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A new approach to ascertain the sensitivity to water stress of different plant water indicators in extra-early nectarine trees

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ABSTRACT

The sensitivity to water stress of different plant water indicators was evaluated during the late postharvest period of extra-early nectarine trees growing in a commercial orchard and submitted to two irrigation treatments: (i) a control (T_C), irrigated at 120% of crop evapotranspiration to avoid any soil water limitations, and (ii) a water deficit treatment (T_D), irrigated at 50% of T_C. The plant indicators studied were: the maximum daily trunk shrinkage (MDS); trunk growth rate (TGR); midday stem water potential (Ψ_{stem}); leaf conductance (Gs); and net photosynthesis (Pn). Although the highest signal intensity (SI) values – the ratio of deficit irrigation treatment values to control values – were reached by TGR, Gs and Pn (2.6, 3 and 2.9, respectively), the sensitivity (S) values – calculated as the ratio of SI to coefficient of variation (SI CV^{-1}) – were higher in Ψ_{stem} and MDS (14 and 11.4, respectively), since their CV values were the lowest (11 and 14%, respectively). A new approach (S^*) is proposed to calculate the sensitivity of the plant water indicators, since the standard method can result in high sensitivity values without identifying differences between irrigation treatments. While S is more influenced by the CV values, S^* would be influenced by both the SI and CV values.

Introduction

Through irrigation scheduling growers can control when and how much water to apply. The goal of an effective scheduling program is to supply the plants with sufficient water while minimizing loss by leaching or runoff.

Inadequate irrigation scheduling can result in plant water stress due to deficit or excess irrigation and may affect the quantity and quality of the fruit at harvest. Furthermore, over-watering is associated with higher costs (both for the water used and the associated energy required) and generates substantial nutrient losses through leaching, which can lead to environmental problems involving groundwater contamination and soil impoverishment. These observations serve to underline the importance of performing accurate irrigation scheduling.

Despite recent advances in precision agriculture, it is difficult to obtain accurate predictions of the crop water requirements for field conditions in perennial fruit tree orchards (Naor and Cohen, 2003). Nowadays, two different approaches are mainly used for scheduling irrigation: the water balance based on reference evapotranspiration and crop coefficients (Allen et al., 1998), and the soil water content and potential (Hanson et al., 2000). Both methodologies have improved water use efficiency compared with traditional methods based only on the grower's experience. However, the uncertainty associated with crop coefficients and the variability in soil water measurements has led to the search for new methods which are able to overcome these drawbacks.

In this respect, irrigation scheduling based on plant water status is postulated as a promising tool for increasing water use efficiency, since plant measurements include factors such as climate and soil water status (Jones, 2004). This methodology attains greater importance under deficit irrigation conditions, making it possible to use threshold values of plant water stress, thus minimizing the risk of watering below the crop needs.

Apart from that, researchers for decades have suggested that stem water potential (Ψ_{stem}) is a useful indicator in many species (Shackel et al., 1997), including nectarine (Naor et al., 2001), pear (Marsal et al., 2002) and grape (Choné et al., 2001). However, its main disadvantage is that it is a tedious measurement which cannot be automated and requires significant labor input (Naor and Cohen, 2003; Ortuño et al., 2009).

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Several manuscripts show that trunk diameter fluctuations (TDF) are sensitive to water deficit (Klepper et al., 1971). In this sense, maximum daily shrinkage (MDS) is considered the safest and most consistent indicator in adult fruit trees (Intrigliolo and Castel, 2006; Ortuño et al., 2006), whereas the trunk growth rate or TGR seems to be more sensitive in younger fruit trees (Goldhamer and Fereres, 2001; Moriana and Fereres, 2002; Nortes et al., 2005). Moreover, it is known that these indicators are easily automated (Puerto et al., 2013).

Plant water indicators are not only affected by the useful soil water content, but they also depend on other variables such as atmospheric demand or crop phenology. Thus, absolute values of indicators without considering evaporative demand might well be meaningless (Galindo et al., 2013). For this reason, it is better to use the concept of signal intensity (SI) for irrigation scheduling, normalizing an indicator's absolute values with respect to values in non-limiting soil water conditions (Goldhamer and Fereres, 2001; Naor and Cohen, 2003; Ortuño et al., 2005). The SI of the plant water stress indicator is a dimensionless variable, in which values above unity indicate deficit irrigation and values equal to unity indicate the lack of water stress (Goldhamer and Fereres, 2004).

The main property that an indicator should have is 'sensitivity' to water stress. Goldhamer and Fereres (2001) define this term as the ratio between SI and the "noise" (coefficient of variation measurements for each indicator measured, CV). Other desirable properties include the possibility of automation, a faster response to water deficit, and the proportionality of the measurements with respect to the level of deficit applied.

