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Water relations of apple and influence on fruit quality (minireview)

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Summary: The saving of soil water content and the improvement of adaptability of plants to periodical insufficient water and use of deficit irrigation technology become more important because of the occurrence of frequently dry periods. The water use efficiency of apples can be increased by the choice of appropriate rootstocks and determination of water requirement of varieties that depend on their growing periods and climatic factors. Depletion of soil water resources need to develop efficient irrigation techniques for quality apple production. A new deficit irrigation strategy (PRD) has been developed that based on partial water supply of root-zone. This does not result a decrease in the sizes and yield of the fruit. The larger fruit size and lower firmness in frequently irrigated trees can result in excessive internal growth stresses that cause higher rate of fruit splitting. Many studies revealed the relationship between irrigation and yield quantity. Recent researches investigate the effects of irrigation on apple fruit quality particularly on the colouration and post-harvest quality. Use of cooling irrigation improves the development of coluour an apple fruit but its schedule can influence on the incomes. Aroma volatiles are responsible for odour and contribute to overall flavour of the fruit and its processed products. Deficit irrigation had only affects some volatile aroma but no the all of concentrations in apple fruit. In the future the high apple quality for consumers could be provided with improvement of transpiration-yield model based on the water requirement of varieties and economic irrigation schedules.

Key words: water, apple, fruit quality

Introduction

Water resources of the World have been limited due to global climatic changes. The improvment of adaptability to drought and water use of cultivated plants and development of new economical irrigation technology become more important for the water management. The water and nutrient uptake, water transport, canopy size can be influenced by the changing type of rootstocks that cause significant differences in the transpiration and water use efficiency in apple cultivars (*Cohen & Naor 2002, Li* et al., 2002, *Shama & Chauhan* 2005). Young and dwarf apple trees are sensitive to drought and the high crop load also affect on their water use (*Lakatos* 2004). Considering the growing technology and economical aspects, the very dwarf type and type of rootstocks were rather used in the intensive high density orchards. Use of M 9 and MM 26 rootstocks with restricted root volumes result an decrease in nurient uptake under drought that cause an decrease in fruit size and expected crop the next season (*Gonda* 1995). The degree of drouht tolerance of apple trees is depend on the interaction between rootstocks and scion. MM 111 rootstocks is considered to have high drought tolerance (*Hrotkó 1999, Davies & Lakso* 1979).

Water demand of apple tree

Apple have generally suffered from drought. The precipitation of July and August months have the most crucial effect on the fruit crops. During this periods the water use efficiency of apple trees is affected by their water demands. This depend on the age, growing periods, climatic factors such as temperature radiation precipitation wind and disponsible water content of soil, respectively. The excessively absence or presence of these factors have regulared the water transport inside the trees. In July the water use of apple trees is the largest because by then the canopy is reached the 80–90 percent of the full shape and the fruit begin to develope very intensively. *Dragoni* et al. (2004) published that the daily water use per tree showed peak vlues around 35–40 L.day-1.tree-1 from middle of June to middle of July, then gradually declining after mid-July. Modelling water uptake by a mature apple tree, australian researchers (*Green* et al. 2003) revealed that the apple trees consumed 70 L of water per day during the middle of summer. The daily water use declined to about 20 L per day with the onset of autumn, coinciding with a reduced evaporative demand and the number of rain days.

The water use efficiency (WUE) can be characterized by the ratio of inputs and outputs. The crops weight would be the output and irrigated water the input in the case of orchard where the unit of WUE can be expressed as kg of crops/water mm. The unit of WUE can be concerning on tree, then the fruit weight of tree (kg/tree) will be the output and the precipitation together with irrigated water mean the input. The water use coefficient as show the amount of water for produce a gram of dry matter is 200–300 for fruit trees. From June to October months the 24 percent of total transpiration area (leaf area+fruit surface) of trees originated from fruits however the only 6 percent of evaporated water left out the fruit surface (*Inántsy* 1998). The results showed that the 'Golden Delicious' apple transpired 50–100 mL of water during development of one piece of fruits. Thus the total water requirement of one piece of apple would be about 170 mL that summarized of transpired water (50–100 mL) and the water content of harvested fruit that was (*Inantsy* 1998).

