M. and 4:00 P.M.) was analyzed (*Figure 2*).

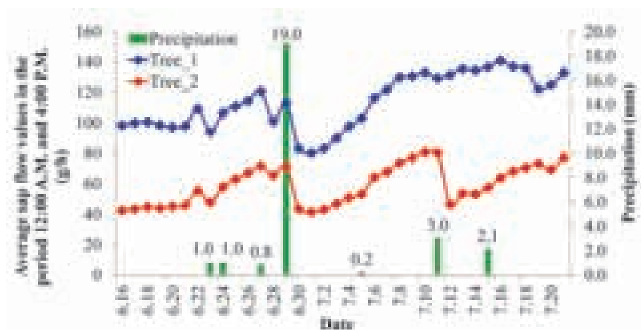

***Figure 2**.* Average sap flow values in the investigated period

It could be observed that the sap flow of trees was decreased after rain, in contrary to the phenomenon, that better water supply of trees pertain higher transpiration. The reason of this event is that, the temperature was decreased due to the cloud cover and raining. After precipitation periods, air temperature was rising again, thus the water consumption was increased as well.

It could be seen that the shapes of the curves were similar, but the local minimum and maximum values were different in the investigated period. The cause of the different flow values was the different leaf area of the fruit trees. In order to compare the transpiration of the trees, the leaf areas (LA) were scanned and evaluated. Based on the results it could be concluded that the higher flow values of the '*Tree_1*' was associated with the higher transpiration area. The total leaf

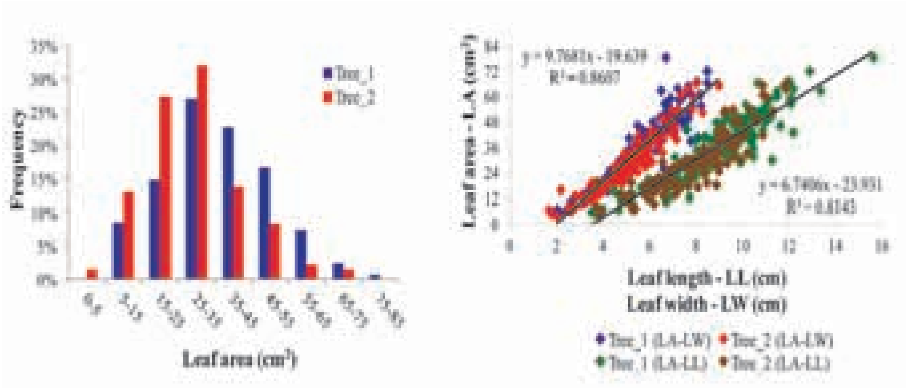

Figure 3. Leaf area properties of the two investigated apple tress

area of the '*Tree_1*' was 5875.9 cm^2, while in the case of the '*Tree_2*' it was 3742.4 cm^2, so the '*Tree_1*' had 36.3% higher transpiration area. In point of leaf area, the '*Tree_1*' had higher average transpiration area, which is represented by the *Figure 3*. There were strong linear correlations between leaf area and leaf width (LW) (r=0.93), and leaf area and leaf length (LL) (r=0.90) too.

Comparing the total flow values in the investigated period with the leaf area, the transpiration per unit leaf area could be calculated. The unified index is the intensity of sap flow, which was 10.92 g/cm^2 in the case of '*Tree_1*' and 9.35 g/cm^2 was in the case of '*Tree_2*'. Similar values indicate that there were no significant differences between the transpiration values of trees.

In our complex measurement, the sap flow values were compared with the soil moisture status. The water potential of the soil was measured by tensiometers, which were inserted in the root zone. We have detected a strong linear correlation (r=0.70, p=0.001) between the investigated parameters (tension and sap flow values). Between the soil moisture and the air temperature a positive linear correlation (r=0.63, p=0.001) could be detected. The cause of lower correlation was that decreasing of the soil water content occurred due to the evaporation and the transpiration of the investigated trees.

Conclusion

The sap flow measurement with stem heat balance (SHB) theory was ideal to determine the dynamic of water use of the apple trees (*Húsvéti rozmaring*). The sap flow values modified, when the air and soil moisture conditions were changed. Based on the data, correlations of the soil-plant-atmosphere system were determined. The leaf area measurements were ideal to compare the sap flow values. Sap Flow meter can be suitable for transpiration monitoring. Further examinations are needed to investigate the instrument for irrigation scheduling and complete the data with remote sensing information to assess water stress of apple trees.

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