DETERMINATION OF WATER UPTAKE DYNAMICS OF INTENSIVE SWEET CHERRY ORCHARD BASED ON SAP FLOW MEASUREMENTS

PhD thesis

Ágota Juhász

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PhD School Name: Doctoral School of Horticultural Sciences

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Head of Ph.D. School: Prof. Dr. Magdolna Tóth
Doctor of the Hungarian Academy of Sciences
Corvinus University of Budapest, Faculty of Horticultural Sciences
Head of the Fruit Sciences Department

Supervisor: Dr. László Tőkei
Corvinus University of Budapest, Faculty of Horticultural Sciences
Head of the Soil Science and Water Management Department

The applicant met the requirement of the PhD regulations of the Corvinus University of Budapest and the thesis is accepted for the defense process.

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Head of the Ph.D. School Supervisor	Supervisor

1. PREMISE

The amount and availability of the water using for irrigation has reduced in the recent years; this is due to several factors including the increased spatial variability of aridity and drouth, the rivality of industrial, agricultural, and personal water use. After some calculation the agriculture is actually using 50-60% of the total water use of humanity. Hence it is essential to have more economic and effective water usage, well planned irrigation management for providing suitable crop. A crucial step is to know the precise amount of water demanded by the orchards.

The adequate water and nutrient supply play an important role in the optimal fruit growing. The land used for fruit crops is around 2.5 millions hectares, majority of this land is located in the central and southern zone of the European Union, where the amount and distribution of precipitation is not adequate. The total irrigated area was 79 000 ha in Hungary in 2011, from which about ~7% (5582 ha) was orchards. This means that 44% of the total fruit plantation got water supply.

For the ecological, economical, and effective operation of the irrigation devices is important to know the exact plant water status. We have choosen sweet cherry trees in our work as subjects for sap flow measurement and the testing of the transpiration model. The plantation 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 the intensive orchards which were planted in the last years. Sweet cherry can be marketable only with the suitable fruit size (28–32 mm). The high density (1000–3000 tree·ha^{-1}) plantation and the optimal canopy and leaf area formation propose the exact irrigation claim. In Hungary 232 ha of sweet cherry was irrigated with 328000 m^3 water in 2011.

One of the critical points of the succesfull fruit production will be the dryer condition predicted by the global climatic models for the Mediterranean region and the frequency of the extreme weather events grown in the Carpatian Basin, and the increased irrigation costs.

Hence it is essential to know the sweet cherry plants demand especially in intensive orchards.

2. AIMS OF THE RESEARCH

1. One of the tasks was to investigate the water uptake characteristics of the early ripening sweet cherry trees grown in intensive orchards for four months of the vegetation period and as well as before and after the ripening.

2. We wanted to estimate the water consumption of the whole sweet cherry plantation.

3. Goal was to analyse the variation of the daily and nocturnal course and characteristics of the sap flow, the night-time sap flow's rate and its importance.

4. One of the purposes was to calculate the crop basal coefficient for early ripening, Hungarian spindle grown, intensive sweet cherry orchards in local conditions.

5. To know better the factors determined the water demand goal was to the analyse the environmental phenomena and progresses which affect the variation of the sap flow.

6. We wanted to compare the outputs of transpiration model with the measured sap flow values and test the model among different weather conditions.

7. Aim was to do the model sensitivity investigation, by the changing of the input data like the leaf area index and minimal stomatal resistance data.

8. Task was to follow the sap flow reaction to the tree's summer pruning.

3. MATERIALS AND METHODS

3.1. Site conditions and measurements

The investigations were carried out in Hungary, in Soroksár Station of Experimental Farm of Corvinus University of Budapest on sweet cherry orchard. The experimental orchard was planted to 4 x 2 m spacing with 1250 trees·ha^{-1} density in spring 2004.

The cultivar is ‘Rita’, ripening early, between 22 -28 May. Trees are budded onto semi-dwarfing *Prunus canescens x cerasus* ’GiSeLA 6’, on moderate vigorous *Prunus mahaleb* ’Korponay’ seedlings, on vigorous ‘Érdi’ and ‘Mazzard’. Trees were choosen that they represent all of the vigorous rootstocks.

Characteristics of trees can be seen in the 1. Table.

1. Table Data of the investigated sweet cherry orchard

Orchard’s area	1,0 ha
Spacing	4,0x2,0m
Plantation’s area	8,0 m^2
Orientation of the rows	N-S
Row-space	grass
Tree number	1250 fa·ha^{-1}
Specie	’Rita’ (IV-5/62)
Rootstocks	Érdi V., Korponay,Vadcseresznye, GiSelA 6,
Train of the crown	Hungarian spindle
Year of the plantation	spring 2004
First production year	2006
Irrigation	Drip system below the foliage

The sap flow measurements were carried out using Dynamax Flow 32 equipment based on stem-heat balance method. Sap flow was measured from 1 of April to 31 of August each year (2008, 2009, 2010, 2011). We have got 43 different sample days in 2008, 43 in 2009, 12 in 2010, 76 in 2011.

