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Using trunk diameter sensors for regulated deficit irrigation scheduling in early maturing peach trees

W. Conejero[a,*], C.D. Mellisho[a], M.F. Ortuño[a], A. Moriana[b], F. Moreno[c], A. Torrecillas[a,d]

[a] Dpto. Riego., Centro de Edafología y Biología Aplicada del Segura (CSIC), P.O. Box 164, E-30100 Espinardo (Murcia), Spain
[b] Dpto. Ciencias Agroforestales, EUITA, Universidad de Sevilla, Crta de Utrera Km 1, E-41013 Sevilla, Spain
[c] Dpto Protección del Sistema Suelo-Planta-Agua, Instituto de Recursos Naturales y Agrobiología (CSIC), P.O. Box 1052, E-41080 Sevilla, Spain
[d] Unidad Asociada al CSIC de Horticultura Sostenible en Zonas Áridas (UPCT-CEBAS), Paseo Alfonso XIII s/n, E-30203 Cartagena (Murcia), Spain

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ABSTRACT

The aim of this paper was to test the possibility of scheduling regulated deficit irrigation (RDI) using exclusively maximum daily trunk shrinkage (MDS) measurements, and that RDI strategies can be applied in early maturing peach trees reducing significantly the seasonal water use. During three growing seasons, 6-year-old peach trees (*Prunus persica* (L.) Batsch cv. Flordastar) grafted on *P. persica* × *P. amygdalus* GF-677 peach rootstock were submitted to different drip irrigation treatments. Control (T0) plants were irrigated above the estimated crop evapotranspiration level (≈130% ET_C) and T1 plants were submitted to RDI, which were irrigated in order to maintain MDS signal intensity (SI) values close to unity (no irrigation-related stress) from the fruit thinning stage to 2 weeks after harvest, at MDS SI values close to 1.3 during the early postharvest period, and at MDS SI values of 1.6 during the late postharvest period. The RDI strategy assayed reduced the seasonal water applied by 35–42% with respect to estimated ET_C without affecting yield efficiency components or the distribution of different peach fruit categories, while improving water productivity. The only vegetative growth component affected by RDI was pruning weight, indicating that vigor regulation as a result of RDI may decrease the competition for assimilates between vegetative apexes and reserve tissues. Also, the absence of any significant effect of RDI on the ratio between yield and the increase in trunk cross sectional area suggested similar carbon partitioning schemes during fruit growth. To improve the precision of MDS SI-driven schedule in RDI strategies changes in the irrigation protocol should be considered so that the scheduled water deficit levels are attained more rapidly. For this, when it is necessary to change from a MDS SI threshold value to a higher one, the daily irrigation rate should be decreased by more than 3%.

1. Introduction

Mediterranean agrosystems are characterised by the aridity of the climate and the persistent shortage of water resources. This situation is aggravated by the strong competition for the water that is available with other non-agricultural users that has arisen in recent years. Consequently, to cope with this water scarcity new and precise tools for accessing crop water requirements are needed, and biological and physical criteria need to be established to develop more adequate and precise deficit irrigation management practices (Goldhamer and Fereres, 2001; Pereira et al., 2002; Naor, 2006; Katerji et al., 2008).

Regulated deficit irrigation (RDI) is an irrigation strategy designed to save water with a minimum impact on yield and fruit quality (Chalmers, 1989; Goldhamer, 1989; Naor, 2006). RDI strategies require precise knowledge of the crop response to drought stress during different phenological phases, in order to identify phenological periods in which adverse effects on productivity are minimized (non-critical periods). In stone fruits trees two critical periods have been defined (Torrecillas et al., 2000). The first one corresponds to the second rapid fruit growth period (stage III), when drought stress induces a reduction in yield due to the smaller fruit size at harvest. The second critical period is the early postharvest period, in which drought stress affects flower bud induction and/or the floral differentiation processes that occur at this time. This leads to a lower germination potential in the pollen in the next bloom and encourages young fruit to drop in the following season (Uriu, 1964; Ruiz-Sánchez et al., 1999).

