Agricultural Water Management 133 (2014) 44–54

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Effects of deficit irrigation in different fruit growth stages on 'Star Ruby' grapefruit trees in semi-arid conditions

J.G. Pérez-Pérez*, J.M. Robles, P. Botía

Department of Citriculture, Instituto Murciano de Investigación y Desarrollo Agrario y Alimentario (IMIDA), c/ Mayor s/n, 30150 La Alberca (Murcia), Spain

ARTICLE INFO

Article history:
Received 11 April 2013
Accepted 1 November 2013
Available online 30 November 2013

Keywords:
Grapefruit
Deficit irrigation
Water relations
Fruit quality
Yield
Water use efficiency

ABSTRACT

Grapefruit (*Citrus paradisi* Macf.) has increased in importance as a crop species in the south-east of Spain in recent years. In spite of the fact that grapefruit is well adapted to semi-arid conditions, the irrigation necessities for fresh fruit production continue to be very high. The scarcity of water resources forces citrus growers to optimise their water use by using deficit irrigation (DI) strategies. The aim of this work was to evaluate the sensitivity to DI applied during different fruit growth stages of 14-year-old 'Star Ruby' grapefruit grafted on 'Cleopatra' mandarin (*Citrus reshni* Hort.), regarding water relations, trunk growth, yield and fruit quality. The experiment was carried out over two years in an experimental orchard located in Torre Pacheco (Murcia, south-eastern Spain). There were four irrigation treatments; Control (100% crop evapotranspiration – ETc) and three DI treatments (50% ETc) applied only during different fruit growth stages; $DI_{Ph\text{-}I}$ (Phase I – cell division), $DI_{Ph\text{-}II}$ (Phase II – cell elongation) and $DI_{Ph\text{-}III}$ (Phase III – final fruit-growth period, ripening and harvest). The midday stem water potential (Ψ_{md}) values of $DI_{Ph\text{-}I}$ and $DI_{Ph\text{-}III}$ were influenced by the rainfall regime in both years, whereas the Ψ_{md} of $DI_{Ph\text{-}II}$ was decreased and remained lower throughout the study period. Annual trunk growth was reduced only by the $DI_{Ph\text{-}I}$ treatment; although the $DI_{Ph\text{-}II}$ treatment decreased trunk growth during phase II it was relieved after the recovery period (during phase III). The main effects of both the $DI_{Ph\text{-}I}$ and $DI_{Ph\text{-}III}$ treatments were related with changes in fruit quality parameters; $DI_{Ph\text{-}I}$ reduced the percentage of juice and $DI_{Ph\text{-}III}$ affected negatively the peel colour when the water stress was moderate. However, the effects of $DI_{Ph\text{-}II}$ were more drastic, decreasing yield due to smaller fruits, altering fruit composition, increasing the titratable acidity much more than the total soluble solids and affecting peel colour, therefore delaying fruit maturation.

1. Introduction

Grapefruit (*Citrus paradisi* Macf.) is the third-most-important citrus crop in the world. Although in Spain it is not very widespread, the area dedicated to grapefruit for fresh consumption has increased considerably in recent decades. Since its price has remained competitive year after year, it is considered a profitable alternative to other, more-widely cultivated citrus crops, such as sweet orange (*Citrus sinensis* (L.) Osbeck), mandarin (*Citrus reticulata* Blanco) or lemon (*Citrus limon* (L.) Burm. f). The main area of grapefruit production in Spain is located in the south-east, where the predominant conditions are those typical of semi-arid regions, characterised by rain scarcity and high evaporative demand. Even though grapefruit is well adapted to dry, warm, semi-tropical humid and tropical climatic conditions (Reuther, 1973), the amount of irrigation necessary for fresh fruit production is very high, forcing citrus growers to find ways to maximise water savings and improve final fruit yield and quality. One way to optimise water resources is to use regulated deficit irrigation (RDI) strategies, based on the imposition of water restrictions during the fruit growth periods of low water-stress sensitivity while covering the full water requirements during the rest of the season (Lampinen et al., 1995). RDI has been investigated widely as a valuable and sustainable production strategy in semi-arid regions (Ruiz-Sánchez et al., 2010). 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 (Romero et al., 2006; González-Altozano and Castel, 1999), sweet orange (Pérez-Pérez et al., 2008a; García-Tejero et al., 2010) and lemon (Domingo et al., 1996).

The response of citrus trees to deficit irrigation (DI) depends mainly on the phenological stage when it is applied (Ginestar and Castel, 1996). The main effects of water stress applied during flowering and the initial stage of fruit growth on mandarin (Romero et al., 2006) and sweet orange (Pérez-Pérez et al., 2008a; García-Tejero et al., 2010) resulted in a reduction in the final fruit load. Water stress applied during the stage of rapid fruit growth drastically affected fruit size and fruit quality in mandarin (Navarro et al.,

* Corresponding author. Tel.: +34 968 357876; fax: +34 968 366792.
E-mail addresses: juang.perez@carm.es, jupepe53@gmail.com (J.G. Pérez-Pérez).

0378-3774/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agwat.2013.11.002

2010) and in sweet orange (García-Tejero et al., 2010). Finally, water stress during maturation had a major effect on the organoleptic characteristics of the fruit in sweet orange, increasing total soluble solids and acidity with no negative effect on yield (Pérez-Pérez et al., 2009). However, the citrus response to RDI depends not only on the phenological stage, but also on the timing and severity of the water deficits, and significant differences have been found among rootstocks (Pérez-Pérez et al., 2008b; Treeby et al., 2007) and species (Ballester et al., 2013). In this sense, two recent studies showed differing responses of mandarin and sweet orange to the same RDI strategy (Ballester et al., 2011, 2013), indicating that these irrigation strategies cannot be extrapolated and need to be designed specifically for each species.

