Maximum daily trunk shrinkage reference values for irrigation scheduling in olive trees

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1. Introduction

During the last two decades, olive production in the Mediterranean basin has intensified, and what was traditionally a rainfed crop, is now frequently irrigated (Eris and Barut, 1995).

Mediterranean agriculture is facing increasing pressure to reduce its consumption of water, and so there is a constant need to improve water use efficiency by crops. For this reason, among the tools that olive growers can use to achieve this goal are more precise irrigation scheduling procedures which involve determining what the crop water requirements are.

To this end, measurement of the plant water status may be useful for irrigation scheduling because of its dynamic nature, which is directly related with climatic and soil conditions, as well as with crop productivity (Goldhamer et al., 2003; Remorini and Massai, 2003).

The sensors used to measure trunk diameter shrinkage and swelling permit continuous and automated registers of the changes in tree water status, and an immediate, consistent and reliable diagnosis of any water deficit situation (Goldhamer et al., 1999; Ortúñ o et al., 2004, 2006b).

Maximum daily trunk shrinkage (MDS) has been demonstrated to be an adequate indicator of the plant water status of trees (Huguet et al., 1992; Cabibel and Isberie, 1997; Cohen et al., 2001; Ortúñ o et al., 2004, 2006a), and MDS measurements have been seen to be a promising tool for the development of automated irrigation scheduling in trees (Li et al., 1989; Goldhamer and Fereres, 2004).

However, it is necessary to develop reference relationships or baselines to interpret the values of a plant-based water status indicator. These reference values are obtained by relating their values in plants under non-limiting soil water
conditions with the evaporative demand of the atmosphere (Goldhamer and Fereres, 2001; Fereres and Goldhamer, 2003; Ortuno et al., 2006b).

There is very limited information in the literature about the use of dendrometers in olive trees to measure trunk diameter fluctuations (TDF) and their possible use in irrigation scheduling. Only the work of Moriana and Fereres (2002) deals with the measurement of trunk diameter fluctuations in young olive trees, and the work of Michelakis (1997) in adult olive trees.

The research reported in this paper was conducted to evaluate the possibility of obtaining MDS reference values in adult olive trees to be used in irrigation scheduling. For this, the behaviour of MDS under non-limiting soil water conditions was characterized and related with parameters concerning the evaporative demand of the atmosphere.

2. Materials and methods

2.1. Plant material and experimental conditions

Experiments were conducted at La Hampa, the experimental farm of the Instituto de Recursos Naturales y Agrobiología (CSIC), which is located at Coria del Río near Seville (Spain) (37°17’N, 6°3’W, 30 m altitude) from 7 June 2005, day of the year (DOY) 158 to 19 September 2005, DOY 262. The sandy loam soil (about 2 m deep) of the experimental site was characterized by a volumetric water content of 0.33 m$^3$ m$^{-3}$ at saturation, 0.21 m$^3$ m$^{-3}$ at field capacity and 0.10 m$^3$ m$^{-3}$ at permanent wilting point, and 1.30 (0–10 cm) and 1.50 (10–120 cm) g cm$^{-3}$ bulk density.

The experiment was performed on 37-year-old olive trees (Olea europaea L. cv. Manzanillo). Tree spacing followed a 7 m × 5 m square pattern. Pest control and fertilization practices were those commonly used by the growers, and no weeds were allowed to develop within the orchard.

Irrigation was carried out during the night by drip using one lateral pipe per tree row and five emitters per plant, delivering 31 l h$^{-1}$ each. Plants irrigation requirements were determined according to daily reference evapotranspiration (ETo) and a crop factor based on the time of the year and the percent of ground area shaded by the tree canopy (Fernández et al., 1998). During the experimental period, total crop evapotranspiration (ETC) was 302 mm.

During the experimental period, olive trees were irrigated daily above their water requirements in order to obtain non-limiting soil water conditions, as it is shown later in Fig. 2. A total amount of water of 416 mm, measured with in-line water meters, was applied during the experiment.

