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AGWAT-4253; No. of Pages 12
ARTICLE IN PRESS
Agricultural Water Management xxx (2015) xxx–xxx
Contents lists available at ScienceDirect
Agricultural Water Management
journal homepage: www.elsevier.com/locate/agwat

Comparison of deficit and saline irrigation strategies to confront water restriction in lemon trees grown in semi-arid regions

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ARTICLE INFO

Article history:
Received 9 January 2015
Received in revised form 7 July 2015
Accepted 18 August 2015
Available online xxx

Keywords:
Leaf water relations
Leaf gas exchange
Regulated saline irrigation
Regulated deficit irrigation
Plant nutrition
Fruit yield
Fruit quality
Citrus fruits

ABSTRACT

The physiological and agronomic responses to two irrigation strategies - regulated saline irrigation (RSI) and regulated deficit irrigation (RDI), intended to confront water restriction - were compared in 15-year-old ‘Fino 49’ lemon trees (*Citrus limon* (L.) Burm. fil.) grafted on *Citrus macrophylla* Wester. Three independent treatments were applied: Control (100% ETc, non-saline water); RDI (25% ETc, non-saline water) and RSI (145% ETc, saline water—40 mM NaCl). The RDI and RSI treatments were maintained along the crop season except during the high evapotranspiration (ET_0) period (corresponding to phase II of fruit growth—cell elongation), when the irrigation dose applied was 100% ETc, with non-saline water. The application of these irrigation strategies produced fresh water savings of 31.5% and 39% for the RDI and RSI treatments, respectively. The use of saline water during the stress periods in RSI trees did not affect the plant water status but decreased leaf photosynthesis, due to high leaf Cl^- accumulation, and altered the leaf mineral nutrition; whereas, in RDI trees, the soil water deficit affected negatively the plant water status and, in consequence, the gas exchange parameters. In RSI trees, the cumulative salt stress decreased yield much more than vegetative growth, while in RDI trees the yield and vegetative growth reductions were related to the irrigation water savings. The total production was affected similarly by both treatments, but the yield reduction was greater in RSI than in RDI trees in the second year. Fruit quality was not affected significantly by RSI but the effects of RDI delayed fruit maturation, based on the smaller fruit diameter, lower juice content and higher titratable acidity and total soluble solids relative to the fruits of control trees. Therefore, based on these results, RDI would be the best irrigation strategy for a long water restriction period, while RSI could be successful for a period of not more than one year.
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1. Introduction

Among the lemon fruit-producing countries, Spain is the second-highest producer and one of the largest exporters of lemons. Approximately 80% of the Spanish lemon production occurs in its arid southeast region, where cultivar ‘Fino 49’ is economically the most important. Lemon trees are mainly grown in the Mediterranean regions, with a semi-arid climate—characterised by low rainfall and high evapotranspiration—that can produce long periods of restricted water supply, especially in summer. The scarcity of water resources forces lemon growers to optimise their water use by applying deficit irrigation (DI) strategies or by using alternative water sources, such as ground water of high salinity.

An alternative way to confront periods of water shortage is to use regulated deficit irrigation (RDI) strategies, based on the restriction of the water supply during the fruit growth periods of low sensitivity to water shortage while covering the full water requirements during the rest of the season (Lampinen et al., 1995). In semi-arid regions, RDI has been investigated widely as a valuable and sustainable production strategy. In this context, several contributions have documented the advantages of RDI strategies with regard to improving the efficiency of water use and fruit quality in different citrus species like mandarin (Panigrahi et al., 2014; Ballester et al., 2014; Romero et al., 2006), sweet orange (Pérez-Pérez et al., 2008a; García-Tejero et al., 2010), lemon (Domingo et al., 1996) and grapefruit (Pérez-Pérez et al., 2014). In all these experiments, the response of the citrus trees to DI depended mainly on the phenological stage when it was applied. So, the main effect of water stress applied during flowering and the initial stage of fruit growth (Phase I) was a reduction in the final fruit load; water stress

