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Effect of deficit irrigation and reclaimed water on yield and quality of grapefruits at harvest and postharvest

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A B S T R A C T

The aim of our research was to discover the effects of the long-term irrigation with saline reclaimed (RW) and transfer (TW) water and different irrigation strategies: control (C) and regulated deficit irrigation (RDI) on yield and fruit quality of grapefruit at harvest and during cold storage. TW-RDI treatment decreased tree canopy (TC) and crop load, resulting in a 21% reduction of fruit yield. Regarding fruit quality, RW notably decreased peel thickness at harvest (about 8%); however, this difference was not remained during cold storage. Sugar/acid ratio was mainly increased by RDI, but also by RW, due to an important increase in soluble solid content (11% of average value for TW-RDI, RW-C and RW-RDI). In addition, RDI combined with RW, significantly increased the number of fruits in small category 5 at the end of cold storage. Finally, neither ratio yield/TC nor irrigation water productivity were affected by any irrigation treatments.

1. Introduction

Current climate change predictions indicate increases in the frequency and intensity of drought periods for Mediterranean areas (García-Galiano, Giménez, Martínez-Pérez, & Giraldo-Osorio, 2015). In these regions, irrigation water is scarce and many orchards suffer from drought periods. In order to overcome this, the development of strategies to optimize water productivity is needed. A useful approach is regulated deficit irrigation (RDI), where water deficits are imposed during phenological periods least sensitive to water stress, with little or no impact on fruit yield and quality. In fact, RDI has been shown to improve water use efficiency and fruit quality in *Citrus* (e.g. García-Tejero et al., 2010), a crop with species of great economical relevance in the Mediterranean and worldwide.

Moreover, the use of non-conventional water sources such as reclaimed water (RW) is also an alternative for farmers in these regions. On the one hand, RW can be beneficial to crops due to its high macronutrient concentration (Pedrero, Mounzer, Alarcón, Bayona, & Nicolás-Nicolás, 2013), considering that an excess of them could be lost through leaching (Romero-Trigueros, Nortes, Alarcón, & Nicolás, 2014). Besides, RW may imply risks to agriculture due to its higher salt concentration. Therefore, an inadequate management of irrigation with RW can exacerbate problems of salinization and soil degradation at the medium-long term, resulting in negative impacts on crop physiology, yield and fruit quality (Nicolás et al., 2016). The use of saline water decreases yield of mandarin trees due to the reduction of both fruit number and weight and it increases the juice soluble solid content (SSC) and titratable acidity (TA) (Navarro, Pérez-Pérez, Romero, & Botía, 2010). Prior, Grieve, Bevington, and Slavich (2007) also reported that irrigation water with an electrical conductivity (EC) of 2.5 dS m^{-1} cause a reduction in yield of orange trees due to a decrease in fruit size.

The maintenance of fruit quality depends on storage conditions to a great extent (Fischer, 2000). However, environmental conditions and agronomic factors, such as the water source quality and irrigation strategies, also have a marked influence on fruit quality at postharvest (Fischer, 2000). Fruit quality at postharvest in *Citrus* managed through RDI has been rarely addressed (e.g. Conesa et al., 2014). Moreover, studies accounting for the effects of irrigation

Abbreviations: C, control; EC, electrical conductivity; RDI, regulated deficit irrigation; RW, reclaimed water; SSC, soluble solid content; TA, titratable acidity; TC, tree canopy volume; TW, transfer water; WP_i, irrigation water productivity; Yield/TC, yield/tree canopy.

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with RW on postharvest quality of *Citrus* have never been carried out.

The experiment reported here is the first one to evaluate of grapefruit quality after being irrigated with RW and RDI for eight years in the field. The aims of this study were to assess the effects of these irrigation strategies on fruit yield and quality at harvest and postharvest during cold storage for 31 days.

2. Materials and methods

2.1. Site characterization and irrigation treatments

The experiment was conducted during 2013–2015 period at a commercial *Citrus* orchard located at Molina de Segura, Region of Murcia (38°07′18″N, 1°13′15″W). The experimental plot was cultivated with 9 year-old (since 2013) 'Star Ruby' grapefruit trees (*Citrus paradisi* Macf) grafted on Macrophylla rootstock spaced 6 × 4 m. Regular irrigation was scheduled on the basis of crop evapotranspiration (ET_c) as described by Pedrero et al. (2015).

Beginning in 2007, two different water sources were used. The first one was pumped from the Tajo-Segura canal (transfer water, TW) and the second one was pumped from Molina de Segura tertiary wastewater treatment plant (reclaimed water, RW). The later showed high levels of salinity and N, P and K (Table 1). Two irrigation treatments were established in the same year for each water source:

i) Control (C) irrigated to fully satisfy crop water requirements (100% ET_c)
ii) Regulated Deficit Irrigation (RDI) which received half the water amount applied to the C (50% ET_c) during the second stage of fruit development (from 26, July to 14, September).

