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Response of young 'Star Ruby' grapefruit trees to regulated deficit irrigation with saline reclaimed water

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ABSTRACT

In this study, the physiological and agronomic effects of irrigating a commercial young grapefruit orchard with saline reclaimed water (RW) combined or not with a regulated deficit irrigation (RDI) strategy were analyzed over three consecutive years. Two water sources, transferred water (TW; $EC_w \approx 1.3\ dS\ m^{-1}$) and reclaimed water (RW; $EC_w \approx 3.0\ dS\ m^{-1}$) were used, and two irrigation treatments, a control treatment (irrigated 100% of the crop evapotranspiration; ETc) and a RDI treatment (irrigated 50% of ETc during the 2nd stage of fruit growth) were performed. Results evidenced that RW, especially under the RDI strategy, increased the soil salinity, particularly in summer due to a greater evapotranspirative water demand. However, soil salinity did not increase, as salts were likely to be washed by rainfall. Stomatal conductance and net photosynthesis were not affected by the use RW combined or not with RDI strategies. However, RDI strategies worsened the tree water status regardless of the type of water used; TW or RW, although re-watering increased rapidly the stem water potential up to values similar to that of the control trees. The RDI treatment, which allowed reaching an average annual water saving of 13.2%, combined or not with RW, did not negatively affect vegetative growth, yield and fruit quality, which might be of great economic and competitive significance for agriculture. The combination of RW and RDI did have not affect negatively the soil and young grapefruits, but further research focused on a longer term should be carried out since detrimental effects might appear.

1. Introduction

In arid and semiarid regions, which are often characterized by a competition for water resources, restriction on water for agriculture is fostering the search of alternative water resources, such as the reuse of reclaimed water (RW), and saving water techniques, such as regulated deficit irrigation (RDI) strategies to cope with forecasted food production requirements (Pedrero et al., 2013).

RW has usually been viewed as a way of disposing of water commonly containing, depending upon its source and degree of treatment, (i) high salt concentration that may derive in undesirable effects for soils and plants (Ayers and Westcot, 1985) and (ii) viruses, bacteria and heavy metals that may pose a potential health threat to the user (Parsons et al., 1995). However, under appropriate management, RW might become a huge potential source for irrigation as it is progressively augmenting (Pedrero et al., 2010), since the volume of treated wastewater is in continuous increase due to (i) environmental concerns, (ii) the progressive implementation of the European Waste Water Directive (91/271/EEC) and (iii) that it is free-of-charge where the "polluter pays" policy is implemented (Mounzer et al., 2013). In addition, RW not only may bring agronomic benefits for crops, as it contains high organic matter and many nutrients which are essential for plant growth, but it also may reduce fertilizer application rates (Pedrero et al., 2013) and prevent pollution of surface or ground water by recycling these nutrients (Maurer and Davies, 1993).

Some studies have already reported the positive agronomical advantages of reusing RW in citrus as an alternative source of water for irrigation, although most of them have used RW with low electrical conductivity (EC) (Parsons et al., 2001with EC = 1.10 dS m^{-1}; Pereira et al., 2011 with EC = 0.99 dS m^{-1}), which are below harmful thresholds for citrus trees (Ayers and Westcot, 1985). On the contrary, few studies have evaluated the effect of irrigating citrus with saline RW and some controversy remains. For instance, Maurer and Davies (1993) found that three-year old grapefruit trees, grafted

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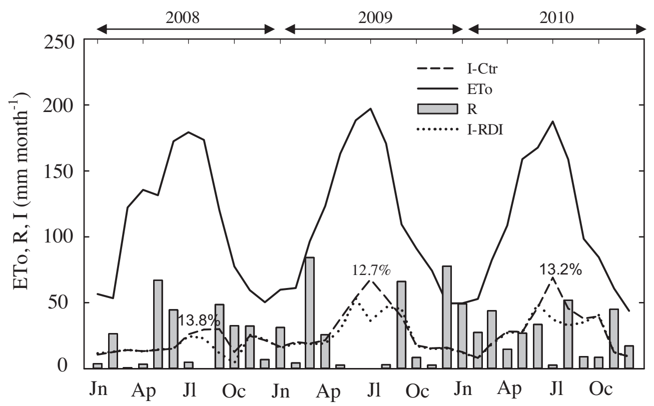

Fig. 1. Monthly values of reference evapotranspiration (ETo), rainfall (R), and irrigation (I) in the control (Ctr) and regulated deficit irrigation (RDI) treatments during 2008–2010. The percentage of water saved each season in the RDI treatment is also shown.

on Swingle citrumelo rootstock and irrigated for three consecutive years with RW (EC = 1.80 dS m^{-1}), whether supplied with fertilizers, reached larger canopies, trunk diameters and fruit yield than trees irrigated with non-saline well water (EC = 0.35 dS m^{-1}). Pedrero et al. (2014) irrigated an adult mandarin orchard grafted on Carrizo citrange rootstock for three consecutive years with saline RW (EC = 3 dS m^{-1}) reporting, at the end of the experiment, a clear reduction of the canopy volume and the fruit yield in trees supplied with RW, which was counterbalanced by a significant increase in the fruit weight. These authors also concluded that RW has the advantage of supplying a large part of the N, P and K requirements, but on the contrary, they found a huge risk of accumulation of salts, Na and B in the soil.