An automatic weather system was installed at the sweet cherry plantation to measure meteorological variables at 10 minutes interval, recorded by Campbell CR 100 data loggers. Temperature and relative humidity were observed by Vaisala HMP35 and soil moisture at two depth (30 and 60 cm) by Campbell CS616 in the research station. Precipitation, wind speed and global radiation were also monitored.

PASW18 statistical program was used for analyzing the relationship between sap flow and meteorological data.

3. 2. Methods

We calculated the K_{cb} (crop basal coefficient) as the ratio of the measured sap flow data and the potential evapotranspiration calculated by the modified Penman–Monteith equation. This coefficient indicates the ratio of the transpiration by vegetation to the whole plantation area for local conditions in intensive (4,0x2,0 m spacing) Hungarian spindle grown sweet cherry orchards.

The Shuttleworth–Wallace (SW) two sources coupled evapotranspiration model transpiration part was used in our work, this model takes into account the fractional covering (f_x) of the vegetation to the soil area.

The total area evapotranspiration (*TET*) is computed by the sum of the following expressions:

$$TET = \frac{f_x}{100} \cdot \lambda \cdot E_{veg} + (1 - \frac{f_x}{100}) \cdot \lambda \cdot E_{soil},$$

where $\lambda \cdot E_{veg}$ is the tree's transpiration, $\lambda \cdot E_{soil}$ is the soil evaporation.

We worked with the trasnpiration part of the equation, which can be described as

$$\lambda \cdot E_{veg} = \frac{\Delta \cdot R_n^{veg} + \rho \cdot c_p \cdot \frac{\delta e_r}{r_a^{veg}}}{\Delta + \gamma \cdot (1 + \frac{r_c}{r_a^{veg}})},$$

where λ is latent heat of vaporization (J kg^{-1}), E_{veg} is the transpiration of plant (mm day^{-1}), Δ is the slope of the saturation vapor pressure curve at mean temperature (mbar K^{-1}), R_n^{veg} is the net radiation over the vegetation (W m^{-2}), ρ air density (kg m^{-3}), c_p specific heat of the air at constant pressure (J kg^{-1} K^{-1}), δe_r vapor pressure deficit at 2 m height (mbar), r_a^{veg} aerodynamic resistance with turbulent and laminar parts (s m^{-1}), r_c is the resistance of the canopy (s m^{-1}) which depends on soil, cuticular and stomatal resistances, γ psychrometric constant (mbar K^{-1}), G is the soil heat flux (W·m^{-2}).

4. RESULTS AND DISCUSSION

Results are shown after the research aims written in the 2. chapter. The selected figures and tables illustrate the most important details of the work.

4. 1. Water consumption of sweet cherry trees and plantations

One of the tasks was to investigate and analyse the water uptake characteristics of the early ripening sweet cherry trees grown in intensive orchards (4x2 m spacing) trained to Hungarian spindle for four months of the vegetation period and as well as before and after the ripening in local conditions. This study based on sap flow measurements made with individual trees and on calculation of water uptake of the plantation's unit area.

Based on the sap flow measurements, the average daily water uptake of the four-year old trees were 24,2; 23,6; 22,8; 10,9 liters from May to August in 2008. One year after this values were: 25,0; 15,6; 23,0; 18,5 liters.

2010 was an extrem humid year. We have got a few data only from July, when the daily water uptake set around 31-50 liters, which provided for and support the new branching and growth of green mass almost on unlimited water availability.

While the seven-year-old trees consumed 55,7, n.d.; 48,3; 44,8 liters per day monthly.

