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# Long-term physiological and agronomic responses of mandarin trees to irrigation with saline reclaimed water

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ABSTRACT

In this study, the physiological and agronomic responses of commercial '*Citrus Clementina* cv. Orogrande' mandarin trees to irrigation with saline reclaimed water (RW) (electrical conductivity ≈ 3.5 dS $m^{-1}$) were evaluated during six consecutive seasons (2008–2013) and compared with those observed in trees irrigated with fresh water from Tagus-Segura" water transfer canal (TW).

Irrigation with saline RW significantly increased soil salinity with remarkably substantial increases from the third season onwards, especially in summer measurements. Even though RW had high concentrations of Na, $Cl^-$ and B, only leaf B concentrations showed higher values than those of TW treatment, although none of them exceeded the maximum toxic threshold marked in leaves for citrus trees. Stomatal conductance, net photosynthesis and plant water status were not affected by the use of RW. However, irrigation with RW led to a reduction of the vegetative growth, which was greater from the third season. During the first three seasons, RW led to reductions of crop fruit load, which were often associated with an increase in fruit weight, hence maintaining yield and water productivity. However, since 2011, the reductions of crop fruit loads were more prominent and yield and water productivity were significantly reduced.

In short, medium to long-term irrigation with saline RW in semiarid conditions negatively affected the soil and trees performance, and hence, suitable management practices should be implemented to ensure the sustainability of soils and mandarin yields subjected to long-term use of these non-conventional water resources.



## 1. Introduction

The evaluation of non-conventional water resources such as reclaimed water (RW) in agriculture has gained importance during the last decades due to the expected scenario of (i) world population increase, (ii) reduction of fresh water availability and (iii) the need to ensure food security all over the world (Faurès et al., 2013).

RW has usually been viewed in a negative light as a product commonly requiring disposal which, depending upon its source and degree of treatment, may contain high concentrations of salt leading to undesirable effects on soils and plants (Ayers and Westcot, 1985). Viruses, other pathogens and heavy metals, if present in RW, may also pose a potential health threat to the user (Parsons et al., 1995). However, with appropriate management, RW has great potential to become a valuable irrigation water source and interest in its utilization is increasing (Pedrero et al., 2010) due to (i) environmental concerns, (ii) progressive implementation of the European Waste Water Directive (91/271/EEC) and (iii) the fact that it is free-of-charge when the "polluter pays" policy is implemented (Mounzer et al., 2013). In addition, RW not only might bring agronomic benefits for crops, as it contains high organic matter and many nutrients, which are essential for plant growth, but it might also 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 proved the agronomical advantages of reusing RW in citrus, but most of them have used RW having, either low electrical conductivity (EC) (Parsons et al., 2001; Pereira et al., 2011) that is below the harmful threshold level for citrus trees (Ayers and Westcot, 1985), or the effect of reusing saline RW was only evaluate in the short-term (experiments from several weeks up to about three seasons). For instance, Maurer and Davies (1993) found that three-year-old grapefruit trees, grafted on Swingle citrumelo rootstock and irrigated for three consecutive years with RW (EC = 1.80 dS $m^{-1}$), with or without fertilizer, had larger canopies, trunk diameters and fruit yield than trees irrigated with non-saline

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well water (EC = 0.35 dS $m^{-1}$). Pedrero et al. (2014) irrigated an adult mandarin orchard with saline RW (EC = 3.4 dS $m^{-1}$) for three consecutive years, reporting at the end of the experiment, only a slight reduction of the canopy volume and fruit yield in trees supplied with RW, which was counterbalanced by a significant increase in the fruit weight. Pedrero et al. (2015) irrigated a young grapefruit orchard with saline RW (EC = 3 dS $m^{-1}$) for three consecutive years and did not observe any significant reductions of vegetative growth or yield. Despite these positive agronomic results achieved by using RW in citrus in the short-term, horticulturists are concerned about long-term effects of irrigation with RW resources due to the possible accumulation of salts within the root zone (Melgar et al., 2009), which could cause decrease in the productivity of the soil, leading to negative effects on tree reserves, fruit bearing capacity, plant vigor and eventually on yield and water productivity. However, few studies have evaluated the long-term effects of using saline RW. For instance, Romero-Trigueros et al. (2014) assessed the physiological effects of five consecutive years of irrigation with saline RW on young grapefruit trees and reported that the use of RW increased the leaf concentration of sodium, chloride and boron and led to significant reductions in the leaf chlorophyll-a concentration.

In the present work, we studied the viability of using saline RW to irrigate adult '*Clementina* cv. Orogrande' mandarin trees, using the same trees tested by Pedrero et al. (2014) but after an additional three seasons (six seasons in total from 2008 to 2013). We provide special reference to the effects on tree water relations, leaf mineral concentrations, vegetative growth, gas exchange parameters, and fruit yield and quality and propose a robust threshold value of electrical conductivity of the saturated soil paste extract beyond which mandarin tree productivity could be reduced.

