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Postharvest deficit irrigation in 'Conference' pear: Effects on subsequent yield and fruit quality

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ABSTRACT

The best time for applying deficit irrigation (DI) to pear is not yet known although it was the first fruit crop to be studied for regulated DI. We explored postharvest application. Over the growing seasons of 2007–2010, three irrigation treatments were applied to 'Conference' pear in an experimental orchard. They were full irrigation (control, C), withholding irrigation after harvest (DI-PH_{a+b}), and full irrigation for two weeks after harvest followed by withholding irrigation (DI-PH_b). According to our previous experience with 'Conference', the DI treatments were to be irrigated if midday stem water potential (Ψ_{stem}) became lower than −1.5 MPa. But it never did. The average annual irrigation water applied to C was 590 mm. This was reduced by 15% for DI-PH_b and by 27% for DI-PH_{a+b}. Fruit yield in DI-PH_{a+b} was similar to C for each of the three years following DI. But a carry-over effect was observed after the dry season of 2008. In 2009 fruit set and crop load were therefore reduced for DI-PH_{a+b} but fruit size was increased. For all years DI-PH_b was similar to C in terms of fruit set, crop load, fruit size, and yield. Fruit soluble solids concentration (SSC), titratable acidity, and flesh firmness were measured in 2009 and 2010. They were the same in C and DI fruit except for 2009 when SSC was higher in DI-PH_{a+b} fruit. 'Conference' adapted to DI in such a way that Ψ_{stem} could be maintained by higher water depletion at a greater soil depth as the experiment progressed. Postharvest DI is recommended for 'Conference' but to the extent that midday Ψ_{stem} does not become lower than −1.2 MPa.

1. Introduction

The current pressure on agriculture to become more efficient in water use has necessitated application of deficit irrigation (DI) in deciduous orchards (Behboudian and Mills, 1997; Naor, 2006; Fereres and Soriano, 2007). Protocols for using DI in pear orchards date back 25 years and were originally based on reducing irrigation during stage I of fruit development (Chalmers et al., 1986). However, the applications of DI during stage I can decrease fruit growth and reduce fruit size at harvest (Marsal et al., 2000, 2002).

Naor et al. (2006) found that reducing irrigation after harvest could be a feasible strategy for 'Spadona' pear. But their results also indicated that responses are determined by the level of water stress present at any given time. Moderate water stress during postharvest increased yield in the following season. However, when water stress was more severe (midday stem water potential (Ψ_{stem}) values below −2.2 MPa) the yield was decreased. Reduction in fruit set arising from postharvest water stress has been related to reductions in stored assimilates in trees for cherry (Marsal et al., 2010), peach (Lopez et al., 2007), and almond (Esparza et al., 2001).

Another factor to consider is that the sensitivity of flower bud formation to water stress varies throughout the postharvest period (Naor et al., 2005). This has been described in peach but not in pear. In peach, early September in northern hemisphere represents the transition time between high postharvest sensitivity and subsequent low sensitivity (Naor et al., 2005). Postharvest water stress has decreased fruit set and increased fruit malformations in the following season for nectarine (Naor et al., 2005) and for peach (Johnson and Phene, 2008).

We were therefore interested in learning whether applying moderate water stress before September or a few weeks later (beyond the sensitive period of peach flower bud formation) could make any difference to pear production in the following season. 'Conference' pear was chosen because it is normally harvested at the beginning of September, two weeks before the sensitive period for peach flower formation. 'Conference' is also very popular in Spain and is different, in terms of its delayed maturity time and lower tree vigour, compared from the 'Spadona' cultivar used by Naor et al. (2006).

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2. Materials and methods

2.1. Experimental orchard

The research was carried out on 'Conference' pear (*Pyrus communis* L.) at the IRTA-Estaciò Experimental de Lleida (41°37′ N; 0°52′ E; 260 m a.s.l), Spain. The orchard was planted in 1999, with a spacing of 4 m between rows and 1.6 m within rows, and with a north–south row orientation. The trees were grafted onto dwarfing quince rootstock (M-A) and trained to a central leader system. One row of pollen-compatible 'Williams' was planted alongside every four rows of 'Conference'. The orchard was managed according to local commercial practices for fertilization, pest management, weed control, and winter pruning. Fruit thinning was not applied. 'Conference' typically bloomed by the end of March; fruit were picked in a single harvest by mid August; and leaf fall began by the end of October. The soil was more than 4 m deep and had a water holding capacity that ranged from 130 mm to 160 mm of water per 1200 mm depth (Marsal and Stöckle, 2011). Soil texture varied from loam, in the top soil layers, to sandy loam, near the bottom of the soil profile.