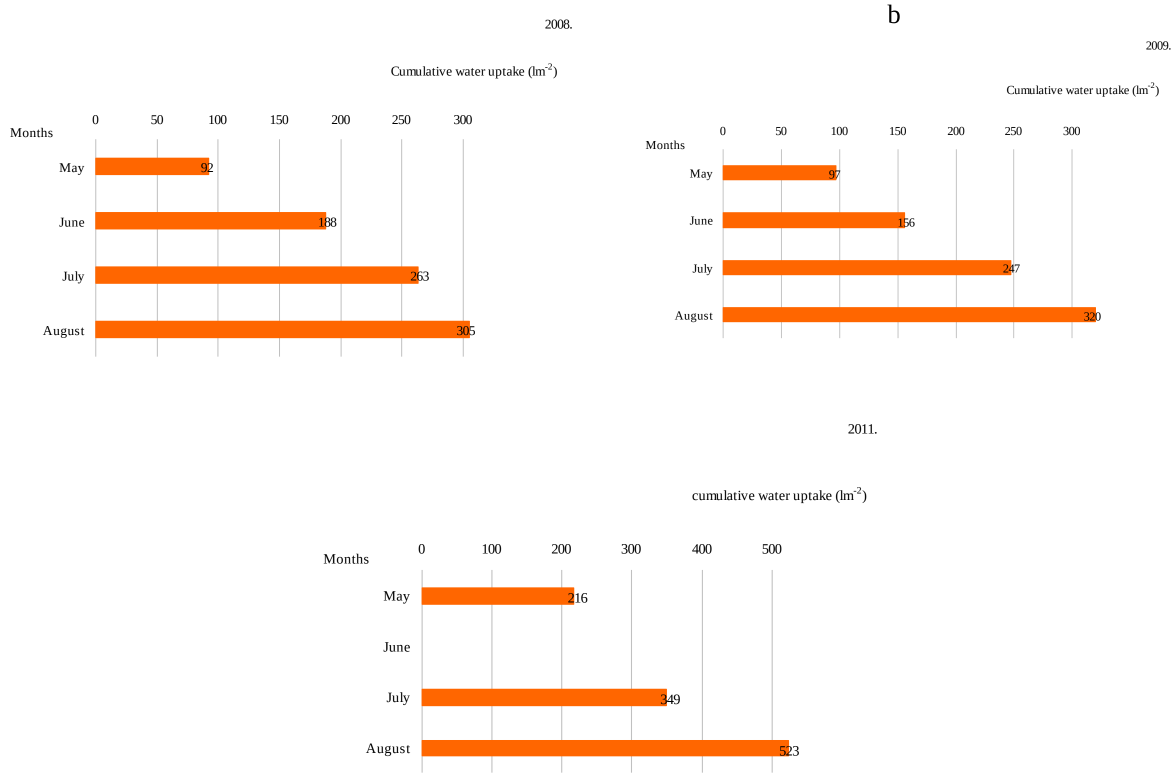
The water uptake varied significantly among the months corresponding to the green mass growing, increasing leaf surface and fruit mass growth's respective periods.

There was increased water consumption by the trees during the ripening period in May independently of the environmental conditions. Weather conditions are more influential on the water uptake and transpiration in July and August. After harvesting (last decade of May) the water uptake of the trees provide for and support the new branching and growth of green mass. The water consumption tapers off after the ripening. We suppose that the increased water uptake during the fruit growing and ripening period (in May) is apparently at the expense of the soil water reserves. The minimal level water uptake in June might be due to the post harvesting period and the unfavorable weather conditions for transpiration.

We calculated the four-year-old sweet cherry orchard's transpiration, which were 92 mm, 96 mm, 75 mm, 42 $mm \cdot m^{-2}$ from May to August monthly. One year after this values were: 97mm, 59 mm, 91 mm, 73 $mm \cdot m^{-2}$. Hence the four and five-year-old intensive sweet cherry orchard's transpiration amount for four month were 305 $mm \cdot m^{-2}$ in 2008 and 320 $mm \cdot m^{-2}$ in 2009 (1. Fig.).

2011 was very dry year, the seven-year-old sweet cherry plantation transpiration was really intensive. The monthly transpiration rate were: 216 mm, n.d., 133 mm, 174 mm. The transpiration was increased by the strong air drought. The cumulative transpiration reached 523 mm·m^{-2} for three months.

a



c

1. Fig. Cumulative water uptake of the intensive sweet cherry plantation based on sap flow measurement

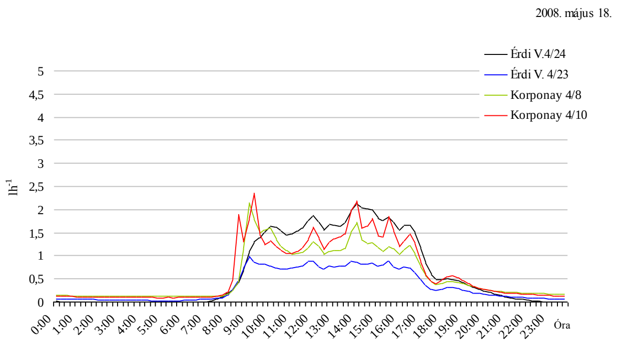
4. 2. Sap flow characteristic of the sweet cherry trees

The daily sap flow rate can help us to plan the irrigation schedule. It is important to know when and how happens the tree's water uptake. The typical daily and nocturnal sap flow rhythm can be seen on the 2.a and 2.b Fig.

We investigated the course of diurnal sap flow. In the morning around 8:00 a.m. the sap flow begins increasing (2.a Fig.). This becomes quite quick and intensive until it reaches a (primary or second daily) maximum (~2,1–4,3 l·h^{-1}) sometimes between 8:00-10:00 a.m. This is usually followed by a depression between 10:00 and 13:00. The daily (prime or) second maximum (1,6–3,1 l·h^{-1}) is reached between 14:00-16:00. Compared to the very intensive morning sap-flow, after 18:00 p.m. the sap flow slowly reduces to a minimal level.