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http://dx.doi.org/10.1016/j.agwat.2015.08.015
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Please cite this article in press as: Pérez-Pérez, J.G., et al., Comparison of deficit and saline irrigation strategies to confront water restriction in lemon trees grown in semi-arid regions. Agric. Water Manage. (2015), http://dx.doi.org/10.1016/j.agwat.2015.08.015

applied during rapid fruit growth (Phase II) negatively affected fruit size and fruit quality; and water stress during maturation (Phase III) had a major effect on the organoleptic characteristics of the fruit, because it increased the total soluble solids content (TSS) and acidity, but without a negative effect on yield. Although the effects of RDI in citrus depend on other factors, such as the timing and severity of the water deficits, rootstock (Pérez-Pérez et al., 2008b; Treeby et al., 2007) and species (Ballester et al., 2013), most studies of RDI have concluded that water restriction in phases I and III of fruit growth has a less negative effect on fruit production than limited irrigation in phase II (Pérez-Pérez et al., 2014; Ginestar and Castel, 1996).

In long periods of water scarcity, a common practice in citrus orchards is the use of water from aquifers. However, this type of water is often of low quality due to excessive concentrations of soluble salts (Cl^- and/or Na^+) and an electrical conductivity (EC) greater than 3 dS m^{-1}, the value considered critical for citrus production (García-Sánchez et al., 2002a). The continued use of saline water reduced the fruit yield of ‘Clemenules’ mandarin grafted on ‘Carrizo’ rootstock, by reducing both the fruit number and fresh fruit weight, while the TSS and titratable acidity (TA) of the fruit juice were increased by the increased salinity (Navarro et al., 2010). Prior et al. (2007) reported that irrigation water with an EC of 2.5 dS m^{-1} caused a 17% reduction in fruit yield during a 9-year period, for ‘Valencia’ orange trees grafted on sweet orange (*Citrus sinensis*) rootstock. This yield reduction was associated with a decrease in the average fruit size. The negative effect of salinity on citrus tree growth and production is related mainly to a gradual accumulation of Cl^- and Na^+ to toxic levels in leaves rather than the osmotic changes in the root medium (Syvertsen and García-Sánchez, 2014). In this scenario, irrigation with saline water has to be managed in a way different from when non-saline water is employed. García-Sánchez et al. (2003) reported, for ‘Fino 49’ lemon trees watered with saline water having an EC of 2.5 or 4.0 dS m^{-1}, that increasing the water application from 100 to 125% ETc increased fruit yield, by decreasing the leaf and soil Cl^- concentrations. However, at the end of an experimental period of three years, trees from both irrigation treatments had a leaf Cl^- concentration of around 1% (dry weight basis), indicating that over a longer period this technique may not be suitable.

On the other hand, Pérez-Pérez et al. (2009) reported that ‘Fino 49’ lemon trees irrigated with saline water in the short-term (from March to early July; the bloom, flowering and phase I of fruit growth stages) underwent fewer physiological alterations than trees under drought in the same time period. This suggests that the use of saline water only in short periods of the season could be a good agronomic practice which saves water of good quality while avoiding the effects of drought on the trees. This technique, which has not been assayed yet, could be termed “regulated saline irrigation (RSI)” – with the use of good- and bad-quality water being combined, depending on the period of the season. Saline water could be applied post-harvest and during flowering, fruit set and phases I and III of fruit growth, since these phenological stages may be less sensitive to the osmotic stress caused by the salinisation of the root zone. Irrigation with saline water in these periods could decrease by more than 50% the use of fresh water, which could be applied in phase II of fruit growth. In this phase the leaf transpiration reaches its highest values of the season, due to the high vapour pressure deficit (high temperature and low humidity), which will increase strongly the leaf Cl^- concentration. In citrus, Cl^- accumulation in the leaves depends on the transpiration stream (Syvertsen et al., 2010). In addition, the fresh water applied after a period of salinisation would leach away the salts accumulated within the soil root zone. Therefore, the aim of this work was to study the physiological and agronomic effects on lemon trees of two irrigation strategies, RDI and RSI, relative to adequate watering with non-saline water, and to determine the soil water status and salinity distribution in the root zone during the whole season. This study was carried out in ‘Fino 49’ lemon trees under field conditions, during two seasons.