The large water requirements of apple trees have to be satisfied by supplementary irrigation. As Hungarian researchers advise that should be applied three or four times with 40–60 mm doses (200–240 mm) depending on the type of soil and orchard (*Gonda* 1995, *Zatykó* 1998). The soil water content of apple orchards is generally maintained close to field capacity throughout the growing season, which requires large quantities of irrigation water in dry climates. The occurrence of frequently drought periods from July to August in addition the depletion of soil water resources need to develop efficient irrigation techniques for quality apple production. Recently the research are carried out to develop irrigation schedules for water saving. The water movements in the root-zone soil are dominated by the water uptake via surface roots. *Green* et al. (2003) suggested an irrigation method based on more frequent irrigation in smaller doses that would result in less water percolating through the root-zone. Such an irrigation strategy should make more efficient use of water by minimizing the leaching losses. Partial Rootzone Drying (PRD) is a new deficit irrigation strategy that has been developed. This may not result in fruit size or yield reductions and could lead to significant water savings (*Caspari* et al. 2004). PRD irrigation method is suitable to investigate the intensity of water uptake of apple varieties and its effect on photosynthesis and transpiration under different water levels of soil (*Tartachnyk and Blanke* 2001, *Einhorn & Caspari* 2004, *Caspari* et al. 2004, *O'Conell & Goodwin* 2004, Tanasescu and Paltineau 2004). Up to date research of orchard are carried out to determine the optimum doses of irrigation for increase of crops and use of transpiration-yield crop model based on water demands of cultivar (*Green & Clothier* 1998, *Green* et al., 2003, *Naschitz & Naor* 2005).

Apple fruit quality

The quality attributes as the large fruit size good colour and extent self-life associated with firmness are required for fresh consumption. The consumers and apple industries have high requirements on quality of fruits such as flesh firmness, peel thickness, aroma and titrable acids levels. The weight of fruits, the development of red colour and the occurrence of sunburn damage could be influenced by shaping of the structure of canopy. *Racskó* et al. (2005) found differences in relationships between canopy density and fruit weigth parameters among the cultivars. The largest fruit weight (180 g) correlated with 8.0–8.2 values of canopy density (R2=0.59–0.53) however the flesh firmness slightly decreased. The large canopy density would be favourable to enhance the green colour of apple cultivar of 'Granny Smith' but disadvantageous for red-coloured cultivars as 'Elstar' 'Gala Princes' and 'Idared' (*Racskó* et al.2005). There are differences in composition of quality between outside and inside fruit of tree. The higher content of soluble solids in outside fruit was more pronounced than for titrable acidity and pH value but high summer temperature diminished this difference. Independent of canopy position, the soluble solids concentrations remained unchanged during ripening while the amounts of sucrose as well as malic acid and titrable acidity decreased with a concomitant rise in the cell sap pH (*Nilsson & Gustavsson* 2006).

The climatic and growing conditions before harvesting have an influence on eating quality of apple. The optimum or ideal conditions for red colour development of apples is found in climates with clear bright days (20–25 °C) and cool nights (below 18 °C) during the pre-harvest period (*Calmers* et al. 1973, *Williams* 1989, *Iglesias* 2001). The influence of temperature on colouring also depends on the cultivars (Saure 1990) because the highly coloured strains produce better coloured fruit under high temperature, low-light or shaded conditions (*Iglesias* et al. 2000).