Nocturnal sap flow was detected on sweet cherry trees with typical course. At night minimal sap flow rate was measured till midnight (0,02-0,1 l·h^{-1}), at about 2:00-3:00 a.m. the sap flow starts to grow, at dawn (5:00-6:00 a.m.) its rate becomes stronger.

a,



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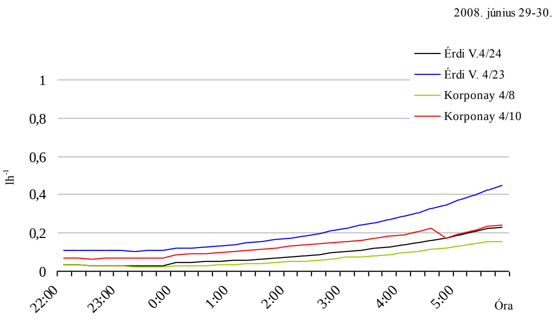


2. Fig. Typical daytime (a) and night-time (b) sap flow course on selected days

4. 3. Daily sap flow

Three sections of the day were distinguished for the purpose of analyzing the water consumption in each phase. Night-time refers to the period between 22:00-6:00, day-time to 6:00-22:00; this is split between morning (6:00-14:00) and afternoon segments (14:00-22:00). The morning water uptake was 5-10 % more than in the afternoon. The average water uptake during the night was 5,6% of day-time water uptake.

4. 4. Sap flow and environmental interactions

To better understand the connection between the transpiration and the weather conditions, the daily pattern of sapflow was analysed in relation of temperature, solar radiation, vapor pressure deficit and wind speed.

Taking a day as a whole (24 hours), there is positive linear correlation between sap flow and the above mentioned investigated parameters. In the morning there is linear correlation, while in the afternoon exponential correlation between sap flow and vapor pressure deficit. Sap flow and global radiation shows cubic relation between 14:00-22:00. We found exponential relation between the VPD and sap flow rate at night (2.a, b Table).

The strongest correlation was found between the sap flow and vapor pressure deficit, this fact has been noticed by other authors. Our results suggest that on certain days – when global radiation exceeded 200 $W \cdot m^{-2}$ – the global radiation is the major factor which determine the sap flow.

2.a Table Relation of the sap flow and the meteorological parameters in the morning, afternoon and night

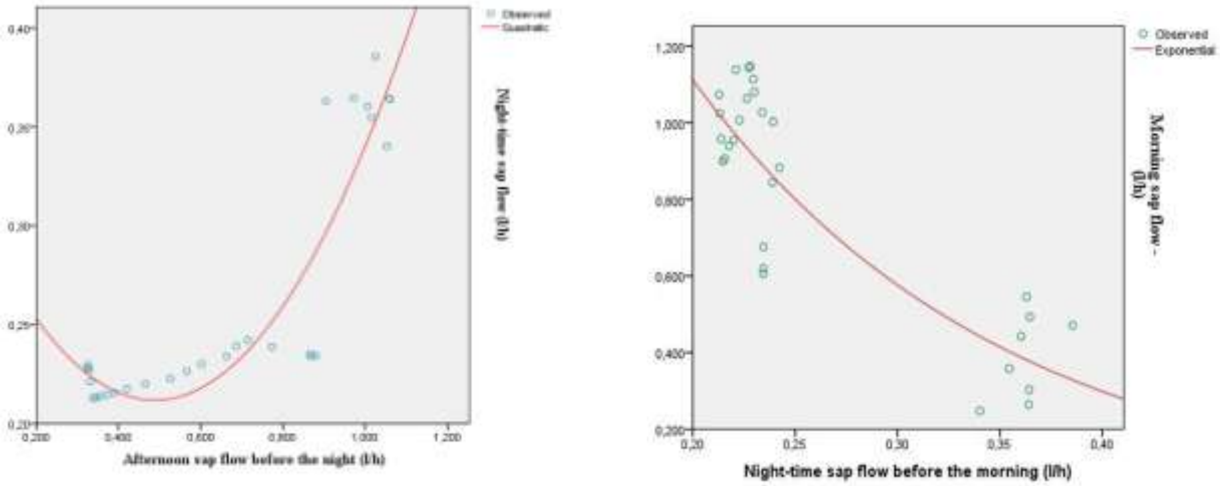
Factor	Model					
	R	R^2	Adjusted R^2	Standard error	ANOVA F	Sig.
Morning						
Temperature (*T*)	0,984	0,968	0,967	0,100	909,910	0,000
Function	Sap flow ($l \cdot h^{-1}$) = -2,407+0,190*T* (°C)					
Vapor pressure deficit (*VPD*)	0,982	0,964	0,963	0,106	807,002	0,000
Function	Sap flow ($l \cdot h^{-1}$) = -0,523+0,159*VPD* (mbar)					
Wind speed (*WS*)	0,790	0,624	0,611	0,344	49,699	0,000
Function	Sap flow ($l \cdot h^{-1}$) = -4,051+2,108*WS* ($m \cdot s^{-1}$)					
Global radiation	0,850	0,802	0,899	0,448	277,677	0,000
Function	Sap flow ($l \cdot h^{-1}$) = 0,007*$\exp^{0,008S\ (W \cdot m-2)}$					
Afternoon						
Temperature (*T*)	0,961	0,924	0,921	0,166	364,051	0,000
Function	Sap flow ($l \cdot h^{-1}$) = 0,013*$\exp^{0,222T\ (°C)}$					
Vapor pressure deficit (*VPD*)	0,976	0,907	0,951	0,130	608,072	0,000
Function	Sap flow ($l \cdot h^{-1}$) = 0,152*$\exp^{0.,60VPD\ (mbar)}$					
Wind speed (*WS*)	0,772	0,596	0,582	0,381	44,226	0,000
Function	Sap flow ($l \cdot h^{-1}$) = 0,036*$\exp^{1,250WS\ (m \cdot s-1)}$					
Globa radiation (*S*)	0,993	0,974	0,984	0,059	640,491	0,000
Function	Sap flow ($l \cdot h^{-1}$) = 0,000000008171S^3-0,00001030S^2+0,005*S*+0,368					
Night time						
Temperature (*T*)	0,893	0,798	0,791	0,718	118,326	0,000
Function	Sap flow (lh^{-1}) = 0,0000002376*$\exp^{1,092T\ (°C)}$					
Vapor pressure deficit (*VPD*)	0,901	0,812	0,806	0,692	129,905	0,000
Function	Sap flow ($l \cdot h^{-1}$) = 0,001*$\exp^{2,277VPD\ (mbar)}$					
Wind speed (*WS*)	0,371					
Function	–					

