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Effects of long-term summer deficit irrigation on 'Navelina' citrus trees

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ABSTRACT

The effects of long-term summer deficit irrigation (RDI) strategies on 'Navelina' orange trees (*Citrus sinensis* L. Osbeck) were assessed in a drip-irrigated commercial orchard located in Senyera (Valencia, Spain). Three irrigation treatments were applied during five consecutive years (2007–2011): a control treatment, without restriction, and two RDI treatments, in which the water reduction was applied during the summer (initial fruit enlargement phase). During the first three seasons, the trees under the control treatment received 110% of the theoretically required irrigation dose (ID), and the RDI treatments received 40% and 60% of the full ID during the deficit period. During the last two years of the study, the control treatment was irrigated at 100% of the ID and the amount of water applied in the RDI treatments was additionally decreased 20% from the reduced ID of the preceding years. The crop's response to summer deficit irrigation was analysed in relation to tree water status, which was assessed by relying on midday stem water potential (Ψ_{st}). The lowest Ψ_{st} values were reached, as expected, at the end of the water deficit period and with the most stressed treatment. These minimum Ψ_{st} values ranged between −1.6 MPa in 2008 and −2.5 MPa in 2010. In most occasions, the trees under RDI treatments showed a fast hydric recovery and had completely re-hydrated one week after restarting irrigation. Summer RDI treatments did not cause negative effects on either the amount or on the quality of the yield if the threshold value of Ψ_{st} = −2.0 MPa was not surpassed. According to the results, it can be concluded that long-term RDI strategies may be applied successfully on Navelina orange trees during summer without negatively affecting the studied parameters while allowing water savings between 12% and 27%.

1. Introduction

Citrus are widely grown under diverse climatic conditions, including in semi-arid regions. Spain occupies one of the first places in the global ranking of citrus producing countries, with an average annual production exceeding 6.6 million t. Almost half of total production (about 3.5 million t) corresponds to the sweet orange group, in which the 'Navelina' orange is the most important cultivar, with a production of about 1.1 million t (MAGRAMA, 2015).

Water scarcity is an important problem in many areas of the world. It particularly affects the Mediterranean basin, with a semi-arid climate, scarce rainfall, hot summers, and a dry season that lasts for over three months. Irrigated agriculture is the sector with by far the largest water consumption. In Spain, about 72% of consumptive water is used for irrigation purposes (Frenken and Guillet, 2012).

Thus, increasing water scarcity demands a more efficient and optimized use of irrigation water. One of the most promising approaches for attaining this objective might be regulated deficit irrigation (RDI). RDI consists of reducing water supplies during certain stages of crop development, when yield and fruit quality might have a low sensitivity to water deficits, and providing normal irrigation doses during the rest of the season, especially during critical periods or phenological stages with a higher sensitivity to water deficits (Chalmers et al., 1986; Mitchell et al., 1984). Many works

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have proved the feasibility and effectiveness of this practice by reducing water use in tree crops with low or null impact on yield and fruit quality (e.g. Carr, 2012; Ruiz-Sánchez et al., 2010).

In order to adequately control the water stress caused by the application of RDI, it is important to monitor plant water status or soil water content appropriately. In this sense, stem water potential (Ψ_{st}) seems to be a sensitive measure of plant water status (Choné et al., 2001; Ortuño et al., 2006). However, Ψ_{st} is not easily measurable, and it is not suited for an automated irrigation scheduling. As an alternative or complement to tree water status monitoring, there are different techniques that allow for the continuous measurement of soil water content. Among others, the frequency domain reflectometry (FDR) probe, with multiple depth capacitance sensors (Fares and Polyakov, 2006; Paltineanu and Starr, 1997), has shown excellent performance so far. It is currently widely used for field applications as a decision-making tool for irrigation scheduling (Martí et al., 2013).

González-Altozano and Castel (2003a, 2003b, 2000, 1999) carried out several RDI tests on an experimental orchard of '*Clementina de Nules*' citrus trees (*Citrus clementina* Hort ex Tan). Different levels of water restriction were compared in the main phenological periods of crop development, and the effects of water restriction on yield, fruit quality, and water use efficiency were assessed. They concluded that the effects of RDI treatments depend, among others, on the phenological period in which the water restriction is applied as well as on the degree of restriction applied. Specifically, they stated that moderate water reduction during the initial fruit enlargement phase, after the June fruitlet drop (July and August in the northern hemisphere), did not affect yield, fruit size, or quality, which allowed for significant water savings (8–22%). These experiments also defined different pre-dawn leaf water potential (Ψ_{pd}) threshold values to avoid negative effects during the phenological period considered. Thus, summer Ψ_{pd} should not surpass −1.2 MPa, which corresponds to values of Ψ_{st} around −1.9 MPa.

