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Water relations of sour cherries (minireview)

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Summary: Recently, the sour cherries as food resources become more important for health preservation and so the modernization of growing technology in sour cherry production will be timely. The global warming and inadequate distribution of precipitation result a decrease in the alternancy of sour cherry production, as well. Sour cherries rather adapted to survival of drought than sweet cherry trees therefore a few studies performed to explore the water requirement of sour cherry varieties. The rootstocks, the type of soils in plantation and the water balance influence the water management of sour cherries. In orchards, in particular first year plantation, use of various row covering contribute to preservation of the natural water pool of soil and affect on the tree vigor, yield and fruit quality. Wide-spread application of integrated fruit growing technology and climate changes the researches are pointed to develop efficient irrigation technology based on transpiration yield model. The crop model based on use of meteorological data was developed for cherry orchards in order to predict transpiration of trees, dry matter production and fruit yield. The linear relationship between dry matter accumulation and transpiration was verified for sour cherry trees. Other models essay to asses the effects of climate changes on crop production. Importance of economical production and fruit quality such as ingredients of raw materials and food increases in intensive sour cherry orchards used by irrigation techniques. Because of climate changes it should more pay attention to research concerning on the stress physiological response of sour cherry varieties and post-harvest fruit quality.

Key words: water balance, irrigation, fruit cracking, rootstock

Introduction

Sour cherries are grown on large area in 27 countries worldwide. State of Michigan, the leading producer, grows sour cherries along the eastern shore of Lake Michigan, where the moderating influence of the lake on winter and spring temperatures is beneficial to production. During the last 30 years the most of cherry production shifted to the eastern part of Europe. Hungary produces 4 percentage of world production so it is the seventh in the range of top 10 countries (*FAO* 2004). The highest rate of sour cherry plantations is registered in the north-eastern part of Hungary (*Nyéki* et al. 2005), where the production was mostly under non-irrigated conditions.

Recently, the sour cherries as food resources become more important for health preservation. The findings that sour cherries (*Prunus cerasus* L. called tart cherries) contain high levels of anthocyanins that possess strong antioxidant and inflammatory properties have attracted much attention to this species (*Wang* et al. 1997, 1999, *Blando* et al. 2004).

During ontogenesis, sour cherry trees have been developed strong root systems with high water absorption in order to survive the drought. The water requirement of cultivars could be proved by good choices of rootstocks and the place of plantations. Thus the irrigation of sour cherry orchard has not been necessary the years before. The global warming and inadequate distribution of precipitation result a decrease in the alternancy of sour cherry production, as well. The amount of rainfalls of the first half of year, are not enough to achieve adequate yields and fruit quality. Moderate watering is needed also after harvest time because the drought after harvest promotes the fall of foliage which will impair the performance of trees in the next year (*Nyéki* et al. 2005). Pot trials proved that not only the root system but the water transport of tree are important in the tolerance to water deficit of sour cherries (Perry 1987). *Hrotkó* (2003) published, that the demands of sweet and sour cherry orchards at least 600 mm of water a year. Sweet cherry compared with sour cherry has rather larger disadvantages under water deficit. The sweet cherry trees with larger canopy are less sensitive to water stress than those have a smaller ones (*Inántsy & Balázs* 2004). The rootstocks, the type of soils in plantation and the water balance affect the water management of sour cherries. The differences among the varieties are resulted by use of rootstocks, technology and their adaptability to climate condition. It is known that 'Mahaleb'rootstock (*Cerasus mahaleb* (L) Mill) developed deep root system with few branches in consequence it has no high requirement of soil and it is also good for droughty soils. 'Mazzard' (*Cerasus avium* L), wild selection of sweet cherry, produces high density branched root system in particular near the upper soil surface. The sour cherry varieties on Mahaleb rootstocks have larger drought tolerance on soft soils than those on Mazzard rootstoks.

Soil and atmospheric effects on tree's water balance

Climate, together with soil type, determines the water needs of trees and productivity of orchards. The daily water use is called evapotranspiration (ET) which is the amount of water evaporating off the soil surface plus the water used (transpired) by the tree. Taking the grass crops cover of the orchard into consideration, the grass reference evapotranspiration (ETo) is generally estimated with the modified Penman-Monteith equation (*Allen* et al. 1998) so that the actual transpiration of trees should be estimated. In practice, meteorological sensors have been placed above the orchard to measure wind speed, temperature and water vapor deficit which need to determine the evapotranspiration (*Allen* et al. 1998, *Dragoni* et al. 2004).

