Evaluation of water balance in apple and pear trees

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SUMMARY

A significant proportion of the aboveground green and dry weight of the plant constitutes the foliage. The canopy is an important factor of plant growth. On one hand the canopy absorbs the solar energy, which is necessary for the photosynthesis, on the other hand accumulates the absorbed nutrients by the roots, and the most of the water-loss happens through the foliages. The determination of the full canopy is not an easy target. In our research we developed a measurement method to determine the leaf area. With the parameters of the examined tree (leaf length and maximum width) and the data of ADC AM 100 leaf area scanner we determined the k-value, with which we can easily and fast evaluate the leaf surface. Furthermore we defined from the water balance of compensation lysimeters the cumulative transpiration of fruit trees and the efficiency of water use of trees.

INTRODUCTION

Presently in Hungary about 100.000 hectares of orchards can be found, from which apple is cultivated on one of the largest areas. The total area of apple and pear orchards is more than 45.000 ha. The data of the Central Statistics Office show that 28% of the apple and pear orchards can be irrigated, but only 21% is irrigated. Horticulture is a water demanding sector, so the high quality fruit-growing is difficult without proper irrigation. Furthermore in some horticultural farms there is no irrigation applied, or its techniques is improper. There are several experiments going on around the world to develop methods of irrigation, which draw different technology combination for the water and energy saving micro-irrigation. One of the biggest professional challenges of the following years is to develop the water resource management for apple and pear trees. For this we have to identify the water norm of the trees in the different phenological stages, the irrigation turns, the watering technology and the transpiration surface.

LITERATRE

HUZSVAI et al. (2005) determined, the leaves were good environmental indicators, thus it was suitable for phenometry measurements. More features of leaves is capable the detection of environmental impacts, from these used mainly the leaf area, e.g. horizontal and vertical leaf surface size, geometry, etc. The size and the location of the leaves determine, what the radiation at the plant's ability to absorb. The size of the leaves we can express with leaf area (LA). In orchard, if increases the leaf area, increases just a certain limit the luminous efficiency, until the mutual shading of the plants does not inhibit that (BALÁZS et al., 1989).

$$LA = \frac{s_{\max} - h_{\max}}{K} = k \cdot (s_{\max} \cdot h_{\max})$$

where: s_{max}: maximum width of leaf
h_{max}: maximum length of leaf
K: species and species characteristic splitting factor
k: species and species characteristic multiplier factor
(HUZSVAI et al., 2005)

Several researcher – including POLSTER AND REICHENBACH (1958) – typed the leaf shape of plants, and defined the K and k values.

In orchard plant's leaf area must determine not only in absolute terms, but compared with the growing area (T) also. The rate of two values called leaf area index (LAI), which is leaf area (m^2) per $1m^2$ soil surface. The LAI is the most suitable index in the cultivation practice for the plant mass (SZÁSZ, 1988; BALÁZS et al., 1989).

$$LAI = \frac{LA}{T} \ (m^2/m^2)$$

LAI – as biophysical status – is an close relationship with amount of the biomass, with the photosynthesis and transpiration scale (NEMANI and RUNNING, 1989). The size and number of leaf determine the leaf area (LA). Some factor influence amount of leaves in the trees. The number of leaf produced is reduced by water stress, nutrient deficiencies and is under hormonal control. Some researchers investigated the number of leaves and growing parameters, which develop on the new shoots under controlled environment conditions (ABBOTT, 1984; JOHNSON and LAKSO, 1985; LINDHAGEN, 1996). Maximal value of LAI – among genetic limits – determinates several environmental and agronomic factors. Environmental factors: rate of temperature and precipitation far the plant requires, and the soil characteristic, thus rate and amount of available nutrients. Agronomic factors: density of crop, nutrient supply, irrigation, etc (HUZSVAI et al., 2005).

The leaf area index change species, stage of development, methods of cultivation, density of crop. WAGENMAKERS (1989) found that leaf area per tree of apples and pears decreased linearly with planting density. VERHEIJ (1972) showed that with apple the leaf area per tree declined with increasing planting density even with unpruned trees, and was accompanied by a relative suppression of lateral growth in the lower parts of the trees.

Several literature deals with the determinate of LAI. These measurements primarily determine the LAI of the field crops, while in an orchard just little time determinate the leaf area index. For assign of the LAI evolve and spread some methods.