2. Material and methods

2.1. Plant material and experimental conditions

The study was carried out in 2008 and 2009 at the experimental station of the IMIDA in Torre Pacheco, Murcia (south-eastern Spain). The soil is an aridisol, with 27.9% clay, 33.5% loam and 38.6% sand, an organic matter content of 0.71% (dry soil), an EC for a 1:5 soil water extract ($EC_{1\text{-}5}$) of 0.30 dS m^{-1}, 17.5% active $CaCO_3$ and a pH of 7.6. The climate is Mediterranean semi-arid, with a mean daily solar radiation above 200 W m^{-2} (> 9 solar hours), a mean annual air temperature of around 17 °C, scarce annual rainfall (283 mm) and a total annual reference evapotranspiration (ET_0), calculated via the Penman–Monteith method, of 1238 mm. The climatic parameters were obtained daily from a weather station located in the experimental orchard.

The experiment was performed in a 1-ha orchard, on 15-year-old ‘Fino 49’ lemon trees (*Citrus limon* (L.) Burm. fil.) grafted on *Citrus macrophylla* Wester rootstock, with a tree-spacing of 8 m × 3 m. The trees used in this experiment had been well irrigated during the previous three years at least. The lay-out of the experiment took the following form: three rows, oriented in a south–east–north–west direction, which were subdivided into three plots. In every plot there was one row per treatment with three trees. One tree per row and treatment was excluded from the study to eliminate potential edge effects. The irrigation was applied through two drip-lines (UniRam™, Netafim, Tel Aviv, Israel) per tree row, 1 m away from each side of the trunk, with six self-compensated, anti-siphon and anti-drainant drippers (3.5 L h^{-1}) per tree, 1 m apart. The amount of irrigation water for well-watered trees was determined by estimating weekly the crop evapotranspiration (ETc), using the following equation: $ETc = ET_0 \times Kc \times Kr$, where ETc is in mm, Kc is the crop coefficient and Kr is the coefficient factor as a function of the shaded area for the crop (Fereres et al., 1981). The Kc values applied during the experimental period were obtained from the “Servicio de Información Agraria de Murcia (SIAM-IMIDA)” for early-harvested ‘Fino’ lemon trees grafted on *C. macrophylla*. The annual amount of fertiliser applied in all irrigation treatments was 300 kg N, 100 kg P_2O_5, 180 kg K_2O and 5 kg MgO per ha and 80 g Fe chelate per tree, supplied through the irrigation system. The irrigation was controlled automatically by a head-unit program (mod. Xilema NX300, Novedades Agrícolas, Torre Pacheco, Spain) and electro-hydraulic valves (mod. uPVC, Regaber, Parets del Vallès, Spain). The frequency of irrigation differed along the season: from two days per week in winter to daily in summer. The amounts of water applied for each irrigation treatment were measured with flowmeters. The pest control practices and pruning were those commonly used by growers in the area.

2.2. Irrigation treatments

There were three irrigation treatments: control, well-irrigated (100% ETc with non-saline water – 0 mM NaCl); RDI, regulated deficit irrigation (25% ETc with 0 mM NaCl) and RSI, regulated saline irrigation (145% ETc with saline water – 40 mM NaCl). The ETc was increased in the RSI treatment to avoid salt accumulation in the root zone. Treatments RDI and RSI were maintained along the crop season except during the high-evapotranspiration period (corresponding to phase II of fruit growth – cell elongation), when the irrigation dose was 100% ETc, with non-saline water, in both treatments. Salt was injected into the irrigation system from a stock

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