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Influence of deficit irrigation in phase III of fruit growth on fruit quality in 'lane late' sweet orange

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ABSTRACT

The aim of this work was to apply one strategy of deficit irrigation (DI) to improve the final fruit quality in 10-year-old 'Lane late' sweet orange grafted on Carrizo citrange (*Citrus sinensis* L. Osb. × *Poncirus trifoliata* L.). The experiment was carried out over 2 years in an experimental orchard located in Torre Pacheco (Murcia, south-east Spain). The deficit irrigation treatment consisted of the stopping of irrigation in phase III of fruit growth (1st October–28th February). The irrigation cut-off in phase III reduced the midday stem water potential (Ψ_{md}), the plant water status being heavily influenced by rainfall. In both years, the DI treatment did not alter fruit yield although mean fruit weight was slightly reduced. The main effects of DI on the final fruit quality were increases of total soluble solids (TSS) and titratable acidity (TA) and a decrease of juice percentage without altering the final maturity index. Plant water-stress integral (S_{Ψ}) was correlated positively with TSS and TA and negatively with juice percentage. In conclusion, a DI strategy could be useful for improving the final content of TSS and the TA, therefore allowing the harvest to be delayed.

1. Introduction

Sweet orange is, economically, one of the most important crops in south-eastern Spain, the major part of the production being destined to fresh consumption. The needs of the international market mean that it is necessary to delay the harvesting of some later varieties of mandarin and sweet orange. Currently, the most important varieties of sweet orange are the Navel group and 'Valencia late'. The region of Murcia has a semi-arid climate, characterised by rain scarcity, high evaporative demand and mild winters (an average of 11 °C in December and January). In this region, the crops of later varieties of sweet orange, like 'Valencia late', 'Navelate' and 'Lane late', are affected negatively by the semi-arid climate because these conditions advance the harvest. It is well known that the climate has an important influence on almost all aspects of citrus growth. In the main citrus regions, the ratio of total soluble solids (TSS) to titratable acidity (TA) determines when the fruit is ready to be harvested. However, the TA of the citrus juice is an important component of the fruit quality and it is vital in determining the time of the harvest (Harding et al., 1940). High temperatures in spring and adequate soil water conditions initiate fruit activity and respiration, reducing significantly the TA in later varieties like 'Valencia late' (Davies and Albrigo, 1994). Fruits with very high sugar content and low acidity at the end of the season may be insipid (Jackson, 1991). This necessitates that the farmers advance the harvest.

There are a lot of studies showing that water stress increases TSS and TA in citrus (Bielorai, 1982; Kuriyama et al., 1981). However, severe water stress can produce a higher increase of TA than of TSS, reducing the fruit quality (Maotani and Machida, 1977; Romero et al., 2006). Thus, one option proposed is the use of regulated deficit irrigation (RDI) (Behboudian and Mills, 1997). Although RDI was designed initially as a tool to improve yield and control vegetative growth (Chalmers et al., 1981), it can be applied to obtain other benefits. Some studies in 'Clemenules' mandarin found that water stress during phase III of fruit growth (the final fruit growth and maturity process) increased TSS and TA (Ginestar and Castel, 1996) without affecting the TSS:TA ratio (González-Altozano and Castel, 1999). However, when water-deficit stress was applied later in fruit development (January–March), there was no increase in TSS or TA (Barry et al., 2004).

We hypothesised that moderate water stress applied during the maturity process period can improve final fruit quality and delay slightly the harvest. The purpose of this study was to determine the effects of a strategy of deficit irrigation (DI) applied during phase III of fruit growth on the water relations, yield and fruit quality in sweet orange 'Lane late' growing under semi-arid conditions.

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2. Material and methods

2.1. Plant material, experimental conditions and irrigation treatments

The study was carried out from 2002 to 2004 at the experimental station of the IMIDA in Torre Pacheco, Murcia (southern Spain, 37°45′ N, 0°58′ W, 30 m a.s.l.). The soil is an aridisol, with 27.9% clay, 33.5% loam and 38.6% sand. The soil had an organic matter content of 0.71% (dry soil), an EC_{1-5} (electric conductivity) of 0.30 dS m^{-1}, 17.50% active $CaCO_3$ and a pH of 7.6. The climate is Mediterranean semi-arid, with a high mean daily solar radiation (higher than 17 MJ m^{-2} day^{-1}), daily solar hours greater than 9, a mean annual air temperature of around 17 °C, low annual rainfall at the experimental site (303 and 300 mm for the 2002–2003 and 2003–2004 seasons, respectively) and a total annual reference evapotranspiration (ET_0), calculated via the Penman–Monteith method (Allen et al., 1998), of 1310 and 1250 mm for the 2002–2003 and 2003–2004 seasons, respectively.