During the day the evapotranspiration increase due to enhance of solar radiation and increase of soil and plant temperatures. The water requirement of plant is increased by the rising of air temperature and decrease of humidity. On sunny days evaporation at the leaf surface, through the stomatal apertures, causes a large potential difference between the stomata and the roots that pulls water to the top of the tree. Available soil moisture i.e. the water that can be extracted by the tree is held at water potentials in the range between –0.1 and –1.5 megapascals (MPa), which approximate field water-holding capacity and permanent wilting percentage, respectively (*Webster & Looney* 2004). The available moisture for the plant is depleted to near the permanent wilting percentage. The crop plants near to the wilting point though will not wither and recover their yield decrease.

When the evaporation of soil surface is decreased by various cover crops to minimum, the climatic factors such as radiation, temperature, wind speed etc. will affect the plant transpiration. *Anderson* et al. (1992) and *Bingham* et al. (1992) provided a nearly ideal water stress experiment when the cherry trees planted into a soil with a restricting layer beginning at 30 cm that combined with the covered surface treatments. They revealed that roots were unable to extract moisture below 60 to 70 cm. These results coincided with the findings of *Núnez-Elisea* et al. (2004) the most water uptake of 'Lapins'/Mazzard and 'Regina'/Gisela 6 cherry trees occurred at 40–60 cm soil depth on sandy loam soil. These shallow soil conditions allow the tree to dry. Wood-strip covering in the orchards is advantageous for the moisture of soil in particular after rainless periods. This type of covering contribute to preservation of the natural water pool of soil in addition enhance the development of trees (*Inántsy & Balázs* 2004). According to others (*Núnez-Elisea* et al. 2004) use of polypropylene fabric row cover was favourable to vigour and branching of sweet cherry trees. Under this type of row covering the leaves of trees were darker green, had significantly higher nitrogen content and the trees produced larger yield and fruit size than fruit of trees growing without row covers (*Table 1*). Authors published that cost of establishing fabric row covers is beginning to be recovered 3 years after planting.

Water needs of sour cherries

The sour cherries compared with other fruit species has lower water demands and rather endure the drought. Whereas the irrigation is indifferent in the "traditional" sour cherry growing technology, a few results concerning on water use of sour cherries are known. Wide-spread application of integrated fruit growing technology demands the use of irrigation techniques based on transpiration yield model in the so/files/aktualis/TN_agroinform_ 200711 28114400_ NV_kulonszam.jpgur cherry production. In addition, the abnormal distribution of rainfall or frequency of drought during fruit development is harmful in quality fruit production under continental climate. The largest water demand of sour cherries is during shoot growing and fruit development that is at first half of May and June in Hungary. The drought of spring and early summer decrease the fruit size of sour cherry varieties with late maturity. On the other hand too many rainfalls resulted in fruit cracking decrease their quality. After harvest good water supply enhances production of photosynthesis of leaves that is favourable to flower bud formation and the yield in next year. Dry summer after harvest, the high density, pre and postharvest irrigation in intensive orchards, all of them contribute to enhance the alternancy.

The water balance of orchards is determined by water conditions of soil and water status of trees. The moisture of soil and climatic factors are influence on transpiration and water use efficiency for yield, respectively. The soil-water monitoring system measure the soil water content within the

Table 1. Effects of syntetic fabric row cover on tree vigour, yield and fruit quality of 4th leaf 'Regina'/Gisela 6 trees (*Núnez-Elisea* et al. 2004)

Treatments	TCSA* (cm^2)	Yield kg/tree	Fruit weight (g) (mm)	Fruit diameter	Firmness (g/mm)	°Brix
No cover (control)	55.5 a†	3.19 a	11.1 a	28.9 a	325.4 a	21.6 b
Fabric row cover	72.3 b	7.39 b	11.6 b	29.5 b	360.9 b	20.4 a
% increase over control	30.3	131.7	10.5	10.2	11.1	–5.6

* TCSA=trunk cross-sectional area

†= the values in a column having different letters are significantly different

area explored by root zone at different (20–30–40–60 cm) depth. Tree water status is being measured by 'leaf water potential' and 'stem water potential'. The measurement of leaf water potential can vary greatly depending on the position of the leaf in the canopy due to large variations in exposure to sunlight and wind. Stomatal conductance measure the movement of water vapor through stomata therefore related to leaf water status.