The measurements of LAI there are direct and indirect technique, but the terrain measurements are in the crop difficultly interpreted, give pointwise data and expensive (GOWER et al., 1999; WHITE et al., 2000).

Making leaf imprint is the most ancient method to determine leaf area. It gives a very precise result, but it is quite time consuming. During the process, the contour lines of the removed leaves must be drawn on a mm-sheet and determine the area. The error is about 1.5%. By the application of comparison method, the chance of error is higher than in the case f the imprint method. During the comparison method, etalons representing the most frequent leaf size of the given plant species are compared to the investigated leaves (BOGNÁR, 2003). Among traditional methods for in situ leaf area determination the calculation-, the weighing- and the planimetric methods are used the most frequently (ROSS, 1981). ANDERSON (1981) used a fisheye optic camera and calculated the LAI from the cover of the sky in the photo. Leaf area can also be calculated by means of a solar radiation sensor (HUNKÁR, 1984). Automatic leaf area measuring devices are also available nowadays. The measurement is fast and precise with these electronic meters and the leaves do not have to be removed (BOGNÁR, 2003). One of the traditional ways is the weighing technique, when the total weight of the leaves are multiplied with an empirically determined coefficient. Naturally this method can be used only for leaves already fallen down and the error of the coefficient is also significantly influences the accuracy of the measurements (JÁRÓ, 1959).

Remote sensing is a widely used method for the spatial and time series examinations of LAI as it is an essential input parameter for several biogeochemical model (REICH et al., 1999). Another practical method is the use of regression models including the correlation between different plant indexes and the LAI (TURNER et al., 1999). Nevertheless the reflectance values are influenced not only by the canopy and pigment area, but the shape and spatial distribution of the leaves too (CLEVERS and VERHOEF, 1993). For the estimation of leaf area with the analysis of remote sensing, NDVI is the most commonly used method (COHEN et al., 2003). The Normalized Difference Vegetation Index (NDVI) is used to determine the leaf area, the quantity of green biomass, the chlorophyll content and the water content of the plant tissue (TUCKER, 1979; CIHLAR et al., 1991, SELLERS et al., 1992, GOWARD et al., 1994).

The leaf area determines the area of transpiration too as transpiration is taking place through the stomas of the lower epidermis (BOYER, 1985). The stoma is a pore, found in the leaf and stem epidermis that is used for gas exchange. The pore is bordered by a pair of specialized parenchyma cells known as guard cells which are responsible for regulating the size of the opening and are the closest thing a plant has to a muscle. (BOLDIZSÁR, 2007). In the case of different apple varieties, the number of stomas can be different: 200-450 pores/m^2 (COWART, 1935; SLACK, 1974). The apple varieties growing faster the density of stomas is higher, while smaller varieties have less stoma density (BEAKBANE and MAJUMDAR, 1975). COWART (1935) established that less stomas can be found in the leaves of lower position. The extent of transpiration depends on several physical factors as well as the opening or the closing of the stomas (JACKSON, 2003). One of the most significant factor influencing transpiration is the wind (MANSFIELD and McANISH 1995). BEUKES (1984) established a negative correlation between transpiration and wind velocity. The transpiration rate is also determined by the leaf temperature and the available moisture content of the soil. Transpiration is increasing if more water is available in the soil: in case of optimal water supply apple trees transpirated more water and the conductance of the stomas increased (ALLEYNE et al., 1989; GOWER et al., 1990; FRENANDEZ et al., 1997).

During the day the water potential of apple and pear trees is decreasing with the increasing transpiration: GOODE and HIGGS (1973) observed the lowest water potential in noontime. LANDSBERG et al. (1975) and FERNANDEZ et al. (1997) examined apple and pear trees under droughty and control conditions. They concluded that the closing of the stomas is an effective physiological control that reduces the rate of transpiration.

MATERIAL AND METHODS

On 1^{st} March 2010 2 pear (*Bosc kobak* and *William's*) and 1 apple varieties (*Regal Prince*) were planted in 3 replications into 9 lysimeters with compensation system of the lysimeter station of the Karcag Research Institute of the Research Institutes and Study farm of the Centre for Agricultural and Applied Economic Sciences of the University of Debrecen. Each lysimeter has a surface area of 0.8 m2 and depth of 2 m. The permanently maintained groundwater level is at the depth of 90 cm serving as the water supply (subsurface irrigation) of the trees in dry periods. The soil surface was covered with black plastic (polyethylene) sheet that stopped evaporation but let the natural precipitation infiltrate into the soil.

