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Tree water relations: Flow and fruit

P.F. Measham[a,*], S.J. Wilson[a], A.J. Gracie[a], S.A. Bound[b]

[a] Tasmanian Institute of Agriculture, University of Tasmania, Hobart, TAS 7001, Australia
[b] Tasmanian Institute of Agriculture, 13 St Johns Ave, New Town, TAS 7008, Australia

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ABSTRACT

This study explores vascular influx of water in sweet cherry (*Prunus avium* L.) fruit because water is a key component of fruit quality and has been implicated in cherry fruit cracking. Flow to fruit is influenced by changing water potential of the fruit, and of potential gradients between the fruit and the spur. Water potential was influenced by vapour pressure deficit. In all seasons of this study, the most negative fruit water potential occurred in mid-afternoon when the magnitude of fruit water potential (Ψ_F) was greater than leaf water potential (Ψ_L) and analysis showed that there was a significant difference in this potential gradient between days with and without rainfall. Frequency analysis of days monitored over seasons further showed a significant association between the incidence of natural or simulated rainfall and the direction of sap flow to the fruit. This implies that manipulation of the driving forces within sweet cherry trees could be a viable management strategy for the prevention of cracking in cherry fruit. Furthermore, it suggests a role for orchard irrigation, in avoiding development of water potential gradients of fruit that favour rapid vascular influx of water following rainfall.

1. Introduction

Perennial tree fruit horticulture is a high risk and high input production system in which water management, usually as irrigation, is a critical component. Many studies relate water use to yield or productivity (Kang et al., 2003, 2002; Livellara et al., 2011; Acevedo-Opazo et al., 2010) and some to fruit size (Boland et al., 2000; Morandi et al., 2007). Tree water use has been extensively studied in a number of fruit crops; apple (O'Connell and Goodwin, 2007), pear (Kang et al., 2002), peach (Cohen et al., 2001), kiwifruit (Morandi et al., 2010), grape (Acevedo-Opazo et al., 2010), apricot (Ruiz-Sanchez et al., 2007) and cherry (Li et al., 2010; Oyarzún et al., 2008). Water supply is essential for normal fruit growth (Gibert et al., 2005) and water deficits can reduce fruit quality (Green et al., 1997).

It is widely accepted that tension caused by potential gradients between the soil, through the plant, and to the ambient aerial environment is the major driving force for water movement through plants (Zimmerman et al., 2002; Tyree et al., 2003). This soil plant atmosphere continuum (SPAC) has been widely studied. For fruit production, research has focussed on improved scheduling and water use through understanding whole tree evapotranspiration (Liu et al., 2012; Livellara et al., 2011; Li et al., 2010) given the increasing need to manage water resources (Rijsberman, 2006; Intrigliolo and Castel, 2010; Collins et al., 2010). In spite of these and earlier studies, the detail of water pathways and potential gradients remains poorly understood in bearing fruit trees. Diurnal patterns of water potential recorded in fruits, including peach (McFayden et al., 1996), apricot (Alarcon et al., 2003) and grape (Greenspan et al., 1994), have been shown to affect diurnal changes in volume and diameter of growing fruit with shrinkage during daylight hours followed by expansion at night. Severe damage (cracking) occurred in bell pepper fruits that had experienced high diurnal amplitudes of expansion and shrinkage (Yao et al., 2000).

It has been suggested that cherry trees do not have a significant water storage capacity (Oyarzún et al., 2008) and studies on other species have shown that phloem-supplied water flow to fruit may supplement reduced xylem flow under high evaporative demand (Choat et al., 2009; Lang, 1990). Thus, water flow to the fruit may be influenced by multiple factors such as changing diurnal water potentials between the fruit and the leaf (Morandi et al., 2007), changing diurnal light intensity (Yamasaki, 2003) and by source–sink interactions (Zhang et al., 2006). In order to maintain fruit integrity, firmness and size, diurnal patterns of fruit influx and/or efflux should be considered in orchard practices, such as irrigation, and warrant investigation.

* Corresponding author. Tel.: +61 3 62261870.
E-mail address: Penelope.Measham@utas.edu.au (P.F. Measham).

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Cherry fruit are strong sinks (Ayala and Lang, 2008) and could therefore influence magnitude of diurnal phloem flow patterns. Fruit diameter variation in peaches has been explained by Morandi et al. (2007) as the contribution of phloem import, xylem import and export, and transpiration export of water and it was suggested by the authors that water flow in both phloem and xylem is driven by both osmotic and turgor gradients.

In sweet cherries, a rapid influx of excess water into fruit approaching harvest maturity can cause cracking of otherwise sound fruit resulting in downgraded quality or, in severe cases, an unsaleable crop (Sekse, 1995). Seasonal variability in incidence of cracking has been related to timing of rainfall (Measham et al., 2009). Mature cherry fruit have high water content and the rate of fruit volume increase in the last growth stages is high (Looney et al., 1996) through turgor driven cell enlargement (Boyer, 1985; Tyree and Ewers, 1991). Recent studies have shown that cherry cracking caused by excess supply of water to fruit after rainfall may result from both flow across the fruit cuticle from surface water and flow from the soil through the vascular system (Measham et al., 2010). The latter water uptake pathway has not been investigated fully in situ (Measham et al., 2010; Knoche and Measham, 2013).