The stem water potential is widely used as an indicator of tree water status. The relationship between stem water potential and leaf stomatal conductance was explored for 'Lapins'/Mazzard cherry trees (*Núnez-Elisea* et al. 2004). In practice the measurement of leaf stomatal conductance is easier and quicker with porometer equipments than stem water potential. When the moisture level of soil is changing slowly the transpiration of leaves is determined by stomatal conductance and the weather conditions.

Transpiration yield models (*Hill* et al. 1984, *Hill* 1991, *Anderson* et al. 1992, *Bingham* et al. (1992) and weather generators (*Semenov* 2006, *Zavalloni* et al. 2006) were developed to asses the effects of climate changes on crop production. Transpiration yield model was primary adapted for irrigation scheduling program. Most of models calculate the whole plant transpiration and photosynthesis using a big-leaf model by modeling up from single-leaf measurements. In this case the canopy is treated as a single big leaf and sunlit and shaded leaves are not treated separately (*Dai* et al. 2004). It has demonstrated that single leaf measurements can overestimate true whole-plant photosynthesis by as much as 40% in grapevines and fruit trees (*Poni* et al. 1997). The photosynthesis intensity of trees in lysimeter trials is significantly different from those planted in field conditions. *Whiting & Lang* (2004) showed net daily whole tree carbon gains of 200–800 g $tree^{-1}$ for 9-year-old sweet cherry trees with leaf areas of ca. 35–40 m^2 while the leaf area of tree on lysimeter was 10-fold less of that. Under well-watered conditions, the transpiration of young sweet cherry tree on lysimeters remained in a range between 10 to 13 kg $m^{-2}day^{-1}$ (leaf area based) when the volumetric water content of soil was kept at about 0.25 m^3m^{-3}. In contrast under water stress, the transpiration decreased slowly when the soil water decreased (*Antunez & Whiting* 2006).

Bingham et al. (1992) and *Anderson* et al. (1992) developed the crop model based on meteorological data to predict cherry orchard transpiration, dry matter production and fruit yield. The model was applied to a cherry orchard with a variety of surface cover treatments, some of which limited the availability of water to the trees. They found that yields were related to tree size as measured by trunk diameter or canopy volume. Yield efficiency ratings (kg of fruit per cm^2 of trunk diameter cross-sectional area) of trees were not different significantly in orchard floor treatments so they were related primarily to tree size. Tree in plots with a complete sod cover had lower yield efficiency ratings indicating that sod cover had a competitive effect over and above its effect of tree size (*Anderson* et al. 1992). The transpiration yield model (*Bingham* et al 1992) indicated a greater reduction in transpiration in plots with a complete a grass sod cover.

Many factors are considered to take part in the determination of sour cherry yield. In particular temperature is used to determine bud phenology (thermal time), canopy development as represented by leaf area index (LAI) and bud mortality through free injury. Total solar radiation is used to determine plant evapotranspiration (ET) that is affected by temperature, vapor pressure and wind as well as amount of antecendent soil water. *Zavalloni* et al. (2006) developed a temperature based model simulating the growth and development of sour cherry (*Prunus cerasus* L.) in order to determine the impacts of climate in past and potential future time trends. They found that the early phenological development was also associated with greater susceptibility to cold injury. The simulations also suggested an increased probability of spring bud damage especially during the past 20–30 years. Other crop models (*Bingham* et al. 1992) revealed the relationship to canopy diameter and other tree parameters was significant. Fruit yield and canopy diameter were plotted against both cumulative seasonal and fruit growth period transpiration. In consequence of this the linear relationship between dry matter accumulation and transpiration was verified for sour cherry trees (*Bingham* et al. 1992).

Irrigation scheduling

In consideration of climate changes the knowledge of optimum water demands of fruit varieties and the development of irrigation systems with high efficiency and low cost in orchards are necessary. During water deficit periods, the irrigation resulted in increase of 13% yield i.e. 520 kg per hectare surplus yield was detected in sour cherry trees (*Gergely* 1978). A significant positive relationship (r=0.860) between irrigation rate and yield gain due to irrigation was found for sour cherry (*Rzekanowski & Rolbiecki* (2000). Sum of precipitation and irrigation rate were correlated positive with the fruit weight of sour cherry 'Lutøwka' (r=0.833). As seen in *Table 2* the degree of water deficit affected remarkably the growth and fruit quality of mature cherry trees.

In generally, the water requirement of plants is different according to their phenological developments. Irrigation studies based on tree response determined that for young trees it is beneficial to irrigate them by a factor of 2 (double) until the trees reach 70% full cover. It seems that "over irrigated" young trees grow even better than if they receive their daily water use allotment based on evapotranspiration. Use of drip irrigation is rather effective for young trees.