The objectives of this experiment were: (i) to evaluate the feasibility of using different plant water stress indicators in extra-early nectarine trees: MDS, TGR, Ψ_{stem}, stomatal conductance (Gs) and net photosynthesis (Pn) for irrigation scheduling; and (ii) to evaluate the suitability of a new algorithm to determine the sensitivity of the indicators to water deficit.

Materials and methods

Experimental site, plant material and treatments

The study was conducted in 2012 during the post-harvest period (between day of the year 167 and 302) in a commercial farm located in Murcia (38°8′ N, 1°13′ W). The experimental plot had an area of 2 ha and consisted of 11-year-old extra-early nectarine trees cv 'Viowhite' grafted onto plum "Puebla de Soto 101" rootstock at a spacing of 6 m × 3.5 m.

The soil, of a clay loam texture with an average depth of 1.55 m, presented a low-available potassium and organic matter content in the main root zone of the soil and a low phosphorus content. The electrical conductivity (EC) of the irrigation water varied between 1 and 1.4 $dS\,m^{-1}$. Cultural practices such as weed control, fertilization, pruning, fruit thinning and banding were carried out by the technical department of the commercial orchard following the usual criteria in the area.

The drip irrigation system had two lines per tree row and nine pressure-compensated emitters (1.6 $L\,h^{-1}$) per tree placed every 75 cm. Irrigation was scheduled weekly and applied daily at night throughout the study period.

Two different irrigation treatments were applied: (i) a control (T_C), irrigated at 120% of crop evapotranspiration (ETc) to maintain non-limiting soil water conditions, and (ii) a water deficit treatment (T_D) which used 50% of the water supplied in the control treatment.

ETc was determined as the product of reference crop evapotranspiration (ET_0) and the crop coefficients (0.55) proposed by the Agricultural Information System of Murcia (www.siam.es) for this area, adjusted for the tree size (Kr = 0.90) (Fereres and Goldhamer, 1990), including an additional leaching fraction applied due to the irrigation water salinity (9%).

Measurements

The soil volumetric water content (θv) was measured from 0 to 1 m depth every 0.1 m with an *in situ* calibrated frequency domain reflectometry (FDR) probe (Diviner 2000, Sentek Pty. Ltd., South Australia). Three access tubes were installed within the emitter-wetting area under the canopy and along the tree drip line for three randomly selected trees. Measurements were taken between 10.00 and 12.00 h (solar time) every 7–10 days during the experiment.

Trunk diameter fluctuation was monitored in six trees, using a set of linear variable displacement transducers (LVDT; Solartron Metrology, Bognor Regis, UK, model DF ±2.5 mm, precision ±10 μm) installed on the northern side of the trunks, 30 cm above the ground and mounted on holders built of aluminum and invar (an alloy of 64% Fe and 35% Ni, which has minimal thermal expansion). Measurements were taken every 30 s, and 10 min means were recorded by a CR1000 data logger (Campbell Scientific Inc., Logan, USA), connected to an AM16/32 multiplexer programmed to report mean values every 10 min. Several indices were TDF-derived according to Goldhamer and Fereres (2001): maximum (MXTD) and minimum (MNTD) daily trunk diameter, maximum daily trunk shrinkage (MDS = MXTD − MNTD) and trunk daily growth rate (TGR, calculated as the difference between the MXTD of two consecutive days).

Midday (12.00 h solar time) stem water potential (Ψ_{stem}) was measured every 7–10 days in one leaf per tree that was enclosed within foil-covered plastic and aluminum envelopes at least 2 h before the measurement, on the same trees that were monitored with the LVDT sensors. Measurements used a pressure chamber (Soil Moisture Equipment Corp. Model 3000) according to the procedure described by Hsiao (1990).

Leaf conductance (Gs) and net photosynthesis (Pn) were measured with CIRAS-2 equipment (PPSystem, Hitchin, Herfordshire, UK) at midday, in the same trees and on the same days as Ψ_{stem} and θv. Measurements were made on mature sun-exposed leaves and saturation under saturation light conditions.

Signal intensity, noise and sensitivity

In order to compare signal intensity (SI), coefficients of variation (CV) and the sensitivity of the indicators described previously, we only used data from those days when measurements for all the indicators were available. In addition, measurements were always taken in the same trees. In this way, variables referring to the sampling day and type and size of the sample did not interfere with the study. SI was calculated as the ratio between the values (V) of T_D and T_C. SI = $V_D \cdot V_C^{-1}$ in the case of MDS and Ψ_{stem}, and SI = $V_C \cdot V_D^{-1}$ in the case of TGR, Gs and Pn. To determine the "noise" we calculated the coefficient of variation (CV) of the measurements for each indicator.

The sensitivity of the indicators was determined using two different algorithms:

(i) Traditional method (S), as proposed by Goldhamer et al. (2000). This is the most commonly used procedure for analyzing the sensitivity of an indicator. S is always higher than 0, and the higher its value the greater the sensitivity (Fig. 1).

$$S = \frac{\mathrm{SI}}{\mathrm{CV}}$$