Given that sweet cherry fruit becomes increasingly susceptible to cracking fruit maturity advances this study was designed to investigate the potential drivers and water flow patterns in sweet cherry trees. The focus was on flow patterns within the spur/leaf/fruit system and the factors that influence movement of water to (and from) fruit as it approaches harvest maturity. It was hypothesised that seasonal growth patterns of cherry fruit showed high rates with maturity as described by Looney et al. (1996), and that diurnal patterns of water potential related to climate, and could influence diurnal changes in volume and diameter of sweet cherry, as in other fruits. Additionally, the major objective of the study was to explore water movement between the tree and the fruit in line with water potential to determine the possible role of such movement in the development of water-related cherry fruit cracking. An improved understanding of how similar amounts of water applied to the soil as irrigation or rainfall, could have differing effects on fruit quality (Measham et al., 2010) due to differing potential gradients may lead to an effective means of managing fruit quality in this valuable species. Manipulating fruit and leaf gradients through water management may mitigate cherry cracking.

2. Materials and methods

2.1. Field conditions and plant material

Mature trees in fourth leaf at the commencement of trials, of variety 'Simone', grown on F12/1 rootstock in a commercial orchard in Tasmania (Australia) (Latitude 42°99′ S, Longitude 147°10′ E) were used in this study. Trees were pruned to a Spanish bush style and subjected to standard industry management practices. The trees were into hilled, east west oriented, rows on a duplex soil at a row and tree spacing of 4.0 and 2.0 m respectively. Irrigation was applied through a dripper system with an automatic refill point of −30 kPa as measured by gypsum blocks (G-bug), placed permanently in the wetted zone. Trees were well managed, produced high quality fruit and showed no sign of disease.

The growing region generally experiences long, cool summers, allowing fruit to develop over 10–12 weeks from full bloom in October to harvest through January and February. Rainfall in the weeks prior to harvest, the most susceptible stage for rain-induced fruit damage (Christensen, 1996; Measham et al., 2009), varied in each season. Total rainfall figures for the three weeks prior to harvest in 2006, 2007 and 2008 were 27 mm, 71 mm, and 5 mm respectively.

Climate data for each growing season was obtained from an Australian Bureau of Meteorology Station at Grove, less than 1 km from the trial orchard and at the same altitude, included rainfall amount (mm), minimum and maximum temperature (°C), and relative humidity. Vapour pressure deficit (VPD) was calculated for trial days from climate data (temperature and humidity) using;

$$\mathrm{VPD} = e_{\mathrm{sat}} - e_{\mathrm{air}}$$

where e_{sat} is the saturation vapour pressure and e_{air} the air vapour pressure determined as per (Murray, 1967).

2.2. Trial designs

Trials in all three years consisted of water relations monitoring of randomly selected trees and in 2006 monitoring growth rates of fruit over time. Procedures for monitoring are given below. A formal trial in 2008 was undertaken assessing the effect of simulated rainfall on leaf and fruit water potentials and fruit cracking at harvest.

Simulated afternoon rainfall was applied to selected trees on one day in a randomised complete block design, with six whole tree replicates. Treatments consisted of simulated rainfall (approximately equivalent to 30 mm) commencing at 1 pm applied with micro irrigation as per Measham et al. (2010), and an untreated control. Fruit (Ψ_{F}) and leaf (Ψ_{L}) water potentials were measured from each replicate at regular (2–3 hourly) intervals throughout the day. The fruit samples used for water potential measurements on this day were immediately placed in cool storage, frozen and then subsequently used to determine osmotic (π) and turgor (T) potentials.

2.3. Measurements

In each season fruit (Ψ_{F}) and leaf (Ψ_{L}) water potentials were measured at regular intervals over sixteen full 24 h periods (consisting of four days, with at least one day with rainfall occurring, per season). Sap flow in fruit pedicels and the adjacent leaf petioles were also monitored on selected days in all seasons, giving a total of thirty-seven full 24 h periods (covering days both with and without rainfall). In 2008 on 3 days spur potential (Ψ_{S}) was measured in addition to Ψ_{F} and Ψ_{L}, and on the same days diurnal sap flow through fruit pedicels and fruit expansion was monitored and recorded, on both attached and detached fruit in order to estimate transpiration (detached fruit had pedicels sealed and remained within the canopy). These three days were not consecutive, given the time required for attachment, but occurred within 1–3 weeks prior to harvest maturity. To assess fruit growth patterns over time fruit growth was measured weekly in 2006 for the five weeks preceding harvest. To assess transpiration demand, leaf-air temperature difference (LATD) was recorded in 2006.

Water potential measurements were made in the field using a portable pressure chamber Instrument (Model 615, PMS Instruments). On each measurement day samples were randomly selected from fruiting spurs at each time interval starting pre-dawn. Fruit and leaf potential was measured from five individual fruit and leaves respectively, immediately following excision from the tree using a sharp scalpel. Spur potential was also measured at each time, using leaves which had been covered with foil and sealed in plastic bags the previous evening (Naor et al., 2006).

Sap flow was monitored using heat-pulse sap flow meters (Bio-Instruments) positioned on fruit pedicels, and in 2006 on adjacent leaf petioles on three randomly selected spurs. Leaf-air temperature difference, (LATD) was measured by a differential copper–constantan micro-thermocouple, as per Shabala (1997) on