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Implementing deficit irrigation scheduling through plant water stress indicators in early nectarine trees

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ABSTRACT

A three-year experiment on early nectarine (*Prunus persica* L. Batsch cv. Flanoba) trees was carried out with the aim of increasing water use efficiency through applying a sustained irrigation treatment, in a commercial orchard in southern Spain. Experiments compared irrigation scheduling using conventional micrometeorology (110% of crop evapotranspiration, ETc) as a control treatment (T_{CTL}), a treatment based on the normal practice of the farmer (T_{FARMER}) and a regulated deficit irrigation treatment (T_{RDI}), which involved irrigating the crop at the same level as the control (T_{CTL}) during the critical periods of the first year (second rapid fruit growth period and 2 months after harvest) and at 60% T_{CTL} during postharvest. In the last two years (2010 and 2011), the irrigation was scheduled to maintain the signal intensity (SI) of the maximum daily shrinkage of the trunk (MDS, SI = MDS_{TRDI}/MDS_{TCTL}) at different water stress levels depending on the phenological stage SI = 1.0 (non-water stress) and SI = 1.4 (moderate water stress). Most of the time that irrigation scheduling was based on MDS SI, this parameter varied only slightly around the pre-established threshold values. The information given by the stem diameter sensors and stem water potential (Ψ_{stem}) gave −1.5 MPa and MDS SI 1.5 as threshold values not to be exceeded during postharvest, since MDS and Ψ_{stem} SI values were only linear down to 1.5. The water saved amounted to 17, 15 and 37% of the amount used in the control in the three seasons, respectively. In contrast, the T_{FARMER} treatment applied more water (about 20 and 5% more than T_{CTL}) during the first 2 years, and 10% less than T_{CTL} during the third season.

1. Introduction

Irrigation scheduling has been defined by many authors, in essence, as how much water should be applied to crops and when to apply it, that is to say, planning water application in irrigated agriculture. However, irrigation planning becomes difficult when external circumstances intervene: water prices, water availability, water quality, etc. Such circumstances, together with tree characteristics and the desired fruit quality at harvest, among others, modify both the amount of water to be applied and the moment to apply it (Conesa et al., 2014; Pérez-Pastor et al., 2007). Besides, orchards located in areas of water scarcity face other threats, including competition from emerging producers, which enjoy lower cultivation costs, further jeopardizing viability. There is growing awareness of the need for sustainable irrigation planning for commercial orchards, and sustainability goes hand in hand with a reduction in the irrigation water used. This, in turn, implies a lesser need for energy, nutrients and labour, thus reducing costs, which helps companies become more competitive, stabilize their production and survive in hostile circumstances. That is to say, a continuous reduction in water inputs throughout the growing season can only be beneficial, as long as fruit quality and yield can be maintained (Fereres and Soriano, 2007).

To perform this type of irrigation it is necessary to understand crop phenology and the duration of non-critical periods, in order

Abbreviations: EC, electrical conductivity; ET_c, crop evapotranspiration; ET_0, reference crop evapotranspiration; FDR, frequency domain reflectometer; G, global solar radiation; LVDT, lineal variable diameter transducers; MDS, maximum daily trunk shrinkage; MNTD, minimum daily trunk diameter; MXTD, maximum daily trunk diameter; P, precipitation; RH, relative humidity; SI, signal intensity; S_{MDS}, water stress integral of MDS; S_{TGR}, water stress integral of TGR; $S_{\Psi stem}$, water stress integral of Ψ_{stem}; T, air temperature; TGR, trunk daily growth rate; T_{CTL}, well-watered trees; T_{RDI}, regulated deficit irrigation; T_{FARMER}, treatment based on the normal practice of the farmer; VPD, vapour pressure deficit; W, wind speed; θ_v, volumetric humidity; Ψ_{stem}, midday stem water potential.

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to reduce the water applied at such moments without producing water stress levels that may damage subsequent yields (Chalmers et al., 1981; Pérez-Pastor et al., 2009a, 2014; Ruiz-Sanchez et al., 2010). For this reason, it is vital to determine the tree water status throughout the year in order to rapidly detect any water stress. To this end, the continuous measurements made by lineal variable diameter transducers (LVDT) of trunk diameter fluctuations, measurements that are easily recordable in a datalogger, and the stem water potential (Ψ_{stem}), which is considered a very sensitive parameter to water stress (McCutchan and Shackel, 1992), could provide knowledge of the beginning and end of these non-critical periods and the plant water stress levels reached in the implementation of regulated deficit irrigation strategies (Pérez-Pastor et al., 2009a, 2014).

Many studies have examined the possibility of scheduling irrigation based on plant water status indicators, and all of them have noted the difficulties involved. Indeed, some authors have used the ratios between traditionally used indicators to detect water stress in certain crops (Fernández et al., 2011; Moriana et al., 2010). For example, Jones (2004) listed and described the advantages and disadvantages of several indicators of soil and plant water status to make irrigation more sustainable, indicating that plant-based methods do not provide information concerning the amount of water to apply to crops. Studies using this type of irrigation scheduling are based on modifying the previously programmed volume of irrigation water according to the MDS signal intensity, increasing (e.g. 10%) the volume if the SI value is above the desired (pre-established) value or decreasing the volume if the SI is below the threshold. That is, if the SI value is to be raised to reach the threshold, the amount of water must be decreased the following week (Conejero et al., 2011b; García-Orellana et al., 2007; Ortuño et al., 2009; Pérez-Pastor et al., 2009b; Puerto et al., 2013; Velez et al., 2007).