On 29^{th} September 2010 the leaves were collected from each tree. The leaves from the lower branches were separately collected from the leaves of the upper branches, and also the fallen leaves were gathered.

The scanning of the leaves was carried out in the laboratory of the Department of Water- and Environmental Management of the Centre for Agricultural and Applied Economic Sciences of the University of Debrecen. The leaf areas were determined by means of a device called Area Meter 100 (AM 100) 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. Nevertheless the digital display of the device ensures a permanent monitoring of the measurement data. By means of the scanner, not only the surface area of the leaves with different sizes and colours, but also of the leaves damaged by pests could be determined. After each scanning the length and width of the leaf, the average and total area and the number, the time and the date of the scanning were displayed and stored.

In our experiment we investigated if knowing the length and the width of the leaf, is it possible to calculate the area by using a multiplying factor. After measuring the length and the longest width of the leaf, we multiplied these two parameters getting the area of a square (A_{square}) that involves the area of the leaf. Then the leaf was scanned, so we got the exact area of it (A_{leaf}). Dividing the two areas, we get a multiplying factor (k) that can be used for further calculations.

$$k = \frac{A_{leaf}}{A_{square}}$$

To determine the rate of transpiration and the water use efficiency of the trees, we processed the data gained by the lysimeter measurements. Transpiration was calculated according to the following equation:

$$\boldsymbol{T = P - D + I}$$

where T is the transpiration of the tree (mm), P is the amount of natural precipitation (mm), D is the drainage water (mm) flowing out through the compensation system and I is the subsurface irrigation water flowing in from the compensation system.

RESULTS AND DISCUSSION

The apple and pear tree leaves collected at the end of the final phenological state were scanned and the total and the average leaf areas were determined (*Table 1.*).

Table 1.

Areas of the collected leaves

Tree variety	No. of tree	Fallen leaves (cm^2)	Leaves from the lower branches (cm^2)	Leaves from the upper branches (cm^2)	Total leaf area (cm^2)	Average leaf area (cm^2)	Average leaf area of the variety (cm^2)
Bosc kobak	1.	8.65	188.31	464.04	**661.00**	**4.35**	**4.42**
	4.	61.46	273.97	289.90	**625.33**	**3.22**	
	7.	30.65	586.88	320.90	**938.43**	**5.69**	
Regal Prince	2.	Dried out					**4.97**
	5.	183.16	121.25	293.89	**598.30**	**5.07**	
	8.	127.45	512.98	775.59	**1 416.02**	**4.87**	
William's	3.	48.11	806.12	1385.97	**2 240.21**	**3.87**	**3.24**
	6.	54.70	129.35	66.24	**250.29**	**2.53**	
	9.	52.56	273.14	72.17	**397.88**	**3.32**	

On the base of the data of the table it can be established that the pear variety *William's* had the smallest, while apple variety *Regal Prince* had the largest average leaf size under the given climatic and edaphic conditions.

Further calculations were done in order to determine if we can find a „k" multiplying factor for the in situ prediction of the leaf area of a tree (*Table 2.*).

Table 2.

The calculated k factors for the investigated trees

Tree variety	No. of tree	K-value for leaves from the lower branches	K-value for leaves from the upper branches	Average k-values
Bosc kobak	**1.**	0.276	0.284	**0.280**
	4.	0.304	0.289	**0.297**
	7.	0.276	0.274	**0.275**
Regal Prince	**2.**	Dried out		
	5.	0.275	0.269	**0.272**
	8.	0.268	0.272	**0.270**
William's	**3.**	0.291	0.289	**0.290**
	6.	0.277	0.279	**0.278**
	9.	0.263	0.283	**0.273**

