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Regulated deficit irrigation based on threshold values of trunk diameter fluctuation indicators in table olive trees

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ABSTRACT

The aim of this study was to establish threshold TGR and MDS values which could be used in regulated deficit irrigation in future work. Three irrigation treatments were performed during three seasons in a 37 year-old table olive orchard in Seville (Spain). Control treatment was irrigated with 125% of the crop evapotranspiration. Regulated deficit irrigation (RDI) treatments were performed according to the phenological stage of the trees and different water stress levels. RDI trees were irrigated only when the threshold values of water stress level was reached. Water stress conditions were applied during the massive pit hardening period (phase II, RDI-2) or during this period and the shoot-flowering period (phase I, RDI-12). The water stress level was performed with the trunk growth rate (TGR) during phase I and recovery and maximum daily shrinkage signal (MDS signal) during phase II. Both parameters were calculated as relative values of the Control trees. TGR threshold values varied from equal to Control (RDI-2) or 0.25 μm day^{-1} less than Control (RDI-12) during phase I. MDS signal (ratio between MDS in RDI vs MDS Control) threshold values varied from 0.5 (RDI-12) to 0.75 (RDI-2). In the recovery period, trees were irrigated when TGR values were lower than Control. This scheduled changed the amount of applied water between high and low fruit load seasons. The total amount of applied water in RDI trees oscillated from 38 to 160 mm, depending on the season and the treatment. The yield was not significantly different between Control and deficit treatments. Fruit volume and number of fruits was affected for the irrigation. Limitations and management of TDF in irrigation scheduling is discussed.

1. Introduction

Irrigation scheduling in fruit trees is commonly calculated according to water balance in full or deficit conditions. The water deficit schedule in olive trees is traditionally based on severe water withdrawal around the beginning of massive pit hardening (Goldhamer, 1999). However, in recent studies zero irrigation conditions before pit hardening and subsequent recovery have been proposed with significant water saving without yield decreases (Lavee et al., 2007; Tognetti et al., 2007). These two proposals are really only a local adaptation of irrigation scheduling to an optimum water stress level according to the crown volume, soil and climatic conditions. All those traditional studies concluded with a recommendation of reductions in water irrigation based on crop evapotranspiration (ET_c), though a sharp change in environmental conditions during a sensitive phenological stage (such as flowering) would affect the results, as reported by Moriana et al. (2003) and suggested by Lavee et al. (2007). Therefore, the level and duration of water stress should be recommended instead of the amount of applied water.

Trunk diameter fluctuation is a water status measurement that has been considered as an irrigation scheduling tool and permits continuous monitoring (Ortuño et al., 2010; Fernández and Cuevas, 2010). The trunk in all the plants present a daily cycle of shrinking and swelling (Klepper et al., 1971). The most common parameters used in irrigation scheduling are the maximum daily shrinkage

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(MDS) and the maximum daily diameter (Goldhamer and Fereres, 2001). However, the strong relationship between these indicators and evaporative demand makes irrigation scheduling more difficult. Goldhamer and Fereres (2001) suggested the use of reference trees (trees over-irrigated in the orchard) in order to calculate the relative values of MDS and maximum daily diameter which minimize this effect.

MDS is the traditional parameter used in fruit crops (Ortuño et al., 2010) and is strongly related to transpiration (Herzog et al., 1995). However, the results found in the literature for olive trees do not show clear differences in MDS under mild water stress conditions (Moriana and Fereres, 2002). This behavior is probably due to the relationship between MDS and water potential. MDS increases with the decrease of water potential until a value is reached from which MDS decreases sharply (Ortuño et al., 2010). This decrease has been related to severe water stress conditions that reduce the transpiration of the tree (Hinckley and Bruckerhoff, 1975). Therefore, in olive trees, MDS would be a valid tool in irrigation scheduling only in severe water stress conditions (Moriana et al., 2011).

Maximum daily diameter is not commonly used in the irrigation scheduling of fruit trees (Ortuño et al., 2010). However, this indicator, or a related form of it, is considered more sensitive than MDS in some trees (peaches, Goldhamer et al., 1999; olive, Moriana and Fereres, 2002), though is strongly related with fruit load (Moriana et al., 2003). Absolute values of maximum daily diameter are not useful because depend of the initial value and especially recovery is difficult to identified (Moriana and Fereres, 2002). Then, the slope of maximum daily diameter, the trunk growth rate (TGR), was suggested in olive trees as indicator (Moriana and Fereres, 2002).