The RDI studies conducted to date have been carried out mainly in sweet orange and mandarin, but little information has been published on the response of grapefruit to water stress in semi-arid conditions. In order to optimise RDI strategies for grapefruit in semi-arid environments, a good knowledge of the effects of DI applied in the different phenological stages of fruit growth is necessary. Thus, the aim of this work was to evaluate the sensitivity to DI of different fruit growth stages in adult 'Star Ruby' grapefruit trees grafted on 'Cleopatra' mandarin (*Citrus reshni* Hort.), with particular reference to the effects on soil-plant water relations, vegetative growth, yield, resource distribution (yield/vegetative growth ratio) and fruit quality. Establishing the fruit growth stages most sensitive to soil water deficit will permit new RDI strategies to be designed for grapefruit.

2. Materials and methods

2.1. Orchard characteristics

The study was carried out in 2007 and 2008 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 electrical conductivity of a 1:5 soil water extract (EC_{1-5}) 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 17.3 MJ m^{-2} day^{-1} (>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 in the experimental orchard.

The experiment was performed in a 1-ha orchard, on 14-year-old 'Star Ruby' grapefruit trees grafted on Cleopatra mandarin (*C. reshni* Hort. Ex Tanaka) rootstock, with a tree-spacing of 4 m × 3 m. The trees used in this experiment had been well irrigated for at least the previous three years. The lay-out of the experiment took the form of three completely randomised plots, with four treatments per plot and three trees per treatment within each plot. In each row, border trees were excluded from the study to eliminate potential edge effects. One drip-line was used in each tree row with three self-compensating drippers (4 L h^{-1}) per tree, 0.75 m apart. The mean annual amount of fertiliser applied in the experimental orchard was 787 kg ha^{-1} NH_4NO_3, 185 kg ha^{-1} $(NH_4)_3PO_4$, 390 kg ha^{-1} KNO_3, 177 kg ha^{-1} Nitro-Magnesium and 36 g per tree Fe chelate, supplied through the irrigation system. The pest control practices and pruning were those commonly used by growers in the area. The irrigation was controlled automatically by a head-unit programmer and electro-hydraulic valves. The frequency of irrigation differed along the season: from two days per week in winter to daily in summer.

2.2. Irrigation treatments

There were four irrigation treatments: a control and three DI treatments, which were applied over two consecutive years. The control treatment involved irrigation during the whole season at 100% ETc. The three DI treatments consisted of irrigation at 100% ETc, except during the following phenological stages of fruit growth: (i) cell division, from just after bloom and fruit set to the end of the physiological fruit drop in June (Phase I), (ii) cell elongation, period of rapid fruit growth (Phase II), and (iii) final fruit growth period, ripening and harvest (Phase III). In these stages, irrigation was applied at 50% ETc, the irrigation time being half that of fully irrigated trees (Fig. 1). The crop coefficients (K_c) applied during the experimental period were 1 in January and February and 0.70 from March to December, in accordance with Amorós (1993) for early-harvested citrus trees in the Mediterranean area.

2.3. Measurements

The volumetric soil water content (θ_v) was measured periodically throughout the experiment, using a neutron probe (model 3332; Troxler Electronics Inc., NC, USA) previously calibrated at the experimental site. Six access tubes per treatment were installed to a depth of 100 cm and readings were taken close to the trees, 10 cm from the drip head and oriented perpendicularly to the drip-lines, at depths of 20-cm intervals to a maximum depth of 80 cm.

The midday stem water potential (Ψ_{md}) was measured fortnightly in one mature, fully expanded leaf from the outer canopy, in the middle third of the tree, in six trees per treatment. The leaves were enclosed within foil-covered plastic and aluminium envelopes at least 2 h before the midday measurement (McCutchan and Shackel, 1992). The Ψ_{md} was measured at noon (12:00–14:00) with a pressure chamber (model 3000; Soil Moisture Equipment. Corp., Santa Barbara, CA, USA), following the recommendations of Turner (1988). The water-stress integral (S_Ψ, MPa·day) was calculated using the Ψ_{md} data, according to the equation defined by Myers (1988):

$$S_\psi = \left| \sum_{i=0}^{i=i} (\bar{\Psi}_{i,i+1} - c)n \right| \quad (1)$$

where $\Psi_{i,i+1}$ is the average Ψ_{md} for any interval $i,i+1$ (MPa), c is the maximum Ψ_{md} measured during the study for any treatment and n is the number of days in the interval.

The trunk perimeter measurements were taken at the beginning and end of each fruit growth stage. Six replicates of each measurement of trunk circumference were taken per tree, in the scion. The relative growth rate of the trunk perimeter (RGR_{Trunk}, cm cm^{-1} day^{-1}) was calculated according to the equation:

$$RGR_{Trunk} = \frac{\ln M_2 - \ln M_1}{t_2 - t_1} \quad (2)$$

where M is the trunk perimeter at t_1 and t_2 (cm) and t is the time between measurements (days). The trunk transverse cross-sectional area (TCSA, cm^2) was calculated as:

$$TCSA = \frac{\pi \times D^2}{4} \quad (3)$$

where TCSA is in cm^2 and D is the trunk diameter (cm). The absolute growth rate of the TCSA (AGR_{TCSA}) was calculated according to the equation:

$$AGR_{TCSA} = \frac{M_2 - M_1}{t_2 - t_1} \quad (4)$$

where M is the value of the TCSA measured at t_1 and t_2 and t is the time between measurements (years).