The design of the experiment was completely randomized with four replications, each replication consisting of three adjacent rows of five trees. Measurements were made in the inner tree of the central row of each replicate, the other trees served as borders.

2.2. Measurements

Micrometeorological 30 min data, namely air temperature, solar radiation, air relative humidity and wind speed at 2 m above the soil surface were collected by an automatic weather station located some 40 m from the experimental site. Daily reference evapotranspiration (ETo) was calculated using the Penman–Monteith equation (Allen et al., 1998).
Daily mean vapour pressure deficit (VPDm) was calculated from mean daily vapour pressure and relative humidity (Goldhamer and Fereres, 2001). There was no rainfall during this period.

The soil volumetric water content (\( \theta \)) of the top 150 mm of the soil profile was measured by time-domain-reflectrometry (TDR) using a Tektronic device (Model 1502C), as described by Moreno et al. (1996). The \( \theta \) content of the soil from 0.2 m down to a maximum depth of 1.20 m was measured every 0.1 m using a neutron probe (Troxler Model 3300) in access tubes installed at two distances of 0.5 and 1.5 m away from the trees. \( \theta \) was measured, every 10–15 days, in the morning during the experimental period.

Trunk diameter fluctuations were measured throughout the experimental period in four trees, using a set of linear variable displacement transducers (LVDT) (model DF \( \pm \) 2.5 mm, accuracy \( \pm \) 10 \( \mu \)m, Solartron Metrology, Bognor Regis, UK) attached to the trunk, with a special bracket made of Invar, an alloy of Ni and Fe with a thermal expansion coefficient close to zero (Katerji et al., 1994), and aluminium. Sensors were placed on the north side and were covered with silver thermoprotected foil to prevent heating and wetting of the devices. Measurements were taken every 10 s and the datalogger (model CR10X with AM 416 multiplexer, Campbell Scientific Ltd., Logan, USA) was programmed to report 30 min means. Maximum daily trunk shrinkage was calculated as the difference between maximum and minimum daily trunk diameter.

### 3. Results

The patterns of all the environmental variables fluctuated widely. Mean daily air temperature (\( T_m \)) and midday air temperature (\( T_{md} \)) presented a similar trend, reaching maximum values in July (Fig. 1A). Average \( T_m \), and average \( T_{md} \) were 25.1 and 31.7 °C, respectively, and average mean relative humidity was 54% (data not shown).

Solar radiation (\( R_s \)) and daily ETo fluctuated widely during the measurements period, showing maximum values in late June and mid-July, and minimum values in mid-August, respectively (Fig. 1B). Total ETo was 653 mm (Fig. 1B). Midday VPD (VPD\(_{md}\)) and VPDm values presented similar trends, and minimum values were obtained in mid-September (Fig. 1C). MDS values varied between 0.15 and 0.94 mm, with a certain trend to decrease (Fig. 1D).

During the measurement period, the volumetric soil water stock (0–1.20 m) was near constant, with values close to that corresponding to field capacity content (Fig. 2A). The mean volumetric soil water content profile during the experimental period is shown in Fig. 2B. The profile was characterized at 0–30 cm by moisture levels above field capacity, beyond which (30–110 cm) the levels were very similar and at around 86–90% of field capacity.

Figs. 3–6 represent the MDS as a function of \( T_m \), \( T_{md} \), \( R_s \), VPDm, VPD\(_{md}\) and ETo. The overall increases in any of the selected environmental variables were associated with increases in MDS. The \( r^2 \) values of the data around the regression lines varied from 0.34 to 0.83.

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**Fig. 2** – Soil volumetric water stock down to 1.20 m depth during the measurement period (A) and mean soil volumetric water content (\( \theta \)) profile (B). Horizontal lines (A) and vertical lines (B) represent volumetric soil water content at permanent wilting point (WP), at field capacity (FC) and at saturation (S), respectively. Vertical and horizontal bars are twice the overall mean S.E.

**Fig. 3** – Relationships between daily mean (\( T_m \), open symbols) and midday (\( T_{md} \), closed symbols) air temperature and maximum daily trunk shrinkage (MDS) values during the measurement period.

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**Fig. 4** – Relationships between daily mean (\( T_m \), open symbols) and midday (\( T_{md} \), closed symbols) air temperature and maximum daily trunk shrinkage (MDS) values during the measurement period.
The regressions of MDS versus the climatic variables measured at midday (T\textsubscript{md} and VPD\textsubscript{md}) were characterized by tighter correlations than that of MDS versus daily mean values (T\textsubscript{m} and VPD\textsubscript{m}) (Figs. 3 and 5), and the regression of MDS values versus E\textsubscript{To} was characterized by a tighter correlation than that of MDS against R\textsubscript{s}, which showed a relatively low determination coefficient (Figs. 4 and 6).

4. Discussion

The high irrigation supply frequency and the amounts of irrigation water supplied were responsible for the constant and high amount of water stored in the soil profile (Fig. 2). For this, the trees were under non-limiting soil water conditions, an aspect of overriding importance when considering the main objective of our work.

Even though the amount of irrigation water applied to plants during the experimental period was clearly above ET\textsubscript{c}, the excellent soil internal drainage (Fig. 2), the absence of plant symptoms and the olive tree water relations (Moreno, unpublished data) indicated the absence of any waterlogging situation.

The regression analysis indicated that the tree water status indicator (MDS) equated with the environmental variables (T\textsubscript{md}, T\textsubscript{m}, R\textsubscript{s}, VPD\textsubscript{m}, VPD\textsubscript{md} and E\textsubscript{To}) and the determination coefficients varied from 0.34 to 0.83 (Figs. 3–6), the highest coefficients being those obtained for the regressions of MDS against VPD\textsubscript{md} (r\textsuperscript{2} = 0.83) and T\textsubscript{md} (r\textsuperscript{2} = 0.79). However, it was expected that MDS would correlate better with the evaporative demand indicators measured on a whole-day basis, rather than parameters measured at midday (Ortuño et al., 2006b). In this sense, Fereres and Goldhamer (2003) showed the greater sensitivity of MDS in young almond trees to changes in VPD\textsubscript{m} rather than in VPD\textsubscript{md}, and explained this behaviour by the association of MDS with daily tree transpiration (Hatfield and Fuchs, 1990). Also, Michelakis (1997) showed that weekly absolute maximum MDS in adult olive trees was highly correlated to the corresponded evaporation of the class A pan values.

Although temperature is not an accurate indicator of the evaporative demand of the atmosphere (Hatfield and Fuchs, 1990), MDS was closely related with T\textsubscript{m} and T\textsubscript{md} (Fig. 3). In this sense, Fereres and Goldhamer (2003) showed that MDS correlated well with both T\textsubscript{md} and T\textsubscript{m}. However, Vélez (2004) indicated that MDS was more directly related with changes in R\textsubscript{s} and E\textsubscript{To} than VPD and temperature in Citrus clementina trees.

Zweifel et al. (2001) showed that stored water plays an important role not only during periods of drought, but whenever water transport occurs within the tree, even in
well-watered trees. In this sense, the fact that the relationships between MDS and the climatic variables (Figs. 3–6) were linear even at high evaporative demand values was probably the result of the efficient water recruitment from additional stem tissue capacitances when evaporative demand increased and stem water potential decreased below a threshold (Ortuño et al., 2006b).

According to the $r^2$ values of the regressions of MDS versus environmental variables, it can be concluded that the MDS reflected changes in the evaporative demand variables, even though the MDS behaviour was best correlated with $\text{VPD}_{\text{md}}$ ($r^2 = 0.83$) and $T_{\text{md}}$ ($r^2 = 0.79$). Baselines or reference values for MDS for use as plant-based water status indicator can be obtained, but must be used within their confidence levels. Moreover, continuous recording of MDS offers the promising possibility of its use in automatic irrigation scheduling in olive trees.

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References