Most of the RDI studies carried out on citrus provide evidence of the advantages and benefits of reducing water application during summer. Citrus fruit has the capacity to accelerate growth after a water deficit period and thus be able to reach their potential size. This capacity, named compensatory fruit growth, is essential for the successful application of summer RDI strategies. However, Ballester et al. (2013) found that summer RDI treatments applied to Navel Lane Late citrus trees might prevent compensatory fruit growth after returning to irrigation at full dosage, depending on the duration and degree of severity of the plant water deficit. The latter study highlights the differences between cultivars in response to RDI, as well as the need for frequent monitoring of plant water status to avoid an excessive reduction of fruit weight that may affect yield.

The majority of RDI studies consider the effects of deficit irrigation treatments during two or three consecutive growing seasons. Other researches deal with the viability of long-term RDI strategies. These long-term RDI strategies may negatively affect yield capacity (Girona et al., 2005; Intrigliolo et al., 2013; Romero et al., 2004); however, some studies have reported substantial water savings without any reduction in yield or fruit size (Hueso and Cuevas, 2010; Johnson et al., 1992). It should be noted that, although there are several studies addressing the application of RDI to 'Navelina' citrus trees (García-Tejero et al., 2010; Aguado et al., 2012), to our knowledge, no investigation has considered the effects of long-term summer deficit irrigation with this cultivar.

The aim of this study is to analyse the feasibility of long-term summer RDI strategies in 'Navelina' citrus trees and the effects on yield, fruit quality, and vegetative growth during five consecutive years (2007–2011).

Table 1
Rainfall and evaporative demand (ETo) registered at the meteorological station nearest to the experimental plot during the studied period.

	2007	2008	2009	2010	2011
Rainfall (mm)	869	796	840	566	616
ETo (mm)	1160	1124	1202	1132	1067

2. Material and methods

2.1. Soil and climate conditions

The experiment was carried out during five consecutive growing seasons (2007–2011) on a commercial drip-irrigated plot of 1 ha in Senyera, Valencia (39°3′N, 0°30′W, 23 m a.s.l.), which was planted in 1982 with 'Navelina' orange trees (*Citrus sinensis* L. Osbeck) grafted on 'Cleopatra' mandarin trees (*Citrus reshni* Hort.) at a spacing of 5 × 5 m, with an average ground cover of about 52%.

The soil was deep sandy-loam with pebbles of alluvial origin, with an average organic matter content of 1.17%, an electric conductivity (EC_{1-5}) of 0.14 dS m^{-1}, 39.1% of active $CaCO_3$, and a pH in water (1/25) of 8.0. It was also poor in total nitrogen (0.06%), available potassium (0.42 meq K^+ 100 g^{-1}) and phosphorus (20.67 mg P kg^{-1} Olsen). A more detailed description of the soil characteristics can be found in Martí et al. (2013).

The irrigation water used had an average electrical conductivity (at 25 °C) of 0.82 dS m^{-1}, with chloride content lower than 2 meq Cl L^{-1} and a SAR value of 3.53.

Climatic data were provided by the meteorological station belonging to the Irrigation Technology Service (STR) of the Valencian Institute for Agricultural Research (IVIA) in Villanueva de Castellón (Spain), less than 500 m from the experimental plot. The climate is Mediterranean semi-arid. The rainfall and the corresponding evaporative demand (ETo) for each year are summarized in Table 1. The average annual rainfall in the period 2000–2012 was 624 mm, and the average annual ETo was 1083 mm. The mean annual air temperature during the same period was 17.1 °C.

Trees received fertilisation through the irrigation system at a non-limiting rate of 260–65–130 kg ha^{-1} per year of N, P_2O_5, and K_2O respectively, split in weekly applications from April to October. Control of plagues and other cultural practices were carried out according to the usual local criteria in that area and were identical for all treatments. Trees were pruned in 2009 and 2011.

2.2. Irrigation treatments

Irrigation was scheduled according to crop evapotranspiration (ETc) at local irrigation conditions ($ETc = ETo \cdot K_c$ where K_c is the crop coefficient) and effective precipitation (E_p). Reference evapotranspiration (ETo) was determined by the FAO56 version of the Penman-Monteith equation relying on daily average data from the meteorological station. The crop coefficient (K_c) was obtained for this location according to Castel (2005) based on the percentage of shaded area in the plot (40.5–54.1%). In the studied period, the different mean seasonal values of K_c values used were as follows: 0.54 in 2007, 0.61 in 2008, 0.59 in 2009, and 0.54 in 2010 and 2011. The theoretical irrigation dose (ID) to ensure full irrigation was calculated as $ID = ET_c - E_p$.

Three irrigation treatments were applied: a control treatment, irrigated without restriction throughout the whole year, and two RDI treatments (T1 and T2), which received the same amount of water as the control except during the restriction period (the initial fruit enlargement phase, from mid-July to early September). The established irrigation treatments, the duration of each one, and the dose applied throughout each growing season are summarized in Table 2.