2.b Table Relation of the sap flow and the meteorological parameters daytime and in the whole day

Factor	Model					
	R	R^2	Adjusted R^2	Standard error	ANOVA F	Sig.
Day time						
Temperature (*T*)	0,935	0,874	0,872	0,182	428,884	
Function	Sap flow ($l \cdot h^{-1}$) = -2,203+0,174*T* (°C)					
Vapor pressure deficit (*VPD*)	0,939	0,882	0,880	0,176	463,827	0,000
Function	Sap flow ($l \cdot h^{-1}$) = -0,392+0,136*VPD* (mbar)					
Wind speed (*WS*)	0,674	0,454	0,446	0,379	51,624	0,000
Function	Sap flow ($l \cdot h^{-1}$) = -1,867+1,148*WS* ($m \cdot s^{-1}$)					
Global radiation (*S*)	0,626	0,891	0,381	0,400	39,854	0,000
Function	Sap flow ($l \cdot h^{-1}$) = 0,001*S*+0,422					
24 hours						
Tempereature (*T*)	0,937	0,877	0,876	0,197	671,801	0,000
Function	Sap flow ($l \cdot h^{-1}$) = 0,127*T*(°C)-1,341					
Vapor pressure deficit (*VPD*)	0,957	0,917	0,916	0,162	1034,677	0,000
Function	Sap flow ($l \cdot h^{-1}$) = 0,122*VPD*(mbar)-0,235					
Wind speed (*WS*)	0,808	0,654	0,650	0,331	177,302	0,000
Function	Sap flow ($l \cdot h^{-1}$) = 1,258*WS*($m \cdot s^{-1}$)-2,164					
Global radiation (*S*)	0,765	0,584	0,580	0,363	132,224	0,000
Function	Sap flow ($l \cdot h^{-1}$) = 0,002*S*+0,218					

The relation between night–time sap flow and afternoon sap flow just before night was strongly quadratic while that between morning sap flow and night time sap flow just before the morning was strongly exponential (3.a,b Fig.). These results were obtained by a regression analysis among the above mentioned variables. According to our results the night time sap flow rate is determined quadraticly by sap flow rate measured in the preceding afternoon. The low level nocturnal sap-flow is in relation with the low level sap flow rate measured earlier in the afternoon. This supports the hypothesis that the higher sap-flow and water availability in the light hours before the night cause higher stomatal opening and sap flow rate during the night.

b,

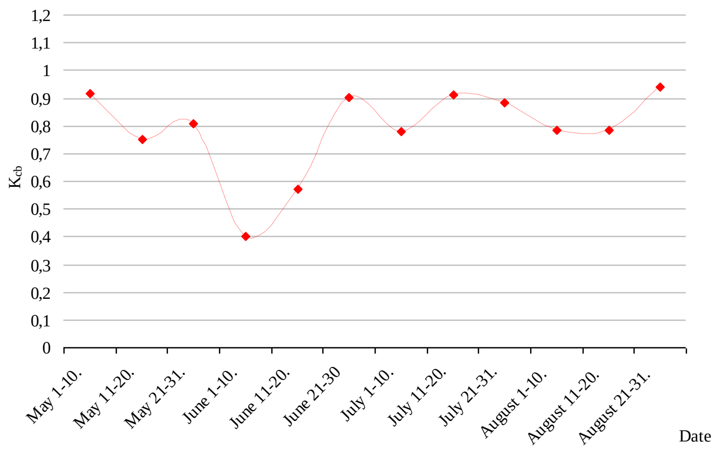


a,

3. Fig. Relation of night time sap flow and afternoon sap flow before the night (a), relation of morning sap flow and night time sap flow before the morning (b)