## 2. Materials and methods

### 2.1. Experimental plot and irrigation treatments

The experiment was performed during six consecutive seasons (2008–2013) in a commercial 0.5-ha orchard cultivated with 9-year old (in 2008) mandarin trees (*Citrus Clementina* cv. 'Orogrande') grafted on Carrizo citrange (*Citrus sinensis* [L.] Osb. × *Poncirus trifoliata* [L.]) rootstock. The orchard was located in Campotéjar-Murcia, Spain (38°07′18″ N; 1°13′15″ W), where the climate is Mediterranean semi-arid with warm, dry summers and mild winter conditions. The annual reference evapotranspiration ($ET_0$) and rainfall were, on average, 1326 and 300 mm, respectively.

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 $cm^{-3}$. It was classified as a Typic Haplocalcid according to Soil Survey Staff (2014). Before the experiment, the soil electrical conductivity ($EC_e$) was 2.1 dS $m^{-1}$ and the sodium adsorption ratio ($SAR_e$) was 2.7.

A total of 192 trees, spaced at 3.5 m between plants and 5 m between rows, were used in this study. 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 3 adjacent rows with 4 trees per row. In each plot, the two central trees of the middle row, here after called "inner trees", were used for measurements and the other ten trees were guard trees.

The irrigation system consisted of a single drip line laid on the soil surface next to each tree row. It provided three pressure-compensating, in-line emitters per tree, each discharging 4 L $h^{-1}$, which were placed 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) for 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 ($K_c$) (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. Annual ETo values registered during the study period and on average for the whole experiment are shown in Table 2. The meteorological data were collected from an automated weather station (Campbell Scientific Ltd., Shepshed, UK) situated on the experimental field. Leaching requirements were not applied in this experiment.

The irrigation control head of the entire experimental area was equipped with pumps, a fertigation system, electrovalves, an automatic irrigation programmer and filters. Two irrigation treatments based on the water quality of the irrigation source were performed. One source (TW), with an average electrical conductivity ($EC_w$) of 1.1 dS $m^{-1}$, was pumped from the "Tagus-Segura" water transfer canal, which supplies a large part of the water used in the Region of Murcia for both human consumption and irrigation practices. The other source (RW) was tertiary reclaimed water (RW) pumped from a nearby wastewater treatment plant (WWTP). This saline water was automatically blended at the irrigation control-head with water from the canal (on average 16%) to fits its $EC_w$ to about 3.5 dS $m^{-1}$, which is well above the threshold (2 dS $m^{-1}$) at which mandarin yield losses might be observed (Ayers and Westcot, 1985).

Trees were irrigated daily from January 2008 until December 2013. The total amounts of water applied were measured with inline water flow meters, with each of the four replicates of each treatment having a flow-meter. The irrigation was controlled automatically by a head-unit programmer and electro-hydraulic valves. All treatments received the same amounts of fertilizer ($N–P_2O_5–K_2O$), applied through the drip irrigation system (215–100–90 kg $ha^{-1}$ $year^{-1}$). Pest control practices and pruning were those commonly used by growers in the area, and no weeds were allowed to develop within the orchard.

### 2.2. Water quality characterization

Four water samples from each irrigation source were collected monthly from 2008 to 2013 in glass bottles, transported in an ice chest to the laboratory and stored at 5 °C before being processed for physical and chemical analyses.

An inductively coupled plasma mass spectrometer (ICP-ICAP 6500 DUO Thermo, England) was used to determine the concentration of Na, K, Ca and Mg. Anions ($Cl^-$, $NO_3^-$, $PO_4^{3-}$ and $SO_4^{2-}$) were analyzed by ion chromatography with a liquid chromatograph (Metrohm, Switzerland). $EC_w$ and total dissolved solids (TDS) were determined using a PC-2700 meter (Eutech Instruments, Singapore), pH was measured with a Crison 507 pH-meter (Crisom Instruments S.A., Barcelona, Spain) and turbidity was measured with a Dinko-D-110 (Dinko Instruments S.A., Barcelona, Spain) turbidity meter.

### 2.3. Soil characterization

Soil was sampled from the area surrounding one central tree in each replicate and treatment. Four soil samples from each replicate of irrigation treatment were collected, twice a year, once in summer (late August or early September) and once in winter (December to January), at a depth of 0.2 m and 0.3 m away from the emitter. Soluble salt contents were determined in the saturated paste extract as described by Rhoades (1982). The electrical conductivity of the saturated paste extract ($EC_e$) was measured with a conductivity meter PC-2700 (Eutech Instruments, Singapore). Ca and Mg were measured using the EDTA titration method, and Na was measured using a flame photometer (Richards, 1954). The sodium adsorption