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Combined effects of deficit irrigation and crop level on early nectarine trees

JM. De la Rosa[a], MR. Conesa[a], R. Domingo[a], E. Aguayo[b], N. Falagán[b], A. Pérez-Pastor[a,*]

[a] Technical University of Cartagena (UPCT), Department of Plant Production, Paseo Alfonso XIII, 48, ETSIA, 30203 Cartagena, Murcia, Spain
[b] UPCT, Department of Food Engineering, Paseo Alfonso XIII, 48, 30203 Cartagena, Murcia, Spain

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ABSTRACT

A three-year long experiment was implemented in an early nectarine (*Prunus persica* L. Batsch cv. Flanoba) commercial orchard to evaluate the effects of deficit irrigation and different crop levels on vegetative growth, plant water status, and fruit yield and quality. Three irrigation treatments were assessed: (i) control, full irrigation (T_{CTL}); (ii) normal practice of the farmer (T_{FRM}); and (iii) regulated deficit irrigation (T_{RDI}), which involved irrigating the crop at the same level as the control (T_{CTL}) during the critical periods of the first year and at 60% T_{CTL} during postharvest. In the last two growing seasons the irrigation was scheduled to maintain the signal intensity (SI) of maximum daily trunk shrinkage ($SI_{MDS} = MDS_{TRDI}/MDS_{TCTL}$) at different water stress levels depending on the phenological stage: SI = 1.0 (non-water stress) and SI = 1.4 (moderate water stress). Besides, during the last two seasons, the interactions between T_{CTL} and T_{RDI} were studied at five different crop levels, which were obtained by controlling the distance between fruits left on the branches: from very low (16 cm between fruits) to very high (8 cm between fruits). Crop water use efficiency (WUE) of T_{RDI} was higher than in T_{CTL} and T_{FRM}, increasing by around 25% in 2010 and 2011, and around 74% the final year. Interestingly, T_{FRM} increased the WUE from the first year by more than 30%. The yield/annual increase in trunk-cross-sectional area (ΔTCSA) ratio increased in T_{RDI} with respect to the other treatments as the experiment progressed, reaching differences of 53%. Vegetative growth was clearly sensitive to deficit irrigation with a strong correlation between the increase in the water stress integral obtained by midday stem water potential (Ψ_{stem}) and the reduction in TSCA. In contrast, fruit production and quality were not affected by water deficit. As regards the interaction between crop level and water deficit, fruit firmness was the only fruit quality parameter studied that presented significant differences, the highest values corresponding to the fruits from T_{RDI} trees and the lowest crop level. In early nectarine trees, the postharvest period can be considered as a non-critical period for applying RDI strategies but only when the water stress integral applied is of low intensity in May and June (much lower than 9 MPa day), in order to limit the decrease in vegetative growth and so not affect the following harvests.

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1. Introduction

Peach and nectarine trees (*Prunus persicae* L. Batsch) are two of the main deciduous fruit species grown in Spain with an average production of 1,175,500 t per year in the period 2010–2012 (FAOTSAT, 2015). Extra-early varieties are mainly characterized by their high export value, being among the first to be marketed due to their attractive colour and taste (Alcobendas et al., 2012). In areas of water scarcity, it is necessary to use irrigation techniques efficiently, not only to save water, but also to increase productivity and obtain good-quality fruits (Fereres and Soriano, 2007).

Generally, growers schedule irrigation according to experience, although they are also conditioned by the volume of water available (low in many areas suffering from water scarcity), the irrigation system installed and the different agricultural techniques of their farms. Thus, while farmers often achieve high efficiencies in water use, they sometimes apply too much water, usually during fruit growth to obtain fruit of maximum size, but also during the postharvest period in early maturing fruit trees. They would therefore benefit from protocols to achieve greater efficiency by optimizing the applied water using soil and plant water status indicators to control irrigation water leaching.

* Corresponding author at: Dpto. Producción Vegetal, ETSIA—Universidad Politécnica de Cartagena, Avda. Paseo Alfonso XIII, 48, E-30203 Cartagena, Murcia, Spain. Fax: +34 968 325793.
E-mail address: alex.perez-pastor@upct.es (A. Pérez-Pastor).

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Deficit irrigation (DI) has traditionally been defined as an irrigation strategy in which the amount of water applied is lower than that needed to fully satisfy the crop water requirements. DI aims to increase water use efficiency (WUE) by eliminating irrigation events that have little impact on yield. However, this application can also have other benefits related with (i) decreasing nitrate leaching, (ii) reducing the energy used during irrigations (since most irrigation equipment is pressurized), and (iii) maximizing the competitiveness of the agricultural sector. Moreover, early studies reported improved fruit quality due to a higher maturity index as result of an increase in the phenolic composition of fruit, especially in the case of extra early varieties with a short ripening time (Buendía et al., 2008; Falagán et al., 2015). In late varieties of nectarine under RDI Thakur and Singh (2013) found a higher concentration of sugars, higher levels of total phenols, and higher antioxidant, ascorbic acid and anthocyanin levels. Differences from the levels obtained in a control treatment increased with the severity of RDI.

One of the most important DI strategies developed in fruit trees is regulated deficit irrigation (RDI, Chalmers et al., 1981), whereby water restrictions are applied in non-critical periods, when fruit growth is less sensitive to soil water deficit, while covering the full water requirements during the rest of the growing season (Buesa et al., 2013; Mitchell et al., 1989). In this sense, Stage II of fruit growth (slow fruit growth rate) and the postharvest period are suitable times for reducing irrigation in extra-early nectarine trees (De la Rosa et al., 2015). Postharvest is the longest non-critical period of the growing season, and is important because it is when carbohydrate reserves accumulate and floral differentiation processes occur (Handley and Johnson, 2000). Therefore, RDI must be managed carefully in order to avoid reductions in bloom and fruit load (Pérez-Pastor et al., 2015). RDI has successfully been studied in a wide range of fruit crops (see reviews of Ruiz-Sánchez et al., 2010 and Pérez-Pastor et al., 2015). In stone fruits (e.g., nectarine), RDI has been used to control vegetative growth, decreasing competition between vegetative and fruit growth (Ruiz-Sánchez et al., 2010). However, a severe water deficit may result in a serious reduction of vegetative growth, reducing the number of fruits per trees (by decreasing the tree size), or even cause disorders in the following harvest (Naor, 2014). To solve this, plant water status needs to be controlled by using indicators when such strategies are applied. Recently, continuous measurements of plant water status through the use of trunk diameter fluctuations (TDF) have been used for irrigation scheduling in real time with high precision, thus reducing the possible dangers of RDI applied during the water deficit periods (Fernández and Cuevas, 2010; Ortuño et al., 2010). Maximum daily shrinkage (MDS), which covers cycles of shrinking and swelling induced by changes in transpiration (Corell et al., 2014) is considered one of the most sensitive water stress indicators (De la Rosa et al., 2014). However, the fact that MDS integrates the effects of weather conditions and the soil water availability promoted the use of MDS signal intensity (SI_{MDS}, Golhamer and Fereres, 2004) as a suitable irrigation scheduling technique (De la Rosa et al., 2015; Puerto et al., 2013).

The response of nectarine yield to water deficit must be considered together with its response to climatic conditions and fruit thinning practices (Naor et al., 2005). In fact, as crop load increases, the seasonal growth of trunk diameter and tree biomass accumulation may be reduced as a result of increased carbohydrate partitioning towards fruit (Berman and DeJong, 1997). However, Intrigliolo et al. (2014) reported that crop load reduction could be employed to alleviate the detrimental effects that long-term RDI strategies have on tree growth.

Early reports assessed the combination of water deficit and crop level in fruit trees (Alcobendas et al., 2012; Intrigliolo et al., 2014; Lopez et al., 2007; Naor et al., 2013). However, to our knowledge, this work represents the first time that the above interaction has been studied using the conceptual approach of SI_{MDS} for irrigation management, while being compared with growers' irrigation practices. For these reasons, a three-year long experiment was implemented in an early nectarine commercial orchard, to evaluate the effects of the deficit irrigation on vegetative growth and crop level using the $SI_{MDS,}$ seeking to maintain the yield and fruit quality standards necessary to increase growers' benefits.

2. Materials and methods

2.1. Experimental site

The study was performed during three consecutive growing seasons (2009–10; 2010–11 and 2011–12) in a commercial orchard located in Murcia (38° 8′ N; 1° 13′ W). Each growing season was taken to begin on the first day of post-harvest and end on the last day of harvest of the following year. The experimental plot had an area of 2 ha of seven-year-old early nectarine trees (*P. 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, without differences between treatments. The soil, with an average depth of 1.55 m, had low available potassium (236 mg kg^{-1}), soluble phosphorus (6.6 mg kg^{-1}) and organic matter (0.8%) contents, a clay loam texture and high levels of chloride and sodium (4.37 and 8.87, respectively, in aqueous extract 1:2). 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), with maximum levels of chloride and sodium of around 12.6 and 13.4 meq L^{-1}, respectively. Usual horticultural practices (eg., weed control, fertilization, pruning, fruit thinning and girdling) were carried out by the technical department of the commercial orchard. The weather was typically Mediterranean, with hot, dry summers and mild, wet winters. Annual average temperatures were 17.9, 17.3 and 17.6 °C for the 2009–10, 2010–11 and 2011–12 seasons, respectively, with the maximum temperature (43.8 °C) occurring in the summer of 2009. Rainfall was mainly distributed between autumn and spring, amounting to 296, 256 and 290 mm, respectively, for the three seasons studied.

A drip irrigation system was installed, with two lines per tree row spaced 1.2 m and 9.33 pressure-compensated emitters (1.6 L h^{-1}) per tree placed every 75 cm.

2.2. Irrigation treatments

During the three consecutive growing seasons of the experiment, three irrigation treatments at commercial crop level, were carried out: (i) Control, T_{CTL}, irrigated at 110% of ETc (maximum crop evapotranspiration) during the whole season in order to avoid limiting soil water conditions; the ETc was determined from the crop reference evapotranspiration (ET_0 Penman–Monteith, Allen et al., 1998); (ii) farmer treatment (T_{FRM}), irrigated according to the farmer's normal practice; this involved applying irrigation water above T_{CTL} levels during the first season, and reducing the irrigation amount as the study progressed as in the case of T_{RDI} (Fig. 1); and (iii) regulated deficit irrigation, T_{RDI}, irrigated for the first season (2009–10) at 110% of ETc during the critical periods (second rapid fruit growth period and two months after harvest) and at 60% of T_{CTL} during late postharvest (from July until the end of the growing season). The irrigation scheduling protocol of this treatment varied each season according to the information obtained from the MDS and midday (12.00 h solar time) stem water potential (Ψ_{stem}) measurements in the previous year. Therefore, during the final two seasons (2010–11 and 2011–12) the irrigation was scheduled to

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