4. 5. Crop basal coefficient (K_{cb})

The crop basal coefficient (K_{cb}) - calculated as the rate of transpiration measured by sap flow and the potential evapotranspiration (by using modified Penman–Monteith equation) was estimated for Hungarian condition for the early ripening intensive sweet cherry orchard. The K_{cb} value was the highest in May (0,9); thus irrigation is essential in this period. In June after the harvest, the K_{cb} value considerably decreased (0,39;0,57), when most of the evapotranspiration was due to soil evaporation. Our results suggest supporting irrigation after ripening time. The transpiration coefficient (0,7 – 0,9) rose again new shoots started growing after the summer pruning and flower bud differentiation in late July.



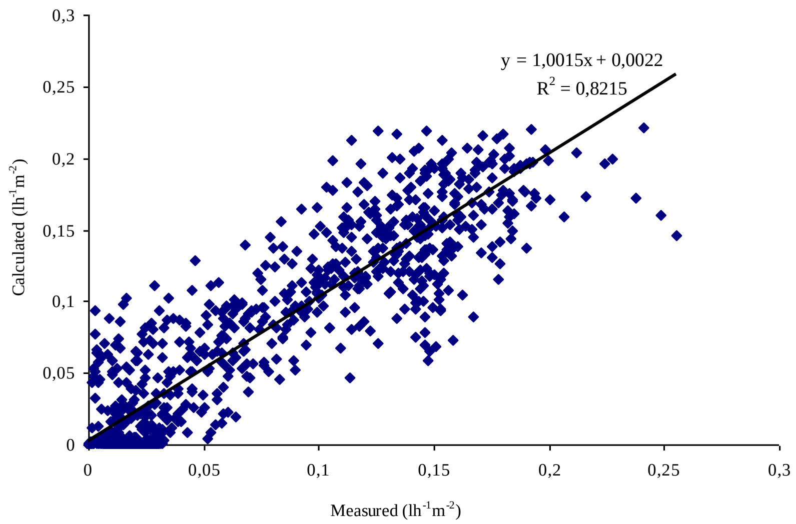
a,

4. Fig. K_{cb} course (based on three years investigation) for sweet cherry orchard in local condition

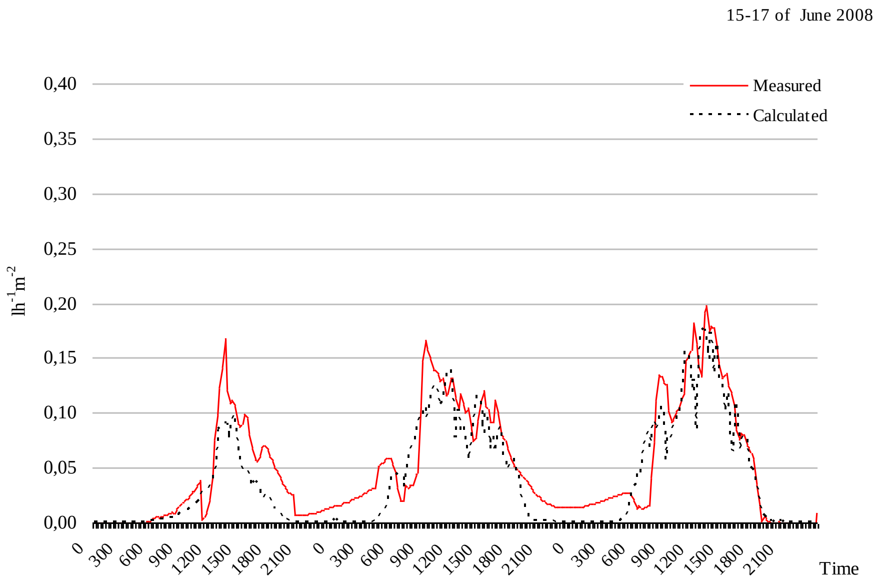
4. 6. Comparison of measurements and model calculation

One of the tasks was to compare the outputs of the Shuttleworth–Wallace (SW) clumped model transpiration part with the measured sap flow values and test the model among different weather conditions. Appropriate agreement was found between the two sources clumped evapotranspiration model's output and between the measured sap flow (as transpiration) data (5. Fig.). Although the model underestimates on cloudy and rainy days and on high vapor pressure deficit days it is suitable to quantify the water loss of the intensive sweet cherry orchards.

We selected a three days period (15–18 of June 2008, 6.Fig.) to show the accordance. On the 15th of June 3,2 mm while on the previous day 5,2 mm rain was falling on the sampling area. There was not favorable weather conditions for the transpiration (light wind, overcast sky, and 85% relative humidity). Under such conditions the model underestimated the transpiration rate. It did not indicate the morning and afternoon maximum. Vapor pressure deficit increased a bit on 16th and 17th of June, the model calculation was better than on the former day. The model follows well the measured fluctuations. While we observed night time transpiration, the model could not get it which might be due to the zero global radiation input data.