The total amounts of water applied to C and RDI were 5938 and 5055 $m^3\ ha^{-1}$ in 2013, 6125 and 5010 $m^3\ ha^{-1}$ in 2014 and 5929 and 4883 $m^3\ ha^{-1}$ in 2015, respectively (Fig. 1).

The experiment was laid out in randomised blocks with 4 replications. Each replicate consisted of 3 rows with 4 trees each. The 2 trees in the center of the middle rows were used for measurements and the rest acted as buffer rows.

2.2. Vegetative growth, yield and fruit quality

Eight trees per treatment were evaluated in 2013–2015 period to determine tree canopy volume (TC), crop load, yield, fruit weight, fruit diameter, specific weight calculated as fruit weight x fruit diameter^{-1} and stem water potential (Ψ_s). The TC was estimated from the height and diameter of the tree's foliage, considering the tree as a pyramid-shaped unit (Hutchinson, 1977). Besides, to evaluate yield efficiency the yield/TC ratio was calculated. Ψ_s was measured using a pressure chamber (model 3000; Soil Moisture Equipment Corp., California, USA) in leaves close to the trunk which were wrapped in aluminum foil at least 2 h before.

The irrigation water productivity (WP_i) was calculated as the ratio between the annual yield ($kg \cdot ha^{-1}$) and the applied water ($m^3 \cdot ha^{-1}$).

Fruits were harvested from 2013 to 2015 and quality parameters were determined in 40 fruits randomly selected (10 for each replicate) every year. Moreover, fruits from second harvest in 2015 were used for the postharvest study. Ninety fruits per treatment

Table 1
Physical and chemical parameters for both transfer water (TW) and reclaimed water (RW) in 2015.

Parameter	Units	TW	RW
EC	$dS\ m^{-1}$	1.00 ± 0.01	3.21 ± 0.20
pH		8.41 ± 0.09	7.70 ± 0.10
Ca	$meq \cdot L^{-1}$	1.99 ± 0.10	3.58 ± 0.20
Mg	$meq \cdot L^{-1}$	1.58 ± 0.10	3.92 ± 0.30
K	$mg \cdot L^{-1}$	3.65 ± 1.40	38.94 ± 1.40
Na	$meq \cdot L^{-1}$	1.86 ± 0.20	18.30 ± 1.20
B	$mg \cdot L^{-1}$	0.10 ± 0.01	0.66 ± 0.04
Cl^-	$meq \cdot L^{-1}$	3.15 ± 0.40	20.10 ± 3.01
NO_3^-	$mg \cdot L^{-1}$	7.70 ± 3.60	25.42 ± 10.6
PO_4^{--}	$mg \cdot L^{-1}$	0.31 ± 0.02	1.73 ± 0.70
SO_4^{--}	$meq \cdot L^{-1}$	5.90 ± 0.50	17.20 ± 3.40

Values are averages ± SE of 12 individual measurements taken throughout the crop cycle.

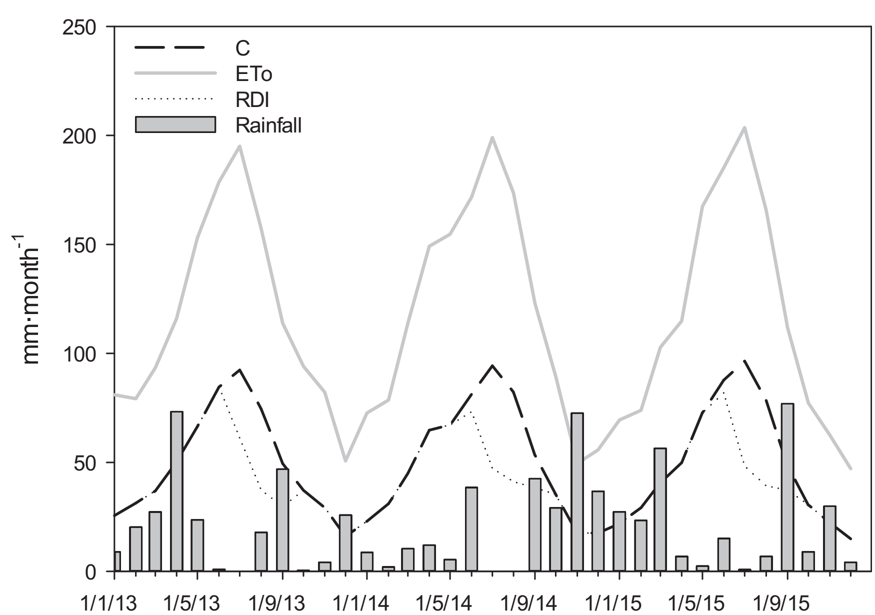

Fig. 1. Seasonal evolution of control irrigation (C, $mm \cdot month^{-1}$), reference evapotranspiration (ET_0, $mm \cdot month^{-1}$), rainfall ($mm \cdot month^{-1}$) and regulated deficit irrigation (RDI, $mm \cdot month^{-1}$) in 2013, 2014 and 2015.