On the other hand, regulated deficit irrigation (RDI), applied when the sensitivity of plant to water stress is the minimum, allows reducing the water use in irrigation during periods with little or no impact on fruit yield and quality while covering the full water requirements during the rest of the season (Chalmers et al., 1981). RDI has been deeply studied in citrus. A valuable RDI review on fruit trees such as citrus and vines was carried out by Ruíz-Sanchez et al. (2010) in Spain. This study concluded that further research is needed to define more precisely the timing and severity of water restrictions, which do not affect fruit yield, weight and quality. For instance, Ballester et al. (2011) evaluated the physiological and agronomic response to two levels of deficit irrigation, performed during July–mid September, on Nules Clementine trees grafted on Carrizo citrange. When irrigation was restricted to 50% ETc (21% of annual water saving), fruit yield and fruit size were not affected. However, when irrigation was restricted to 30% ETc (28% of annual water saving), fruit yield was notably reduced (reduction of 15%), mainly due to a reduction in fruit size. Pérez-Pérez et al. (2014) evaluated the sensitivity to RDI (50% ETc) of different fruit growth stages in adult grapefruit trees grafted on 'Cleopatra' mandarin (Citrus reshni Hort.). They concluded, under the conditions of their study, that RDI during: (i) phase I, cell division, led to changes in the resource distribution; vegetative growth being reduced much more than yield and only induced small changes in fruit composition, (ii) phase II, cell elongation, affected plant water relations decreasing final fruit size and yield and (iii) phase III, final fruit growth period, had only significant effects of fruit quality by increasing soluble solid content and titratable acidity and delaying fruit maturity.

Additionally, salt and water stress tolerance in citrus are widely influenced by rootstock where plants are grafted on, as they may condition the amount of Cl^- and/or Na which may accumulate in the foliage (García-Sánchez et al., 2002).

Therefore, to a certain extent, there is wide evidence that research aimed at evaluating the effect of irrigating with saline RW or applying RDI as a saving water technique for a wide range citrus and rootstocks has been carried out. However, there is little research focused on the possible effects of the interaction between drought and salinity stresses in citrus (Syvertsen et al., 1988; Pérez-Pérez et al., 2007), overall, in the case of young citrus trees, in which, hydric and saline stresses may affect both the vegetative growth and yield (Fereres and Soriano, 2007). Therefore, it becomes an interesting issue as the salinity effects may be intensified whether dehydration (Pedrero et al., 2014).

Therefore, the objective of this work was to evaluate the sensitivity to the combination of RDI and irrigation with saline RW in young 'Star Ruby' grapefruit trees grafted on *Citrus Macrophylla* rootstock, giving special reference to the effects on tree water relations, leaf mineral concentrations, vegetative growth, gas exchange parameters and fruit yield and quality.

2. Materials and methods

2.1. Orchard characteristics

The experiment was conducted from 2008 to 2010 at a 0.5 ha commercial orchard located in Campotéjar-Murcia, south-eastern Spain (38°07′18″N; 1°13′15″W). This area is characterized by a Mediterranean semi-arid climate with warm, dry summers and mild winter conditions. The annual reference evapotranspiration (ETo) and rainfall is on average 1326 and 300 mm, respectively. The soil within the first 90 cm depth had a loamy texture (24% clay, 33% loam and 43% sand) with an average bulk density of 1.41 g cm^{-3}.

The experimental plot was performed on 4-year (in 2008) young 'Star Ruby' grapefruit trees (*Citrus Paradisi* Macf) grafted on Macrophylla rootstock [*Citrus Macrophylla*] with a tree spacing of 6 m × 4 m. A total of 192 trees were used in the study. The experiment took the form of four completely randomized plots, with four treatments per plot and twelve trees per treatment within each plot. In each plot, the two central trees "inner trees" of the middle row were used for measurements while border trees were excluded from the study to eliminate potential edge effects.

The irrigation system consisted of a single lateral drip line laid on the soil surface next to the tree trunk. It provided three self-pressure compensating on-line emitters per tree discharging 4 L h^{-1} each, placed at 1 m from the trunk and spaced 1 m apart. The irrigation doses were scheduled based on the daily crop evapotranspiration (ETc) accumulated during the previous week. ETc values were estimated as reference evapotranspiration (ETo), calculated with the Penman–Monteith methodology (Allen et al., 1998), and month-specific crop coefficients (K_c) (Castel et al., 1987). K_c values employed for the control treatment from January to December were: 0.58, 0.63, 0.53, 0.56, 0.50, 0.58, 0.62, 0.71, 0.66, 0.73, 0.74 and 0.73, respectively. In addition, a reduction coefficient (K_r = 0.5) which accounted for eventual decrease in evapotranspiration because of the partial soil covering by the crop canopy (young grapefruit trees) was used (Fereres et al., 1982). The monthly evolution of the ETo during the experiment is shown in Fig. 1. The meteorological data were collected from an automatic weather station (Campbell Scientific Ltd., Shepshed, UK) sited on the experimental field.

Trees were irrigated daily during the three-year experiment. The total amounts of water applied were measured with inline water flow meters, placed on the four replicates of each treatment. The irrigation was controlled automatically by a head-unit programmer and electro-hydraulic valves. All treatments received the same amounts of fertilizer N–P_2O_5–K_2O, although each year it was increased due to the tree growth (in 2008: