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Transient soil salinity under the combined effect of reclaimed water and regulated deficit drip irrigation of Mandarin trees

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ABSTRACT

Regulated deficit irrigation (RDI) strategy using saline reclaimed water is becoming a frequent practice under semiarid Mediterranean climatic conditions in the southeastern region of Spain. There is a concern that the long-term use of this strategy will affect the production sustainability of the agricultural soils. This paper evaluates the field consequences of this strategy on the accumulation of salts within the plant root zone. Full and regulated deficit surface drip deficit irrigation was combined with fresh water (EC 1 dS m^{-1}) and saline (EC 3 dS m^{-1}) tertiary reclaimed water to irrigate adult mandarin trees over a 3-year period. The control treatment received 100% of the crop evapotranspiration "ETc" and the RDI treatment received 50% of ETc during the 2nd stage of fruit growth. Soil water content was monitored every other week within the soil wetted volume under the emitter. Gravimetric soil samples were collected from 3 depths and at 3 distances to the emitter, twice a year: at the end of irrigation season and at the conclusion of RDI period. Soluble salts, electrical conductivity and sodium adsorption ratio were determined in the saturated paste extract. The results show how the RDI strategy intensifies the development of salinity gradient away from the emitter even when using good quality water. The combination of RDI with saline reclaimed water produced transient saline-sodic conditions at the outer superficial limits of the wetted bulb under the emitter. The appearance of such adverse conditions is alarming and would threaten the sustainability of agricultural soils. Therefore soil water deficit should be avoided whenever saline reclaimed water is in use for irrigation.

1. Introduction

In dry areas, water scarcity and increasing competition for water resources are pressurizing farmers to adopt different water saving techniques and strategies which may range from a simple periodic estimation of the soil water balance terms to a precise assessment of temporal and spatial distribution of water exchange within the soil–plant–atmosphere continuum. Thus, regulated deficit-irrigation strategies (RDI) are being accepted as valuable and sustainable production solutions (Geerts and Raes, 2009; Ruiz-Sánchez et al., 2010) that save water without having significant negative impacts on final yield. In addition, the use of reclaimed water for irrigation is progressively augmenting (Mantell et al., 1985; Del Amor García, 2000; Levine and Asano, 2004; Pedrero et al., 2010) because the volume of treated wastewater is in continuous increase due to environmental concerns and the progressive implementation of the European Waste Water Directive (91/271/EEC) and, it is free-of-charge where the "polluter pays" policy is implemented.

Raine et al. (2007) estimated that up to 10% of the irrigated lands in Australia could be adversely affected by the adoption of precision irrigation. Inappropriate scheduling of water and fertilizers application has led to salinity buildup under long term use of drip irrigation (Darwish et al., 2005) and the prolonged use of wastewater for irrigation increased the compaction of the receiving soil and reduced its capacity of holding nutrients (Wang et al., 2003). Wallach et al. (2005) reported the development of soil water repellency under irrigation with secondary treated sewage effluent in field soils. Soil water repellency affected the distribution uniformity of moisture content in the soil profile following irrigation events in the summer, and rainfall events in the winter. Oster (1994) reported that the use of poor quality water requires some changes from standard irrigation practices, such as selection of appropriately salt tolerant crops, improvements in water management and, in some cases, the adoption of advanced irrigation technology.

The region of Murcia, located in the south-east of Spain, represents a typical semi-arid Mediterranean area. It falls within the Segura-River basin that is characterized with a structural deficit between available water resources and agricultural and urban

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demands. The annual deficit rises up to 606 Mm^3 when considering local resources, and 258 Mm^3, when considering the transbasin diversions (Tagus-Segura) (Ibor et al., 2011). Therefore, Murcian farmers seldom get to satisfy 100% of their crop water requirements and thus, they are in continuous need either to handle the deficit or to look for using non-conventional water resources (desalinated or reclaimed water) for irrigation. Furthermore, frequent water-shortage periods are even forcing farmers to combine both, deficit strategies and irrigation with reclaimed water. In Murcia-Spain there are at least 96 operating water treatment plants "WTPs" delivering more than 102.1 hm^3 per year (ESAMUR, 2009), which restore up to 6% of the annual renewable water resources (PHCS, 1997). Nonetheless, almost all types of these effluents remain moderate to highly saline and consequently their use in irrigation for long term may significantly affect the physical and chemical properties of soils especially under modern and intensive agricultural system in arid and semi-arid areas (Ayars et al., 1993; Hillel, 2000; Pérez-Sirvent et al., 2003; Angin et al., 2005). Consequently, the combination of water saving strategies (precision and deficit irrigation) with the use of saline reclaimed water may cancel the advantages of both choices and produce an accumulated negative impact on the production potentiality of fruit trees, on the availability of water in the soil and on the growth pattern of the plant rooting system.