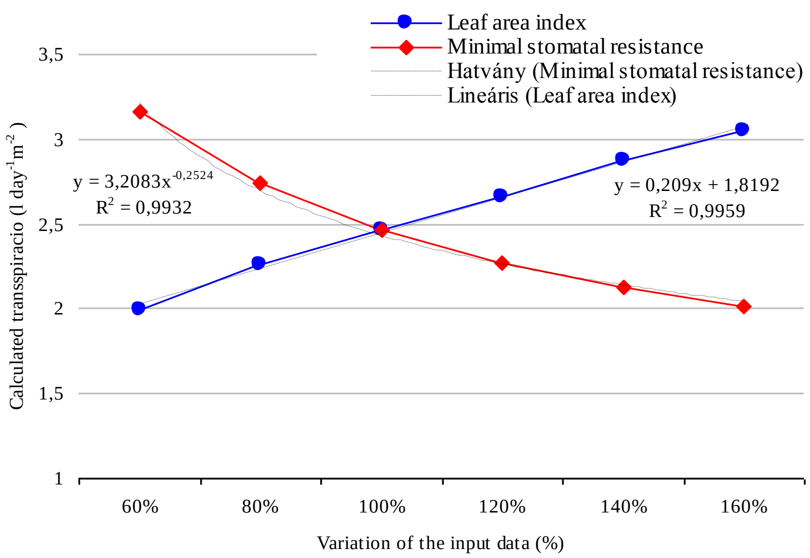
5. Fig Comparison of the calculated and the measured transpiration



6. Fig. The calculated and the measured transpiration on 15–17 of June 2008

4. 7. Model sensitivity

Model output instability is caused partly by the uncertainty of the input data. Sensitivity analysis of the model was made by changing stepwise (by 20%) the input plant parameters such as minimal stomatal resistance and leaf area index. According to our results, varying the leaf area index (input to the model) shows a linear relation with the model's output, and by changing the minimal stomatal resistance the relation is rather a negative power function. The 20% reduction and increase of the above mentioned input did not cause significant deviation but wider fluctuation produced notable variance in the result.

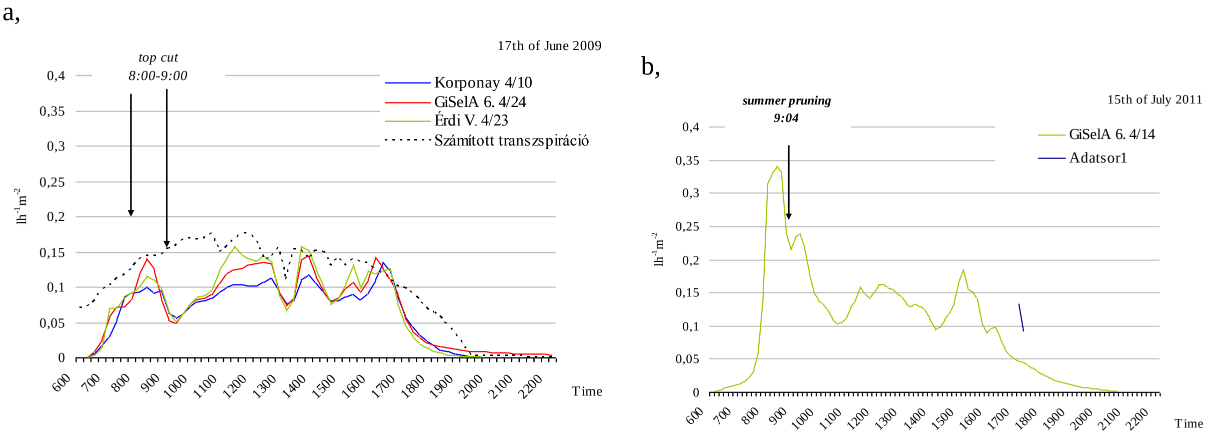


7. Fig. Model sensitivity for the leaf area index and for the minimal stomatal resistance

4. 8. Impact of the summer pruning for the sap flow

On the 17th of June 2009 and on the 15th of July 2011 severe summer pruning was carried out on the sweet cherry trees. The trees were headed at the 3,5 meters level. We followed how the pruning influences the sap flow rhythm of the trees (8. Fig). The former successfully used SW model served as control.

Based on our experiments, the summer pruning of the trees does not cause severe long-term drop in the sap flow. We sensed only short-term shrinkage. It might be due to the fact that leaves on the lower, wetter foliage levels have come out to the breezy and sunshine exposed part of the crown. These leaves have taken over the intensive transpiration role.



8. Fig. Impact of the top cut and summer pruning for the sweet cherry tree's sap flow on 17th of June 2009 (a), and on 15th of July 2011 (b)

4. 9. Practical applications

The effective and economic irrigation is crucial in the intensive orchards. As much water must be got out as much plants need on local circumstances. Our research results can help to harmonize the water supply and the plant's water use, and develop the irrigation development. The water rationing and dosage can be optimized.