Much less water per tree applied via the drip system relative to the sprinklers in sweet cherry orchards (*Neilsen* at al. 2005) and the damages of evapotranspiration are smaller and easier, more efficient fertigation than for sprinklers. During summer, young, small trees will need about 18-54 L of water per day and large trees up to 1200 L per week,

Table. 2 Effects of full-season deficit irrigation on growth, yield and fruit quality of young 5th to 6th leaf) 'Lapins'/Mazzard trees (*Núnez-Elisea* et al. 2004)

Irrigation regime (%ER)*	Yield kg/tree		Average fruit weight (g)		TCSA** cm^2	
	2003	2004	2003	2004	2003	2004
25	0.726 a	2.903 a	9.8	10.2 a	70.4 b	108.9
50	0.322 b	0.771 b	9.3	9.2 b	69.6 b	17.9
100	0.118 b	0.952 b	9.6	9.5 ab	77.8 a	119.3
Sign. P>0,05			*ns*			*ns*

* ER= weekly evaporation replacement as measured with USDA class 1 pan evaporimeter
** TCSA= trunk cross-sectional area

although water requirements will vary depending on environmental conditions and the soil type (*Geisel* et al. 2002). It was revealed that drip irrigation resulted in a narrow wetted strip close to a part of potential root zone (*Hrotkó* 2003, *Neilsen* et al. 2005). However, it reduce cherry tree vigour, but not yield nor fruit size in the first three growing seasons (*Neilsen* et al. 2005). Partial root zone drying (PRD) irrigation technique has been developed to make more efficient use of water in particular apple, pear and also try to apply for sour cherry. PRD irrigation was applied alternately; two poly-tube lines, each with an independent valve, have been installed at each row. Irrigation was switched from one side of the root system to the other at approximately 2-week intervals (*Núnez-Elisea* et al. 2004). *Hrotkó* (2003) suggested the microjet irrigation four cherry orchards in terms the sprinklers should be placed between the trees and not below the trees. He advises to irrigate 30-40 L of water per tree in more times a month during dry periods.

A new irrigation technique has been developed for efficiently irrigation of root zone, e.g. water percolation below the root zone can be decreased by increasing irrigation intervals (a few pulses a day) and by increasing the number of emitters. In the cherry orchards on fine sand loamy soil used by drip irrigation the deep water percolation related to water consumption of trees and irrigation initiation time (*Isberie* et al. 2004).

Water relations and fruit cracking

At high summer temperatures sweet cherry trees produce fruit deformities such as doubling or spuring of the fruit. On the other hand too many rainfalls or over irrigation during fruit ripening cause fruit cracking. Sour cherries are less prone to cracking than sweet cherries. One of model for revelation of cracking mechanisms has been based on the difference in osmotic potential between surface and fruit juice (*Sekse* 1998). The water covered the fruit surface has a smaller osmotic potential than fruit juice and so the water diffuses towards the concentrated solution (high sugar content) or high osmotic potential into the fruit. As the sweet cherry fruit has higher sugar content than in sour cherry the heavy rainfalls or irrigation cause larger damages as like as fruit cracking in sweet cherry production.

According to other model of fruit cracking the water uptake by root and sap import through the sweet cherry fruit stem can increase to turgor pressure in the fruit which is the driving force for fruit cracking. The mechanisms in sweet cherry fruit cracking are complex that includes both fruit water balance and morphological features (*Sekse* et al. 2005). They found that the rate of water uptake was in the range 20 to 30 il/h per fruit and was linear over a 6 hour period. Magnitude of the water uptake through the fruit surface is 2 to 3-fold that of uptake via the fruit stem. According to this model water uptake through the fruit surface adds to the internal turgor pressure caused a cracking (*Sekse* et al. 2005) but can also have a devastating effect on epidermal cells and the cuticle (*Glenn & Poovaiah* 1989, *Sekse* 1995, 1998). Some varieties predisposed not to produce fruit cracking under wet weather conditions that may be explained by the lack of turgor pressure or the structure of fruit stem and cuticle (*Inántsy & Balázs* 2004).

However, most of studies were dealing with water use and fruit quality of cherry varieties but these could be partly applied for sour cherries as well. Because of climate changes it should more pay attention to research concerning on the response of sour cherry varieties to environmental stresses and post-harvest fruit quality.

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