This three-year long experiment aimed to examine the feasibility of scheduling deficit irrigation based on maximum daily trunk shrinkage (MDS) in early nectarine trees, as a way to increase water productivity and maintain the fruit quality standards necessary to increase profitability.

2. Material and methods

2.1. Experimental site

The study was performed over three consecutive years (2009, 2010 and 2011) in a commercial orchard located in Murcia (38°8′ N; 1°13′ W). The experimental plot (2 ha) consisted of 7-year-old early nectarine trees (*Prunus persicae* L. *Batsch* cv Flanoba) grafted onto hybrid GF677 rootstock at a spacing of 5.5 m × 3.5 m. At the beginning of the experiment the trunk diameter of the trees averaged 14.2 cm, with no differences between treatments. The soil, with a bulk density of 1.44 g cm^{-3} was well-drained and had a clay loam texture, an average depth of 1.55 m, a low available potassium (236 ppm) and phosphorus (6.6 ppm) content, low organic matter (0.8%), and high levels of chloride and sodium (4.37 and 8.87, respectively in the water extract, 1:2). Electrical conductivity was 0.99 dS m^{-1} (water extract 1:2, 25 °C).

The electrical conductivity (EC) of the irrigation water varied between 1.5 and 2.5 dS m^{-1}, according to the source used (irrigation canal, well or a mix of both). Normal cultivation practices (e.g. weed control, fertilization, pruning, fruit thinning and banding) were carried out by the technical department of the commercial orchard. A drip irrigation system was installed, with two lines per tree row and 9.33 pressure-compensated emitters (1.6 l h^{-1}) per tree placed every 75 cm.

2.2. Irrigation treatments and measurements

During the three years of the experiment, three irrigation treatments were applied: (i) Control, T_{CTL}, irrigated at 110% of ETc (maximum crop evapotranspiration) during the whole season in order to avoid limiting soil water conditions, determined from the crop reference evapotranspiration (ET_0 Penman-Monteith, Allen et al., 1998); (ii) Regulated deficit irrigation, T_{RDI}, irrigated for the first year (2009) at 110% ETc during the critical periods (second rapid fruit growth period and two months after harvest) and at 60% T_{CTL} during late postharvest (from July until the end of the growing season). The irrigation scheduling protocol of this treatment varied each year according to the information obtained from the MDS and Ψ_{stem} measurements in the previous year (Table 1), therefore, during the two last years (2010 and 2011) the irrigation was scheduled to maintain the signal intensity (SI) of the maximum daily shrinkage of the trunk (MDS, $SI = MDS_{TRDI}/MDS_{TCTL}$) depending on the phenological stage at different water stress levels: SI = 1.0 (non-water stress) during the fruit growth and early postharvest (May) and SI = 1.4 (moderate water stress) during late postharvest period (from July until the end of the growing season in 2010, and from the end of May until the end of the season in 2011); and (iii) Irrigated according to the criteria followed by the farmer, T_{FARMER}. The SI threshold values proposed are derived from the MDS values obtained for T_{RDI} in 2009.

At the beginning, T_{RDI} was irrigated with the same schedule as T_{CTL}, that is, according to the ETc determined by FAO methodology. Later, the irrigation volumes were adjusted to maintain SI close to the pre-established threshold values. Maintaining the signal intensity involved increasing the irrigation dose every week by 10% if the SI weekly average was higher than the threshold value or decreasing the same when the SI was below the threshold. Based on the results obtained in 2010, the protocol was changed in 2011 in order to avoid severe water stress in the plants, reducing the water amount in T_{RDI} according to the MDS signal, although never below 30% ETc.

ETc was determined as the product of reference crop evapotranspiration (ET_0), the crop coefficients proposed by the Agricultural Information System of Murcia (www.siam.es) for this area, adjusted for the tree size (Fereres and Goldhamer, 1990), and an additional leaching fraction applied due to the irrigation water salinity.

Irrigation was scheduled weekly with a frequency that varied from 1 to 2 times per day in spring-summer to 1–7 times per week for the rest of the year. The start time of any irrigation was the same for all the treatments, and was during the night.

Hourly meteorological data were measured from an automatic weather station located at the orchard. The variables measured were temperature (T), relative humidity (RH), global solar radiation (G), wind speed 2 m above the soil surface (W), and precipitation (P). Daily ET_0 was calculated according to the FAO-56 Penman–Monteith equation (Allen et al., 1998) and air vapour pressure deficit (VPD) from the T and RH.

The soil volumetric water content (θ_v) was measured from 0 to 1 m depth every 0.1 m with an in situ calibrated frequency domain reflectometer (FDR) (Diviner 2000, Sentek Pty. Ltd., South Australia). Three access tubes per treatment were installed within the emitter-wetting area under the canopy and along the tree drip line for three randomly selected trees. Measurements were taken between 10.00 and 12.00 h (solar time) every 7–10 days during the last two years of the experiment.

Trunk diameter fluctuation was monitored in 6 trees per treatment, using a set of linear variable displacement transducers (LVDT; Solartron Metrology, Bognor Regis, UK, model DF ± 2.5 mm, precision ± 10 μm) installed on the northern side of trunks, 30 cm above the ground and mounted on holders built of aluminium and invar (an alloy of 64% Fe and 35% Ni that has minimal