It is important to bear in mind that in peach trees RDI can reduce yield if the recovery of tree water status is delayed after deficit irrigation, particularly when the drought stress

* Corresponding author. Tel.: +34 968 396227; fax: +34 968 396213.
E-mail address: wenceslao@cebas.csic.es (W. Conejero).

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extends into the stage III of fruit development (Girona et al., 1993; Goldhamer et al., 2002). For this reason, in early maturing peach trees, with their very short period from fruit set to harvest and a very long post-harvest phenological period, deficit irrigation should be applied only during the post-harvest period in order to avoid any effect on yield and fruit quality.

In recent years, the use of plant-based water status indicators has become very popular for planning more precise irrigation programmes, because it is recognized that the tree itself is the best indicator of its water status (Shackel et al., 1997; Fernández and Cuevas, 2010). Since the plant water status controls many physiological processes and crop productivity, this information can be highly useful in irrigation scheduling (Ortuño et al., 2010). Particularly under deficit irrigation conditions, the continuous control of tree water status is crucial in order to prevent a moderate, potentially beneficial, drought stress from becoming too severe and ending in a reduction of yield (Domingo et al., 1996; Johnson et al., 1992). In this sense, sensors like LVDTs are able to measure daily trunk diameter fluctuations (TDF) with great precision, generating sensitive parameters which strongly correlate with established plant water status parameters (Ortuño et al., 2010). The most common TDF parameter for the irrigation scheduling of stone fruit trees is the maximum daily trunk shrinkage (MDS) (Huguet et al., 1990; Ortuño et al., 2010). Moreover, the operational advantages of TDF measurements, such as the possibility of connecting remotely operated irrigation automatic devices, and the ability to rapidly adjust schedules in response to the daily signal, make MDS a very suitable tool for precise irrigation scheduling (Goldhamer and Fereres, 2001).

The magnitude of MDS even in a fully irrigated tree is not constant over a period of days with the same water status but different environmental conditions (Zweifel and Häsler, 2001). On the other hand, from earlier studies, it is known that MDS values increased in response to drought stress (e.g. Moriana et al., 2000; Deslauriers et al., 2003; Ortuño et al., 2006; Intrigliolo and Castel, 2007; Klepper et al., 1971), though severe conditions of drought stress decrease MDS values (Moriana et al., 2000; Ortuño et al., 2006; Intrigliolo and Castel, 2007). Because of this, absolute MDS values registered without considering the evaporative demand might be meaningless, and for irrigation scheduling it is better to use the concept of signal intensity (SI), normalizing the absolute MDS values with respect to those in non-limiting soil water conditions (actual MDS/reference MDS) (Goldhamer and Fereres, 2001; Naor and Cohen, 2003; Ortuño et al., 2005, 2006, 2010). These MDS values in non-limiting conditions may be obtained from over-irrigated trees (so called reference trees), or reference equations that can estimate these values from meteorological data, so called baselines (Goldhamer and Fereres, 2001). Therefore, MDS SI is a dimensionless variable, where values above unity indicate drought stress levels, while SI values of unity indicate the absence of irrigation-related stress (Goldhamer and Fereres, 2004; Ortuño et al., 2010). In addition, SI values clearly below unity could be used to predict the presence of trees suffering very severe drought stress, or a flooding stress in reference trees because this stress also induces an increase in MDS values (Vanniere, 1992; Ortuño et al., 2007).

The research reported in this paper was conducted to test the hypotheses that (i) RDI scheduling can be based exclusively on MDS measurements, and (ii) that by maintaining MDS SI values close to unity during fruit growth (absence of irrigation-related stress), a moderate water deficit during early postharvest period and a more severe drought stress during late postharvest period, it is possible to save water without affecting yield and fruit components.