By our results the most important irrigation period for the early ripening intensive grown sweet cherry orchards is during the fruit growing and ripening period (in May), when the water uptake is the highest. After harvesting (last decade of May) the water uptake of the trees provide for and support the new branching and growth of green mass. The water consumption tapers off.

Our investigation method could be used for the study of the water uptake of other, early ripening stone fruits such as apricot or sour cherry.

The Shuttleworth–Wallace model is suitable to quantify the water loss of the intensive sweet cherry orchards, and can be served as control by the investigation of the summer pruning impacts for the sap flow.

5. NEW SCIENTIFIC RESULTS

1. We determined the water uptake characteristics of the early ripening sweet cherry trees grown in intensive orchards trained to Hungarian spindle for four months from the fruit growing and ripening period till the end of new branching and growth of green mass growing. Based on the sap flow measurements, the daily water uptake of the four and five-year old trees was between 10 and 40 liters, while the seven-year-old trees consumed 40–60 liters per day. The transpiration amount of the four and five-year-old intensive sweet cherry orchard calculated for four months were 305 $mm \cdot m^{-2}$ in 2008 and 320 $mm \cdot m^{-2}$ in 2009. The cumulative transpiration reached 523 $mm \cdot m^{-2}$ for three months in 2011.

2. We investigated the course, characteristic, rate and rhythm of the daily and the nocturnal sap flow of the sweet cherry trees. We analysed the water consumption of different phases of the day. The morning (6:00–14:00) water uptake was 5–10 % more than in the afternoon (14:00–22:00). The average water uptake during the night (22:00–6:00) was 5,6% of day-time water uptake. We revealed the relation between night–time sap flow and afternoon sap flow just before night. There was strongly quadratic relation between the above mentioned agents while that between morning sap flow and night time sap flow just before the morning was strongly exponential.

3. The crop basal coefficient (K_{cb}) - calculated as the rate of transpiration measured by sap flow and the potential evapotranspiration (by using modified Penman–Monteith equation) was estimated for Hungarian condition for the early ripening intensive sweet cherry orchard. The K_{cb} values varied between 0,4–0,9 depending on the phonological course.

4. We studied the connection between the transpiration and the weather conditions, the daily pattern of sapflow was analyzed in relation of temperature, solar radiation, vapor pressure deficit and wind speed. The strongest correlation was found between the sap flow and vapor pressure deficit. Our results suggest that on certain days – when global radiation exceeded 200 $W \cdot m^{-2}$ – the global radiation is the major factor which determine the sap flow.
Taking a day as a whole (24 hours), there is positive linear correlation between sap flow and the above mentioned investigated parameters. In the morning there is linear correlation, while in the afternoon exponential correlation between sap flow and vapor pressure deficit. Sap flow and global radiation shows cubic relation between 14:00-22:00. We found exponential relation between the VPD and sap flow rate at night.

5. Appropriate agreement was found between the two sources Shuttleworh–Wallace evapotranspiration model's output and between the measured sap flow (as transpiration) data. Although the model underestimates on cloudy and rainy days and on high vapor pressure deficit days it is suitable to quantify the water loss of the intensive sweet cherry orchards.
Sensitivity analysis of the model was made by changing stepwise (by 20%) the input plant parameters such as minimal stomatal resistance and leaf area index. According to our results, varying the leaf area index (input to the model) shows a linear relation with the model's output, and by changing the minimal stomatal resistance the relation is rather a negative power function. The 20% reduction and increase of the above mentioned input did not cause any significant deviation but wider fluctuation produced notable variance in the result.

6. Based on our experiments, the summer pruning of the trees does not cause severe long-term drop in the sap flow. The former successfully used Shuttleworth–Wallace model served as control by this investigation.

SELECTED PAPERS OF THE AUTHOR RELATED TO THE RESEARCH TOPIC

Refereed journal

Juhász, Á., L. Tőkei, Z. Nagy, K. Hrotkó (2008) Előzetes adatok a cseresznyefák vízfogyasztásáról. *Kertgazdaság* 2008. 40. (4). p.17.

Juhász, Á., Tőkei, L., Nagy, Z., Hrotkó, K. (2008) Estimating of water consumption of cherry trees *International Journal of Horticultural Science* 14 (4) pp. 15–17.

Juhász, Á., Nagy, Z., Tőkei ,L., Hrotkó K. (2010) Cseresznyefák vízfogyasztásának megfigyelése. *Agrár és Vidékfejlesztési Szemle* 5. (1) supplement, Agriculture and Countryside in the Squeeze of Climate Change and Recession, Conference Issue Hódmezővásárhely 2010.04.22. ISSN 1788-5345, pp. 274-279.

Juhász Á., Sepsi P., , Hrotkó K, . Tőkei L. (2011) Transpiration of high density sweet cherry orchard. *Acta Hort*, elfogadva, nyomtatásban

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