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Physiological and agronomic mandarin trees performance under saline reclaimed water combined with regulated deficit irrigation

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ABSTRACT

The physiological and agronomic effects of irrigating a commercial mandarin orchard with saline reclaimed water (RW) combined with regulated deficit irrigation (RDI) strategies were analyzed over three consecutive years. Two water sources, fresh water ($EC_w \approx 1.4\,dS\,m^{-1}$) and RW ($EC_w \approx 3.4\,dS\,m^{-1}$) and two irrigation treatments, a control treatment (irrigated at 100% of the crop evapotranspiration; ETc) and a RDI treatment (irrigated at 50% of ETc during the 2nd stage of fruit growth) were examined. Results evidenced that RW, especially under the RDI treatment, increased soil salinity, particularly in summer due to a greater ETc demand. Soil solution Na and B concentrations exceeded the phytotoxic maximum thresholds proposed in the literature for citrus but Cl did not. Despite this, only B exceeded the maximum toxic threshold in leaves but no toxicity symptoms were shown. Stomatal conductance and net photosynthesis were not affected by the use of RW or RDI. RDI worsened the plant water status, especially during the first year due to a higher crop load. Vegetative growth and yield were also negatively influenced by the RW, particularly under RDI. Fruit quality, however, was practically not affected.

These results manifest that, in arid and semi-arid areas, such a combination of RW and RDI may affect negatively soils and plants in the long-term because of salts and B accumulation. Suitable management practices must be developed to ensure the sustainability of soils and mandarin yields subjected to these non-conventional water resources, particularly under RDI strategies.

1. Introduction

Nowadays a diverse range of factors such as population growth, industrial development, sustained increase of living standards and specifically the trend towards irrigated agriculture have led Mediterranean countries to increased competition and potential bilateral conflicts between users and regional administrations for the use of water (MED WS & D WG, 2007). Consequently, there have been extensive water withdrawals that have come to exceed renewable water resources in some regions, increasing the pressure on water resources (Iglesias et al., 2007). Moreover, climate change forecast reports that the situation is likely to worsen in the near future (Faurès et al., 2013). All the aforementioned data suggests an urgent need to explore new alternative water sources and also strategies to cope with crop water requirements in order to maintain or enhance sustainable agricultural production. In that regard, the use of non-conventional water resources for irrigation such as reclaimed water (RW) is progressively augmenting (Pedrero et al., 2010) as 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). For instance in Murcia, a semi-arid region located in southern Spain where this study has been carried out, there are 89 operating wastewater treatment plants (WWTP) delivering almost 109 hm^3 per year (ESAMUR, 2012), which restores about 6.5% of the annual renewable water resources (CHS, 1998). RW should be hence considered in agriculture and adopted in areas with limited freshwater resources. In such water stressed regions, RW is also of great interest for irrigation purposes because it usually contains a great concentration of organic matter and nutrients such as N, P and K that brings noteworthy agronomic benefits for crops. However, depending upon its source and degree of treatment, RW may contain high concentrations of heavy metals, trace elements, viruses, bacteria and especially salts. As a result, the use of saline RW for irrigation may derive in undesirable effects on soils and plants and may pose a potential health threat to the consumer (Pedrero et al., 2013). In Murcia, ESAMUR (2012) reported

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that at least 93% of RW has an electrical conductivity (EC) greater than 2 dS m^{-1} and about 37% has EC values greater than 3 dS m^{-1}. However, despite the high salt concentration in the RW, the ever-increasing demand of fresh water owing to the urban growth in the coastal zone of Murcia and the large demand from intensive agricultural activity have made the RW reuse indispensable for irrigation (Pedrero et al., 2013).

Besides RW, other agricultural adaptation strategies such as those aimed at improving the temporal and spatial distribution of water exchange within the soil–plant–atmosphere continuum have been to a certain extent evaluated. Particularly, regulated deficit irrigation (RDI) technique has been accepted as a valuable and sustainable irrigation solution that allows saving water without having significant negative impacts on final yield (Chalmers et al., 1981). RDI consists of cutting-off or reducing partially the irrigation during low water stress sensitivity periods of the crop cycle, when adverse effects on productivity are minimized (Mitchell et al., 1986).

On the one hand, there is previous research dealing with the physiological and agronomic performance of citrus supplied with saline RW (Pereira et al., 2011) and on the other hand there are several studies in which the effect of the RDI strategy has been evaluated (Pérez-Pérez et al., 2008; Ruiz-Sanchez et al., 2010). However, to our knowledge, few investigations have studied interactions between drought and salinity stress at the same time (Syvertsen et al., 1988; Pérez-Pérez et al., 2007) or plant recovery after these stresses have been relieved. In fact, it is difficult to quantify the combined effects of salinity and drought because salinity effects become more intense during dehydration. Therefore, this should be studied further, especially for severe water shortage conditions such as those in Murcia region. However, this combination could produce undesirable stress levels that may have negative effects on the soil agronomic characteristics (Mounzer et al., 2013); consequently, this approach requires precise knowledge of crop response to water deficit and salinity, as both factors' tolerance varies considerably by species, cultivar and stage of growth.