2. Materials and methods

2.1. Experimental conditions, plant material and treatments

The experiment was performed in a plot of the CEBAS-CSIC experimental station in Murcia (Spain) (38°06′N, 1°02′W) during three growing seasons (2007, 2008 and 2009). The soil, classified as a Lithic xeric haploxeroll (Soil Survey Staff, 2006), is stony (33%, w/w) and shallow, with a clay-loam texture. Analytical data showed a high lime content (56% calcium carbonate), very low organic matter content (0.34%), low cationic exchange capacity (12.6 meq 100 g^{-1}), and low available potassium and phosphorus levels. Available soil water and bulk density were 200 mm m^{-1} and 1.58 g cm^{-3}, respectively. The volumetric soil water content at saturation, field capacity and permanent wilting point were 0.49, 0.35 and 0.15 m^3 m^{-3}, respectively. The irrigation water had a mean EC of 1.1 dS m^{-1} and an average Cl^- concentration of 26 mg l^{-1}.

The plant material consisted of 6 year old (in 2007) early maturing (mid-May) peach trees (*Prunus persica* (L.) Batsch cv. Flordastar) grafted on *P. persica* × *P. amygdalus* GF-677 peach rootstock and trained to an open-centre canopy. Tree spacing followed a 5 m × 5 m square pattern. Hand-thinning was used to space fruitlets along the fruit bearing stems to 25 cm for the commercial crop load. Pest control was that commonly used by the growers, and no weeds were allowed to develop within the orchard. Fertilization practices followed the principle of re-establishing nutrients taken up by the plants, and then all treatments received the same amount of nutrients. In order to avoid the use of more concentrated solutions in T1 during the deficit irrigation periods, fertilizers were applied in both treatments only during the timing of water application corresponding to T1 treatment.

Crop irrigation requirements (ET_C) were estimated according to daily crop reference evapotranspiration (ETo), calculated using the Penman–Monteith equation (Allen et al., 1998), and a crop factor based on the time of the year (FAO 56, Allen et al., 1998) and the percentage of ground area shaded by the tree canopy (Fereres and Goldhamer, 1990). Control plants (treatment T0) were irrigated daily above the estimated crop evapotranspiration level (≈130% ET_C) in order to obtain non-limiting soil water conditions. Before fruit thinning (day of the year (DOY) 67, 71 and 79 in 2007, 2008 and 2009, respectively), the regulated deficit irrigation (RDI) treatment (T1) was irrigated at 100% ET_C values. The RDI plants were then irrigated to maintain MDS SI at three different plant water status levels. From fruit thinning to 2 weeks after harvest (DOY 141, 137 and 144 in 2007, 2008 and 2009, respectively), RDI plants were irrigated to maintain MDS SI at values close to unity (no irrigation-related stress). During the early postharvest period (from 2 weeks after harvest (DOY 142, 138 and 145 in 2007, 2008 and 2009, respectively), to DOY 195, 190 and 190 in 2007, 2008 and 2009, respectively), RDI plants were irrigated to maintain MDS SI values close to 1.3. Finally, during the late postharvest period (from DOY 196, 191 and 191 in 2007, 2008 and 2009, respectively, to when the leaves fall (DOY 233, 265 and 256 in 2007, 2008 and 2009, respectively)), RDI plants were irrigated to maintain MDS SI values close to 1.6.

In T1, the irrigation rate was decreased by 3% when the MDS SI did not exceed the threshold value on the previous day, and increased by 3% when the MDS signal intensity exceeded the threshold value. This irrigation protocol was based on that proposed by Goldhamer and Fereres (2001) for mature trees under high frequency irrigation. The MDS signal intensity threshold values of 1.3 and 1.6, and the application period, were adopted because, according to previous experience (Conejero, 2008; Abrisqueta et al., 2008), they would induce different drought stress levels. For both the T0 and T1 treatments, irrigation was carried out during the night using a drip irrigation system with one lateral pipe per tree row and eight emitters (each delivering 2 l h^{-1}) per plant. An informatiza-