The combined effects of larger fruit size and lower firmness in frequently irrigated trees may result in excessive internal growth stresses that caused higher rate of fruit splitting (*Opara* et al. 1997). However the lenticel cracks on fruit skin are due to microclimatic changes, the degree of damages is related to the genetic backgrounds of cultivars. The lenticel cracking is localized to the fruit epidermis (that is the cuticle and underlying 2 to 3 layers of cells) while the fruit splitting due to the moving of layers of cells inside the fruit flesh. When the expansion of cuticle occurs too rapidly under the fruit enlargement which may occur when the microclimate changes from cool cloudy conditions to hot dry sunny conditions the wax development may lag. In this event the underlying cells begin to produce suberin along the surface of fruit which are not suitable for consumption quality. The development of cuticle might be changed by combining factors *e.g.* certain 'Fuji' cultivars are genetically predisposed to fruit cracking and flecking, whereas some 'Golden Delicious' cultivars are susceptible to russet associated with climate (*Curry* 2003).

While the cuticle cracking occur solely on the shaded and uncovered coloured side of fruits (*Schrader & Haut* 1938, *Shutak & Schrader* 1948) in contradiction with them the splitting in mainly occur on the intensively coloured sides

(*Racskó* et al. 2005/a). The low level of transpiration is generally before development of fruit splitting. Werner (1935) published that the water supply in the texture of fruits increased under high relative humidity when the transpiration was low in consequence the flesh splitting was happened. The frequently of fruit splitting was mainly under genetic control (*Opara* 1993). Correlations were found between the structure of cuticle and the ratio of splitting fruits (Shutak and Schrader 1948) but there were differences in sensitivity to flesh splitting among the varieties (*Racskó* et al. 2005/a).

Effects of irrigation on fruit quality

Fruit, as like as leaves, demonstrate diurnal fluctuations in water potential (*Chapman* 1971, *McFadyen* et al. 1996). The largest water potential was measured in predawn and the dropping of water potential in fruit was smaller than in the leaves (*Mills* et al. 1997). The high midday temperature closed to 40 °C retarded the fruit growing (Ferguson et al. 1999). Cooling by sprinkler irrigation is one of currently available method for reducing fruit temperature (evaporative cooling) that significantly improving fruit colour and reducing sunburn. This technique has been used in locations with high temperatures and low relative humidity of USA and Spain. Irrigation applied at mid-day increased fruit colour but less consistently than when applied at sunset. In late July the anthocyanin content for each side of the fruit was significantly higher in fruit cooled at sunset than in the trees without cooling irrigation. Similar results were obtained at harvest when irrigation was applied at mid-day and at sunrise (*Iglesias* et al. 2005). A decrease in minimum fruit and orchard temperatures affects anthocyanin biosynthesis because at lower temperature-originated by cooling irrigation applied at sunset or sunrise- respiration (a process with consumes carbohydrates) occurs at a slower rate and photosynthates accumulate and there is therefore more raw material for the "pigment pool". Temperature reduction caused by cooling irrigation also increases phenylalanine ammonia-lyase activity that took part in the development of red colour consequently the synthesis of anthocyanin (*Faragher* 1983, *Tan* 1980, *Arakawa* et al. 1988, *Iglesias* et al. 1999).The cooling irrigation improve the quality of fruit particularly has direct effects on fruit colour size and firmness. The best response and income were obtained by cooling irrigation applied at sunset (*Iglesias* et al. 2005). It is known some of the attributes in respect to sale such as fruit size colour or flesh firmness peel thickness and aroma for consumptions would be changed by water supply of trees. Irrigation schedules have an influence on the size and firmness of apple particularly during fruit development. Frequently watered trees produced fruits with lower flesh firmness and lower soluble solids than non-irrigated trees (*Opara* et al. 1997). Since large fruit size and high flesh firmness are desirable quality attributes in the fresh apple industry, the combination of increase in fruit size and flesh crushing stress (firmness) in high crop density trees showed that the crop density management could affected on the harvest quality of apple. *Opara* et la. (1997) found that some of orchard management factors such as frequent irrigation which significantly increase fruit size and reduce flesh strength in 'Gala' apples are likely to increase the amount of fruit with stem-end splitting.