This study, carried out under Mediterranean climate conditions, aimed at evaluating during three consecutive years the effects of using saline tertiary-treated RW supplied by surface drip irrigation and subjected to a RDI treatment during the second stage of fruit growth on both the physiological and agronomic response of mandarin trees and on the soil salinity within the root zone.

2. Materials and methods

2.1. Experimental site, plant material and design

A three-year experiment (2008–2010) was conducted at a commercial orchard located in Campotéjar-Murcia, 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 experimental plot consisted of 0.5 ha cultivated with 8-year old (in 2007) mandarin trees (*Citrus clementina* cv. 'Orogrande') grafted on Carrizo citrange (*Citrus sinensis* [L.] Osb. × *Poncirus trifoliata* [L.]) rootstock. The soil within the first 90 cm depth had a loamy texture (26% clay, 32% loam and 42% sand) with an average bulk density of 1.37 g cm^{-3}. Before the experiment, the soil electrical conductivity (EC_e) was 2.1 dS m^{-1} and the sodium adsortium ratio (SAR_e) was 2.7.

A total of 192 trees were used in this study. They were spaced at 3.5 m between plants and 5 m between rows. The experimental design was a randomized complete design with four blocks and four experimental plots per block. The standard plot, which covered about 210 m^2 was made up of twelve trees, organized in three adjacent rows with four trees per row. The two central trees of the middle row were used for measurements and the other ten trees were guard trees.

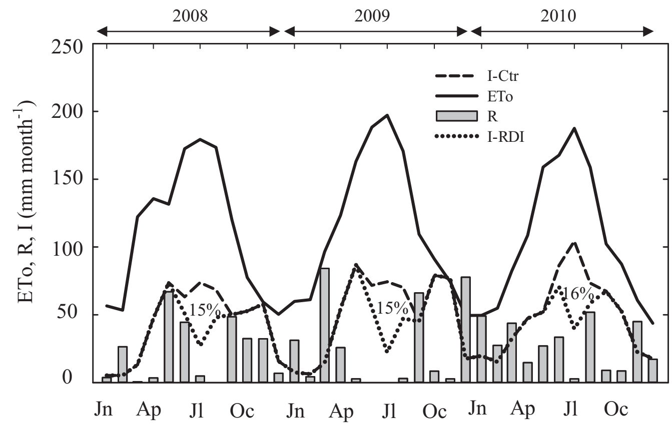

Fig. 1. Monthly values of reference evapotranspiration (ETo), rainfall (R), and irrigation (I) in the control (Ctr) and regulated deficit irrigation (RDI) treatments during 2008–2010. The percentage of water saved each season in the RDI treatment is also shown.

2.2. Irrigation system and management

The irrigation system consisted of a single drip line laid on the soil surface next to each tree row. It provided three self-pressure compensating on-line emitters per tree discharging 4 L h^{-1} each, placed at 0.85 m from the trunk and spaced 0.9 m apart. The irrigation doses were scheduled on the basis of the daily crop evapotranspiration (ETc) accumulated during the previous week. The daily ETc values were estimated by multiplying the daily ETo, calculated with the Penman–Monteith methodology (Allen et al., 1998), by the month-specific crop coefficients (Castel et al., 1987).

The monthly evolution of ETo during the study period 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.

The irrigation control head of the entire experimental area was equipped with pumps, a fertigation system, electrovalves, an automatic irrigation programmer and filters. The irrigation system was supplied with two water sources; one source (TW), with an average electrical conductivity (EC_w) of 1.4 dS m^{-1}, was pumped from the "Tagus-Segura" water transfer canal which supplies a large part of the water used in the Murcia Region for both human consumption and irrigation practices. The other source (RW) was tertiary reclaimed water (RW) pumped from a WWTP. This saline water was automatically blended at the irrigation control-head with water from the canal to reduce its EC_w to about 3.4 dS m^{-1} as an intermediate value between the threshold for significant mandarin yield losses (2 dS m^{-1}) and the average EC of 4 dS m^{-1} at the outlet of the WWTP.

Trees were irrigated daily from January 2008 until December 2010. The total amounts of water applied were measured with inline water flow meters, placed on the four replicates of each treatment. The three treatments received the same amounts of fertilizer (215–100–90 kg ha^{-1} year^{-1} of N–P_2O_5–K_2O), which were applied through the drip irrigation system. Pest control was that commonly used by growers, and no weeds were allowed to develop within the orchard.