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Regulated deficit irrigation in persimmon trees (*Diospyros kaki*) cv. 'Rojo Brillante'

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ABSTRACT

The response of persimmon trees to deficit irrigation applied in three different phenological stages was evaluated during three consecutive seasons in a commercial orchard planted with the cv. 'Rojo Brillante', the most important cultivar in the Mediterranean basin. The experiment was performed in a drip-irrigated orchard located in Valencia, Spain, planted with eight-year-old trees at a spacing of 5.5 m × 4 m and grafted on the rootstock *Diospyrus lotus*. Three regulated deficit irrigation (RDI) regimes were tested and compared to a Control treatment irrigated at full water requirements. In the RDI treatments, moderate water restrictions (50% of Control irrigation), were applied during one of three periods (i) RDI_{spring}, where water restrictions were applied from late May to mid July; (ii) RDI_{summer}, deficit irrigated from mid July to late August and; (iii) RDI_{fall}, in which water restrictions were applied from late August early September to mid November. Results showed that persimmon fruit growth was sensitive to water stress. RDI reduced final fruit weight being this reduction more marked in the most stressed treatment (RDI_{summer}). This decrease in fruit weight was also because spring and specially summer RDI treatments increased the number of fruit harvested. Thus, RDI techniques allowed water savings of up to 20% without any reduction in yield increasing significantly the water use efficiency. In spite of the similar yields obtained in RDI and control trees, the economic return was negatively affected by deficit irrigation, because the lower fruit weight resulted in a decrease in the fruit commercial value. In conclusion, fruit growth of persimmon cv. 'Rojo Brillante' was shown as highly sensitive to deficit irrigation. Based on the results obtained, RDI would need further research in order to define an RDI strategy that could increase water use efficiency without affecting the economic return.

1. Introduction

The low revenues obtained by citrus growers during the last years in some areas of the southeast of Spain are forcing farmers to search for alternative crops that could be adapted to the characteristic soil and environmental conditions of this area. Persimmon (*Diospyros kaki* L.f.) is one of the alternatives, whose cultivation is steadily increasing in the last years because of the current high fruit commercial value. This crop is a deciduous fruit tree native to China, which is the first persimmon producer country of the world (FAOSTAT, 2010). Spain is along with Italy the main persimmon producer of the European Union.

The chronic water scarcity existing in the southeast of Spain might result in irrigation being the main limiting factor for persimmon production in the area. In these conditions of water shortage, regulated deficit irrigation (RDI) has been shown as a suitable technique that can be applied by growers to reduce the amount of water to apply in some crops with none or minimal reductions on yield (Ruiz-Sánchez et al., 2010). RDI was developed in the 1980s as a strategy to reduce tree growth of vigorous trees and to save water (Chalmers et al., 1981; Behboudian and Mills, 1997). Water restrictions are applied in phenological periods, when fruit growth is less sensitive to soil water deficit (i.e. non-critical), while during the rest of the season, full tree water requirements are applied. Therefore, the use of RDI techniques, requires the knowledge of the crop sensitive periods to deficit irrigation, which are different from each crop depending on their agronomic and physiological characteristics.

In citrus, for instance, RDI has been studied in depth in a large number of species (García-Tejero et al., 2010; Ballester et al., 2011, 2013). The sensitive periods of this crop to deficit irrigation have been clearly identified and the effects of water stress on vegetative and reproductive growth are well documented in the literature (Ruiz-Sánchez et al., 2010). In persimmon, however, to the best of our knowledge, no studies have been conducted in order to explore the effects of RDI on yield and its components.

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Scheepers (2010) in South Africa assessed the effect of different levels of water and fertilizer applications on vegetative growth and yield in 'Triumph' persimmon trees. This author observed that higher irrigation rates increased vegetative growth and yield due to an increase in fruit weight while fruit drop was not affected by the irrigation treatments. Other studies performed in Japan, however, have related water deficit during flowering and fruit set with a reduction in persimmon fruit drop (George et al., 1996; Hase et al., 1988). This reduction in fruit drop experienced in deficit-irrigated persimmon trees during flowering and fruit set suggests the possibility that RDI strategies could be used by growers in this crop to increase the fruit load to values that could allow similar yields to those obtained in well-watered trees. However, before suggesting the deliberate adoption of any RDI technique, the consequences of this strategy on yield, its components and the economic return need to be carefully quantified.

Recently a new persimmon RDI research platform was established in eastern Spain (Badal et al., 2010). In a previous report, we explored in detail the effects of plant water stress on fruit drop (Badal et al., 2013). The aim of the present experiment was to assess the effects of RDI strategies applied in three different periods: (i) spring (main fruit drop period); (ii) summer (end of fruit drop period and linear phase of fruit growth) and; (iii) fall, (last phase of fruit growth and ripening) on yield and its components and on vegetative growth of persimmon trees cv. 'Rojo Brillante'.

2. Materials and methods

2.1. Plot characteristics and irrigation treatments

The experiment was carried out during three consecutive seasons (2009–2011) in a 0.52-ha commercial private orchard planted with persimmon (*D. kaki*) trees, located in Manises (39°30_N, 0°24_E, elevation 44 m), Valencia (Spain), where the climate is typically Mediterranean. The cultivar employed was 'Rojo Brillante', which produces only female flowers and hence has no chance of pollination. Trees were eight years old, planted at a spacing of 5.5 m × 4 m and grafted on the rootstock *Diospyrus lotus*. The soil was calcareous; of sandy loam to sandy clay loam texture with an effective depth of 0.8 m. Trees were drip irrigated with two laterals per row and a total of 8 emitters of 4 L h^{-1} per tree. At the beginning of the experiment trees had a canopy ground cover of 33 ± 0.38% of the soil surface area allotted per tree and an average trunk diameter of 12 ± 1 cm. Four irrigation treatments were applied during the three years of experiment:

1) Control, irrigated at 100% *of the estimated water requirements during the entire season.* Water needs were calculated according to the crop evapotranspiration ($ET_c = ET_o K_c$). Reference evapotranspiration (ET_o) was obtained with data from a meteorological station located in the orchard. Considering that persimmon tree water needs are not known, irrigation was applied using a high crop coefficient value that varied from 0.20 in March to 0.9–1.0 at full canopy growth. In addition it was ensured that the irrigation regime maintained soil water content in the 0–60 cm depth at near constant levels between field capacity and the refill point (80% of field capacity), avoiding percolation loses (Fig. 1). For this purpose, in the control plots, three sets of soil capacitance probes (EnviroScan, Sentek, Australia) with sensors located at 10, 30, 50 and 75 cm soil depth were installed.
2) RDI_{spring}, irrigated at 50% ET_c from May 22nd to July 3th (day of the year (DOY) 142–184) in 2009, from June 7th to July 16th (DOY 158–197) in 2010 and from May 16th to July 8th (DOY 136–189) in 2011. During the remaining part of the seasons, 100% ETc was applied. Since flowering occurred after April 20th, 18th and 4th (DOY 110, 108 and 95) for 2009, 2010 and 2011, respectively, the periods of water restrictions coincided with the main fruit drop period once flowering had occurred.
3) RDI_{summer}, irrigated at 50% ET_c from July 4th to August 14th (DOY 181–230) in 2009, from July 16th to September 3rd (DOY 197–246) in 2010 and from July 29th to August 26th (DOY 210–238) in 2011. During the remaining part of the seasons, 100% ETc was applied. The periods of water restrictions coincided with the end of fruit drop period and with the main linear phase of fruit growth.
4) RDI_{fall}, irrigated at 50% of the control treatment from August 21st to October 30th (DOY 233–303) in 2009, from September 3rd to November 12th (DOY 246–316) in 2010 and from August 26th to November 15th (DOY 239–319) in the last experimental season. Before the water restrictions started, 100% ETc was applied. In this treatment the water restrictions started when fruit drop had clearly ceased (see Badal et al., 2013 for details on seasonal fruit drop) and coincided with the end of fruit growth and ripening. When RDI finished, irrigation was ceased for all treatments.

The experimental layout was a complete randomised plot with three replicates of six-seven sampled trees per treatment. In each replicate, perimeter trees were used as guards. Water flow meters were installed at the beginning of each replicate in order to monitor the amount of water applied to each treatment.

Field practices were those commonly applied in the area. Some light fruit thinning was applied in 21st and 19th of August in 2009 and 2011, respectively, by removing some damaged, smaller and clustered fruit. Because water restrictions applied during spring and summer reduced fruit drop (see Badal et al., 2013 for details), fruit thinning was more intensively applied in the RDI_{spring} and RDI_{summer}, treatments. In season 2009, an average of 25, 87, 37 and 19 fruit per tree were hand thinned in treatments Control, RDI_{spring}, RDI_{summer} and RDI_{fall}, respectively. In 2010, hand thinning was not performed and in 2011; 14, 27, 20 and 15 fruit per tree were removed in treatments Control, RDI_{spring}, RDI_{summer} and RDI_{fall}, respectively.

2.2. Determinations

Plant water status was monitored weekly by measuring stem water potential (Ψ_s) at solar noon with a Scholander pressure chamber (Soil Moisture Equip. Corp. mod. 5100A). Measurements were taken in two bagged leaves per tree and two trees per replicate (a total of six trees per treatment). Control treatment measurements of Ψ stem were carried out approximately every week from May to October. RDI treatments were measured at the beginning of each season and during the period of water restrictions and the recovery phase.

Fruit growth was monitored by measuring 10 fruit in two trees per replicate (six trees per treatment, a total of 60 fruit per treatment) from the beginning of June until harvest. Fruit were tagged and measured with a digital calliper. Vegetative growth was assessed by measuring the trunk perimeter at the beginning and at the end of each experimental season. Trunk of sampled trees was labelled at 0.25 m from the soil and measurements were taken with a tape measure.

Yield and number of fruit per tree were determined at the time of harvest. In 2009, fruit were picked at once on November 3rd. The remainder seasons, however, trees were harvested in two times according to the fruit ripeness. In 2010, fruit was picked on October 19th and 26th while for the last experimental season this took place on October 4th and 19th. For each sampled tree, yield was weighed and fruit counted to obtain the average fruit