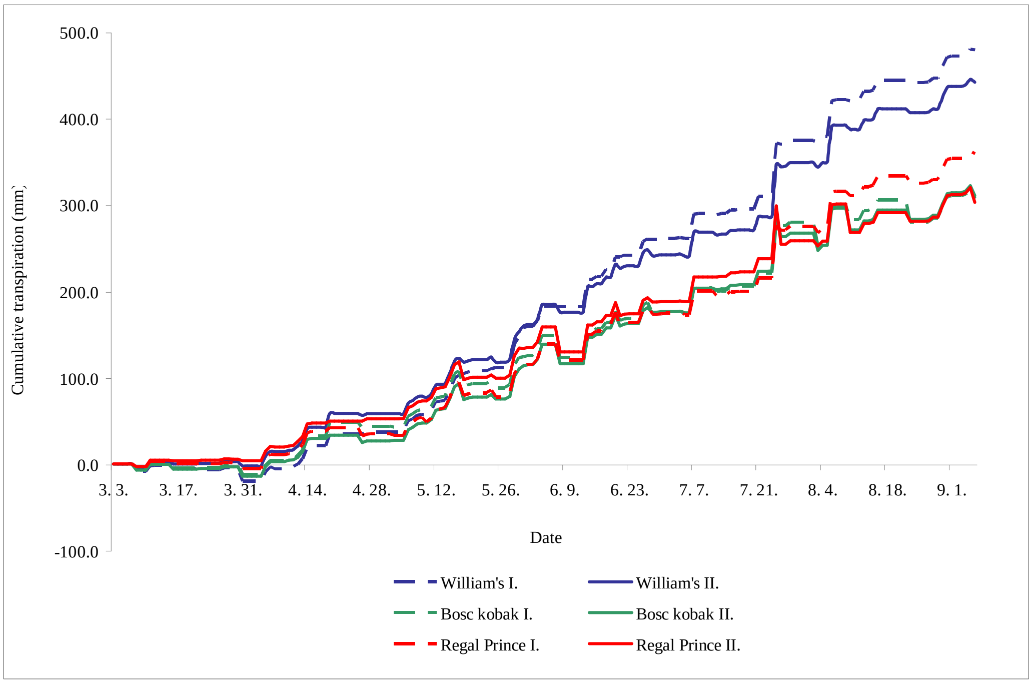
It could be established that the k-values were the smallest in the case of the apple variety *Regal Prince* which shows longer but narrower leaf shapes comparing to the shape of the pear leaves. Among the investigated fruit tree varieties *William's* had the most leaves (798) its relatively high k-value is the sign of roundish leaf shape. Variety *Bosc kobak* had the smallest difference in the number of leaves among the replications.

Calculating the leaf area for 1 m^2 the LAI can be determined. Among the investigated varieties variety *William's* has the largest value of LAI.

In order to characterize the water use of the fruit trees, the transpiration of them was compared. As the investigated period was extremely wet, no subsurface irrigation water flew into the soil through the compensation system, but drainage waters were regularly collected. The water balances of the lysimeters were positive as the input by natural precipitation resulted in saturated state in the soil all over the investigated period with even regular deep percolation water. Hence the transpiration of the trees could be calculated as the difference between the natural precipitation and the drain waters (*Fig. 1.*).

Figure 1

Cumulative transpiration of the fruit trees



On the base of the cumulative values of transpiration it can be established that in the beginning growing phases no differences could be detected among the trees. From May some differences could be figured out indicating the difference in the speed of the leaf growing characteristic to the different varieties. The highest differences in the transpiration started to form out when the trees reached the full development of their leaves. The highest transpiration values were detected in the case of variety *William's*, while not considerable differences could be figured out between varieties *Bosc kobak* and *Regal Prince*.

The water use efficiency values were also determined for the investigated fruit trees. This index shows how much water was used by the plant for transpiration from the total water input. As the amounts of drain water were the lowest in the case of variety *William's*, the highest transpiration and water use characterised this variety: the water use efficiency was above 80%, while 50-60% was characteristic for the other two varieties.

CONCLUSIONS

One of the main problems of in situ determination of leaf area is that the price of the accurate devices is high. The advantages of the calculation method we used are as follows: it is fast, not invasive and variety specific. It provides the possibility of good estimation of the leaf area by measuring only the length and width of some leaves and calculating the k-value from them.

After the development of their full leafage, considerable differences could be figured out in the water balance of the lysimeters planted with the three fruit tree varieties. On the base of the water use efficiency indexes we established how much water was used by the trees to generate their own body from the total water input.

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