The experiment was performed in a 1-ha orchard, on 10-year-old 'Lane late' sweet orange trees (*Citrus sinensis* (L.) Osb.) grafted on 'Carrizo' citrange (*C. sinensis* L. Osb. × *Poncirus trifoliata* L.). The experiment started in 2002, with trees having a fully-developed canopy and a tree-spacing of 3 m × 4 m.

There were two irrigation treatments, a control and a deficit irrigated (DI) treatment , which were applied in 2 consecutive years. The control treatment was irrigated at 100% ET_c. The DI treatment consisted of non-irrigation during phase III of fruit growth (final fruit-growth period, ripening and harvest, from 1st October to 1st March). Full irrigation (100% ET_c) was applied for the rest of the orchard cycle. Crop coefficients (K_c) applied during the experimental period were 1 in January and February and 0.60 from March to December, according to Amorós (1993) for late sweet orange trees in the Mediterranean area.

The experiment had a completely randomised design and three replications per treatment were used in the statistical analysis, each replication consisting of three trees. In each row, border trees were excluded from the study to eliminate potential border effects. A drip line was utilised in each tree row, with three self-compensating drippers (4 L h^{-1}) per tree, 0.75 m apart. Daily climatic data at the experimental site and neutron probe measurements were used to calculate the water application.

The mean annual amounts of fertilisers applied during the experimental period were 260 kg ha^{-1} N (NH_4NO_3), 103 kg ha^{-1} P_2O_5 ($(NH_4)_3PO_4$), 173 kg ha^{-1} K_2O (KNO_3) and 13.2 g Fe chelate per tree, supplied through the irrigation system. The amounts of water applied for each treatment were measured with flow-meters. The irrigation applied to the control and the DI treatment for the 2002–2003 season was, respectively, 592 and 475 mm. The corresponding values for the 2003–2004 season were 649 and 557 mm. The DI involved 20% less irrigation than the control in the first season and 14% less in the second season. Pest control practices and pruning were those commonly used by growers in this area.

Daily values of air temperature, solar radiation, relative humidity, rainfall and wind speed were measured using a manual weather station located 2 km from the experimental plot.

2.2. Plant water relations

Midday stem water potential (Ψ_{md}) was measured weekly 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, California, USA), following the recommendations of Turner (1988). The water-stress integral was calculated using the Ψ_{md} data, according to the equation defined by Myers (1988):

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

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

2.3. Gas exchange measurements

Gas exchange measurements were taken monthly, between 09:30 and 11:30 h in daylight hours (to avoid high afternoon temperatures and air vapour pressure deficit), from leaves exposed to the sun. The net CO_2 assimilation rate (A_{CO_2}), stomatal conductance to water vapour (g_s), transpiration rate (E) and intercellular CO_2 concentration (C_i) were measured, following the protocol described by Pérez-Pérez et al. (2008), with a portable photosynthesis system (Li-6400, Li-Cor, Lincoln, NE, USA) equipped with a broad leaf chamber (6.0 cm^2). The Li-6400 was also equipped with a red/blue light source (6400-02B LED).

2.4. Yield and fruit quality

Annually, in early March, during the experimental period (2002–2004), individual tree yield was measured in three trees per treatment and per replicate (nine trees per treatment). The number of fruits and the total fruit weight of each tree were measured.

When fruits reached commercial size, a sample of 15 fruits per tree was collected, randomly, from the nine trees per treatment, for analysis of fruit quality. Fruit weight and the equatorial and longitudinal diameters were determined. External colour was determined in three points of the equatorial area, with a tri-stimulus colour difference meter (Minolta CR 300). The external colour index was calculated as:

$$ECI = a^* \times 10^3 \times (L \times b^*)^{-1}$$

where ECI is the external colour index, L indicates lightness and a^* and b^* are the chromaticity coordinates.

Fruits were cut in the equatorial area and peel thickness was measured at three points. Fruits were squeezed and the juice filtered for measurements of the total soluble solids content and titratable acidity. All fruit fractions were separated, weighed and expressed as juice, peel and pulp percentages. The TSS of the juice was measured at 25 °C with a digital refractometer (Atago, Palette PR100) and TA was determined by titration with 0.4 N NaOH and phenolphthalein indicator (results are expressed as percentage of citric acid in the juice). The maturity index (MI) was expressed as the TSS × 10/TA ratio.

2.5. Statistical analysis

The data were analysed using analysis of variance (ANOVA) procedures and means were separated by Duncan's multiple-range test.

3. Results and discussion

3.1. Plant water status and gas exchange

The midday stem water potential (Ψ_{md}) in the control treatment during phase III of fruit growth was maintained between