There have been no studies that use this technique for irrigation scheduling in olive trees. The present work is designed to establish threshold TGR and MDS values which could be used in regulated deficit irrigation in future work. In addition, this work describes problems and limitations in the parameters used. Our hypothesis is that the use of relative values of TGR and MDS, obtained from the relationship between the data of reference trees (over-irrigated) and deficit treatments, will permit successful control of deficit irrigation.

2. Materials and methods

2.1. Site description and experimental design

Experiments were conducted at La Hampa, the experimental farm of the Instituto de Recursos Naturales y Agrobiología (CSIC), located at Coria del Río near Seville (Spain) (37°17′ N, 6°3′ W, 30 m altitude). The experiment was performed on 37-year-old table olive trees (*Olea europaea* L. cv Manzanillo) from 2008 to 2010 seasons. Tree spacing followed a 7 m × 5 m pattern. 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 0.1 $m^3 m^{-3}$ at permanent wilting point, and 1.30 (0–10 cm) and 1.50 (10–120 cm) g cm^{-3} bulk density. Pest control, pruning and fertilization practices were those commonly used by growers and weeds were removed chemically within the orchard. Drip irrigation was carried out during the night using one lateral pipe per tree row and five emitters per plant, spacing 1 m, delivering 8 L h^{-1} each. Micrometeorological data were obtained by an automatic weather station located around 40 m from the experimental site. Daily reference evapotranspiration (ET_o) was calculated using the Penman–Monteith equation (Allen et al., 1998).

The experimental design was a completed randomized experiment with 3 treatments of irrigation. Each treatment was in a plot with six trees located in a single row with two adjacent guard rows. There were 6 trunk diameter fluctuation sensors per treatment and 1 sensor per tree.

2.2. Irrigation phases considered

The seasonal cycle of the trees were divided in 4 phases according to Rallo (1997):

Phase I occurred from the shoot flush (around mid-February, day of the year (DOY) 45) until the beginning of the period of massive pit hardening (around DOY 169).
Phase II occurred from massive pit hardening until the last week of August. We considered that massive pit hardening began when a decrease in the growth rate of the longitudinal diameter of the fruit was measured (Rapoport et al., 2013). There is no morphological indicator to establish the end of this phase. Then the end of this phase was established in order to obtain a complete rehydration before harvest (around DOY 240).
Phase III was the period of rehydration and occurred from the end of August until harvest (around DOY 275).
Phase IV. Postharvest. Typical date of the beginning of post-harvest is beginning of October.

2.3. Treatment description

The water stress levels were estimated according to the trunk diameter fluctuation indicators. Rains produced an unreal daily cycle of trunk diameter fluctuations. Therefore the date where rain was measured and three days later, irrigation was not scheduled in RDI treatments. Maximum daily shrinkage (MDS) was calculated as the difference between the maximum daily diameter and the minimum daily diameter (Goldhamer et al., 1999). Trunk growth rate (TGR) in day "*n*" was calculated as the difference between the maximum daily diameter of day "*n* + 1″ minus those of day "*n*" (Cuevas et al., 2010). According to Goldhamer and Fereres' (2001) approach, water stress level was defined in comparison with an over-irrigated Control. The MDS signal was established as the ratio between the value of MDS in the deficit treatment and MDS in Control trees.

TGR was used when moderate conditions of water stress were imposed because it was reported as most sensitive to water deficit conditions (Moriana and Fereres, 2002). On the other hand, in severe conditions MDS was the indicator selected because showed clearer the affection of transpiration.

The irrigation treatments were:

- *Control treatment.* Irrigation requirements were determined according to daily crop evapotranspiration (ET_c) calculated with FAO method (Allen et al., 1998). Crop coefficient values (K_c) were previously estimated in the orchard (Fernández et al., 2006). In addition, a reduction according to tree size was considered (K_r 0.7). Trees were irrigated daily with 125% crop evapotranspiration (ET_c) until harvest. Irrigation season started around early May when according to the average year small amount of rains were expected.
- *Regulated Deficit Irrigation 2 (RDI-2).* No water stress was performed in phases I and III. In these phases, irrigation was applied when TGR was lower than Control. Moderate water stress were applied during phase II, and irrigation was applied when the MDS signal was lower than 0.75. This value of MDS signal (and the one described below) was estimated from the MDS vs stem water potential relationship of Moriana et al. (2000). In this latter work the maximum values of MDS was around 800 μm. We considered that a target value of midday stem water potential around −2.5 MPa could be suitable. The equation of this work estimated