Use of sufficient and deficit irrigation affect the fruit size and colouration depends on the periods of fruit enlargement. *Kilili* et al. (1996) and *Mills* et al. (1997) supposed that late season withholding irrigation, between after full bloom 104 day and harvest days (198 days) can be used for improvement of fruit quality in apple production. In this case the total soluble solids, firmness intensified red skin colour of fruits were larger than in well-watered ones. The late deficit irrigation showed no change in fruit water relations and composition (titrable acidity and the concentration of sugars and minerals) or size during stress period when compared to control (*Kilili* et al. 1996). Under dry conditions, the apple trees produced fruits with high quality but their size decreased compared with the well-watered trees. Many studies (*Bonany & Camps* 1998, *Mpelasoka* et al. 2001, Caspari et al. 2004/a) also revealed the average weight of fruit was decreased due to insufficient irrigation and the flesh strength and dry mater were increased in the small sized fruits. None of deficit treatments of Partial Rootzone Drying affected the incidence of post-harvest disorders such as bitter pit and water core (*Caspari* et al. 2004/a). Others (*Einhorn & Caspari* 2004) found that deficit irrigation had no influence on the growth and size of fruits.

Titrable acidity tended to be higher in early deficit irrigated fruits than in sufficient irrigated ones during stress period and beyond. This indicated that organic acids might have contributed to fruit osmostic adjustment (*Mills* et al. 1997). Deficit irrigation had only affects some of volatile aroma but no the whole concentration of aroma (*Mpelasoka* et al. 2000).

Irrigation and post-harvest quality

When the cell division phase finishes, apple fruit growth occurs almost entirely by cellular enlargement, due to carbohydrate accumulation and water uptake (*Smith* 1950, *Lakso* et al., 1989, *Pavel & DeJong* 1995) and the cortical cell size that determines fruit size at maturity (*Smith* 1940). The number of cells within the fruit and their size are likely to affect the mechanical properties of the cortical tissue that the consumer perceived as textural quality. Trees exposed to soil water deficits in early June, even when irrigated throughout the remainder of the season, produced smaller fruit than those irrigated continuously (*Goode* 1975).

Irrigation increases fruit size that result the fruit has larger cortical cells due to greater cell expansion rather than having more cells (*Denne* 1963, *Atkinson* et al. 1998). Larger cells are also likely to be responsible for a decrease in fruit firmness. The trees that produce fruit with larger cells in response to a light crop senesce more rapidly and show greater susceptibility to storage disorders (*Martin & Lewis* 1952). The increase in fruit size was associated with a greater loss of fruit texture and quality during storage than in smaller fruit from non-irrigated trees (*Atkinson* et al. 1998).

Many studies have shown that deficit irrigation reduces final fruit size and/or yield of apples (*Lötter* et al. 1985, *Ebel* et al. 1993, *Mpelasoka* et al. 2001). The deficit irrigation may improve the fruit quality at harvest and after storage (Failla et al. 1990, *Mpelasoka* et al. 2000), however the relationship between fruit quality and lack of water has been effected by environmental factors such as area and year (*Caspari* et al. 2004).

Deficit irrigation shows up a favourable effect on aroma of apple during fruit maturity and after cold storage whilst production of volatiles in increased. Aroma volatiles are responsible for odour and contribute to overall flavour of the fruit and its processed products (*Brackmann & Streif* 1993). The major volatile compounds that contributed to higher odour units for deficit irrigation was trans-2-hexanol whose concentration was higher in fruits from deficit irrigation than in well-watered ones (*Mpelasoka* et al. 2002). Fruit maturity is one of significant factors affecting production of volatiles. *Song & Bangerth* (1994, 1996) found that the fruits harvested four weeks before "optimum harvest time" were very low in their production of volatile compounds in 'Golden Delicious' apple variety. In earlier harvested fruits contained much lower amounts of fatty acids known as early precursors of volatile aroma compounds, particularly of palmitic-, stearic-, oleic- and linoleic acids than in late harvested fruits (*Song & Bangerth* 1994). *Harb* et al. (1994) also revealed a high and positive correlation between linol- and linolenic acids and volatile production. These compounds decreased strongly after six months in ultra low oxygen-storage in about the same manner as aroma production.

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