2.2. Irrigation management

Drip irrigation was applied with two drippers per tree (4 l h^{-1} for each dripper). There was a single pipeline per tree row which passed close to the tree trunks. The orchard was irrigated on a daily basis to fully replace crop evapotranspiration (ET_c) minus effective rainfall. ET_c was calculated by multiplying reference evapotranspiration (ET_o) by the crop coefficient (K_c) (Allen et al., 1998). The Penman–Monteith method was used to determine ET_o. K_c was estimated from a weighing lysimeter (Girona et al., 2011) planted in 'Conference' and located in the middle of the experimental plot. The lysimeter trees were planted at the same time and were trained to the same system as the experimental trees. Weather data were obtained from the Catalan Agrometeorological Network located 12 km from the experimental site. Average annual rainfall during 2007–2010 was 384 mm and the corresponding average value for ET_o was 1023 mm. During the irrigation season (mid-March to mid-October) average rainfall, over 2007–2010, was 120 mm.

2.3. Treatments

The experiment spanned over 2007–2010 but the irrigation treatments were applied over 2007–2009. They were: (1) full irrigated to replace the ET_c minus effective rainfall (control, C), (2) full irrigation until harvest (mid August) and then no irrigation from harvest until leaf fall as long as the midday stem water potential (Ψ_{stem}) was higher than −1.5 MPa (DI-PH_{a+b}), and (3) full irrigation until two weeks after harvest and no more irrigation from then until leaf fall provided that Ψ_{stem} was higher than −1.5 MPa (DI-PH_b). Our intention was that if Ψ_{stem} became lower than −1.5 MPa, the DI trees would be irrigated at 20% of C. Based on our previous experience with 'Conference', at a Ψ_{stem} of lower than −1.5 MPa there would be significant reductions in stomatal conductance, photosynthetic rate, and fruit growth (Marsal et al., 2008).

2.4. Experimental design

A randomized complete block design was used with four block replicates. Each block housed three experimental plots, each having three rows of six trees. Measurements were only taken from the four central trees in the middle row of each plot. All the other trees in the plot were guard trees.

2.5. Plant and soil measurements

The volume of water applied was measured weekly using digital water meters (CZ2000-3M, Contazara, Zaragoza, Spain) located in each plot. Ψ_{stem} was measured (Shackel et al., 1997) at solar noon from two shaded-leaf samples located near the base of the trunk. The leaves were wrapped in plastic bags covered with aluminium foil one hour before Ψ_{stem} was measured using a pressure chamber (Model 3005, Soil Moisture Equipment Corp., Santa Barbara, CA, USA). Two trees were monitored per plot on a weekly basis. Leaf conductance (g_l) was determined with a steady-state porometer (Model Li-Cor 1600, Li-Cor Inc. Lincoln, Nebraska, USA). Measurements were taken at noon from three sunlit leaves on two trees per plot.

Soil water depletion patterns were estimated from soil water content measurements. No measurement was done in 2007. Gravimetric method was used in 2008. In 2009 soil water content was measured with 80 capacitance probes (Model 10HS, Decagon Devices Inc., Pullman, Washington, USA). The soil samples used for the gravimetric measurements were taken using an auger with a removable sleeve and were weighed immediately. The sample sites were located in each elemental plot and between two consecutive drippers located between the central experimental trees and at an orthogonal distance of 0.1 m from the pipeline. Samples were taken at depths of 0.2, 0.4, 0.6 and 0.8 m into the soil profile. They were taken at harvest and at the end of the postharvest irrigation period (mid October). The dry mass of each sample was measured after drying the soil to constant mass in a forced convection oven at 105 °C. The percentage of soil water content was converted from a gravimetric to a volumetric measure considering the soil's bulk density of 1.5 g cm^{-3}. Soil water depletion was calculated as the percent difference between the readings for the two dates at each depth. Readings of capacitance probes were taken on an hourly basis by twelve data loggers (Model EM50R, Decagon Devices Inc., Pullman, Washington, USA). Five probes were accommodated per data logger and were inserted in each elemental plot at depths of 0.2, 0.4, 0.6, 0.8 and 1.2 m in the soil profile. A small trench was dug to place the sensors horizontally and was positioned according to the same sampling criteria applied at the soil sampling sites.

2.6. Soil water balance calculations

As soil water content was only measured in the zone wetted by the drippers, a more general postharvest soil water balance (WB) was estimated for each treatment and the year according to the following equation:

$$WB = \text{Irrigation} + \text{Effective rainfall} - ET_c \qquad (1)$$

Effective rainfall was estimated as half of actual rainfall when this was greater than 10 mm. To calculate postharvest ET_c, we used K_c derived from the pear lysimeter located within the experimental plot (Girona et al., 2011). Postharvest average values of K_c; for the control treatment; were 0.62, 0.60, and 0.52 for, respectively, 2007, 2008, and 2009. Deep percolation was assumed to be zero for the DI treatments. Since the soil water content for control was always close to field capacity, deep percolation was considered to occur if WB were positive. The K_c for stress conditions ($K_{c\ stress}$), was calculated by means of a linear approximation between midday stem water potential and relative ET (Johnson et al., 2005). When plant transpiration is close to zero, minimum relative ET corresponds to 0.05, which is the rate due to soil evaporation (Girona et al., 2011). When plant transpiration is zero, leaves have closed stomata that lose turgor. It was assumed this would correspond to a Ψ_{stem} of −3.0 MPa according to the available data on pressure volume curves