Under water shortage conditions or the presence of soluble salts in the soil solution, the availability of the soil–water tends to be reduced as the total hydraulic head decreases. Consequently the plant-root water uptake may decrease below its potential rate. The response of a crop to pressure head appears to be different from the response to osmotic head (Shalhevet and Hsiao, 1986) and the combined effect of both matric and osmotic heads seems to be a complex phenomenon (De Jong van de Lier et al., 2009). The latter is difficult to characterize and requires long term investments and therefore it is still not well documented, especially for fruit trees. Moreover, water uptake by plant-roots tends to increase salt concentration in the soil solution especially under saline conditions. The application of regulated deficit irrigation (RDI) during periods of high evapotranspirative demands would induce an additional undesired osmotic water potential. This can lead to roots being exposed to higher toxicity hazards and to very different soil osmotic and matric water potentials from the bulk of the soil during the water depletion period.

This study aimed at assessing the distribution and buildup of salinity within the root zone of adult mandarin trees irrigated by surface drip irrigation using saline tertiary-treated wastewater and subjected to RDI strategy during the 2nd stage of fruit growth for being identified less susceptible to water deficit.

2. Materials and methods

2.1. Experimental site and plant material

The experiment was conducted over a 3-year period (2008–2010), at a commercial orchard located in Campotejar-Murcia, Spain (38°07′18″N; 1°13′15″W). The annual reference evapotranspiration "ETo" and rainfall is on average 1320 and 300 mm respectively. The minimum and maximum temperature is registered in January and August respectively. The experimental plot of 0.5 ha was cultivated with 8-year old (in 2007) mature mandarin trees (*Citrus clementina* cv. 'Orogrande') grafted on Carrizo citrange (*Citrus sinensis* [L.] Osb. × *Poncirus trifoliata* [L.]). The soil had a loamy texture (26% clay, 32% loam and 42% sand) with an average bulk density of 1.37 g cm^{-3}. The trees were spaced at 3.5 m between plants and 5 m between rows.

2.2. Irrigation system and management

The irrigation system consisted of a single lateral drip line laid on the soil surface next to the tree trunk. It provided 3 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 daily evapotranspiration of the crop "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 a month-specific crop factor as shown in Table 1 (Castel et al., 1987). 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, filters, fertigation system, electrovalves and an automatic irrigation programmer (NTC-Mithra Nutricontrol). Furthermore, it was supplied with two water sources; the first source was pumped from the "Tagus-Segura" water transfer canal "TW" and had an average electrical conductivity near unity (EC ≈ 1 dS m^{-1}). The second source was tertiary reclaimed water "RW" pumped from the wastewater treatment plant "WWTP" of the North of "Molina de Segura". This saline source was automatically blended at the irrigation control-head with water from "TW" to reduce its EC value down to ≈3 dS m^{-1} as an intermediate value between the threshold for significant yield losses (2 dS m^{-1}) and the average EC of 4 dS m^{-1} at the outlet of the WWTP.

2.3. Irrigation treatments

Two irrigation treatments were differentiated for each water source. The first was a control treatment "Ctr" irrigated throughout the growing season to recover 100% of the soil–water lost by daily ETc. The second was a regulated deficit irrigation treatment (RDI) irrigated similarly to the "Ctr" treatment, except during the second stage of fruit growth when it received 50% of the water amount applied to the control. This growth stage was identified for being unsusceptible to moderate water stress (González-Altozano and Castel, 1999). In our case, this stage extended over a time period of 55–65 days between late June and early September. No leaching fraction was added to the irrigation doses since most farmers in the region of Murcia could not satisfy the average annual citrus water requirements of 600–750 mm (García-Tejero et al., 2010; Pedrero, 2011).

The total amounts of water applied were measured with inline water flow-meters, placed on the four replicates of each treatment. All treatments received the same amounts of fertilizer (215–100–90 of N–P_2O_5–K_2O kg ha^{-1} $year^{-1}$) 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.

2.4. Statistical design and analysis

The experimental design of each treatment was 4 standard experimental plots of 210 m^2 each and distributed following a completely randomized design (Fig. 1). The standard plot was made up of 12 trees, organized in 3 adjacent rows. The two central trees of the middle row were used for measurements and the other 10 trees were guard trees. Statistical analysis was performed by weighted analysis of variance (ANOVA) using linear model for SPSS software (version 17.0, SPSS Inc., Chicago).