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Feasibility of trunk diameter fluctuations in the scheduling of regulated deficit irrigation for table olive trees without reference trees

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ABSTRACT

Regulated deficit irrigation (RDI) results are affected by the actual water stress level reached during the treatments. The irrigation scheduling based on water status measurements, such as trunk diameter fluctuations, can control in an accurate way the water restrictions. However, the number of works that use these indicators as isolate parameter to control the schedule is scarce in general, and very scarce in olive trees. Building on previous works, the aim of this article is to schedule an RDI strategy in olive trees based on threshold values of maximum daily shrinkage (MDS) and trunk growth rate (TGR) without reference trees. The experiment was performed in a 40 years-old table olive orchard (cv Manzanillo) in Seville (Spain) for 3 years (seasons from 2011 to 2013). Three different irrigation treatments were considered in a completely randomized block design. Control trees were over-irrigated (125% crop evapotranspiration, ET_c) in order to obtain fully irrigated conditions. Water stress conditions were applied during Phase II (pit hardening) in the RDI-2 treatment or during Phase II and Phase I (full bloom) in RDI-12. In both RDIs, a treatment recovery (Phase III) was performed before harvest. The trunk diameter fluctuation indicator was selected according to the phenological stage. TGR was used in conditions of full irrigation or moderate water stress level, such as Phase I and Phase III. TGR threshold values based on previous works were selected: 20 μm day^{-1}, RDI-2; 10 μm day^{-1}, RDI-12 (Phase I) and -5 μm day^{-1}, both treatments, Phase III. Only in one season RDI-2 was scheduled with TGR values (-10 μm day^{-1}) during Phase II. MDS threshold values were determined as the ratio between measured MDS and fully irrigated MDS (the so called MDS signal). The latter was estimated from a baseline. During Phase II, RDI-2 was irrigated with a threshold value of 0.9, while RDI-12 was irrigated with a threshold value of 0.75. MDS signal was not useful for most of the period considered and it did not agree well with fruit drop or fruit size. Conversely, the average of TGR during Phase II was significantly linked to fruit drop and fruit size, and so were the midday stem water potential and stress integral. Recommendations about the management of TGR are discussed. The water stress level in the experiments was moderate and no significant differences in yield were found. However, the trend of yield reduction in RDI-12 was likely related with a fruit drop and a reduction in crown volume. The yield quality did not decrease in the RDIs treatments, on the contrary, pulp:stone ratio improved significantly in some of the seasons.

1. Introduction

Water scarcity around the world has been reduced the irrigation availability. Deficit irrigation scheduling has been suggested in most of the fruit trees. Regulated deficit irrigation (RDI) and partial root drying (PRD) are two different options of water deficit management. In some fruit trees such as olive orchard, PRD has not improved the results of RDI (Fernández et al., 2006). Since PRD needs more labor force, farmers commonly prefer RDI schedul-

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ing. Regulated deficit irrigation (RDI) is an irrigation scheduling method first reported in the 70s, based on differences in water stress sensibility during the season (Chalmers et al., 1975). Traditional RDI works reduce the amount of water provided during the most resistant phenological stages using the percentage of crop evapotranspiration (Behboudian and Mills, 1997). Such strategy has produced contradictory results. Similar recommendations in RDI scheduling caused clear differences when they were performed at different sites (for instance, Girona (2002) in peaches; Johnstone et al. (2005) in tomato).

The irrigation season in olive trees could be divided into four different periods according to water stress sensibility. The full bloom/fruit set period is considered the most sensitive to drought conditions (Moriana et al., 2003), while the pit hardening period is the most resistant (Goldhamer, 1999) in relation to yield. Oil accumulation is also considered a sensitive period (Lavee and Wodner, 1991) though several works suggest that moderate water stress increases oil production (Moriana et al., 2003; Lavee et al., 2007). The postharvest period has not been studied, probably because in the main producing zone this is the rainfall season. The results of irrigation works in olive trees strongly suggest that different levels of water stress during the same phenological stage change the effect on yield (Goldhamer, 1999; Moriana et al., 2003; Lavee et al., 2007).

Irrigation scheduling based on water status measurements could provide a useful tool to control the water stress level in RDI. In this way, water stress conditions in different sites will be comparable and RDI strategies could be easily performed out of the experimental orchards. Trunk diameter fluctuations are daily cycles of swelling and shrinking suggested in several fruit trees as an irrigation scheduling tool (Ortuño et al., 2010). There are two indicators obtained from daily curves: maximum daily shrinkage (MDS) and trunk growth rate (TGR) (Goldhamer and Fereres, 2001). In olive trees, MDS is not reported as a useful indicator, while TGR is considered an early water stress detector (Moriana and Fereres, 2002). There are only a few works using these parameters in olive RDI. Recently, Moriana et al. (2013) suggested a threshold value of $-5\ \mu m\ day^{-1}$ of TGR during pit hardening and recovery in table olive trees and concluded that MDS is not an easy tool in these conditions. However, Corell et al. (2013) suggested a different approach to estimate MDS in order to reduce the influence of the environment. Moriana et al. (2013) used the reference tree approach (Goldhamer and Fereres, 2001) which, in brief, requires trees to be fully irrigated at the orchard in order to eliminate the environmental effect. These "reference trees" could affect the results obtained. Threshold values based in previous experiments could change the usefulness of some indicators such as MDS. The aim of this work is to combine previous results in order to obtain an irrigation approach that uses only threshold values of MDS and TGR without reference trees. This objective will be studied from two points of view. First, the present work considers the ease of data interpretation. Secondly, the robust relationship between both indicators and processes relate to yield results, such as fruit drop or fruit size, will be studied as well.

2. Material 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 (IRNAS-CSIC), located in Coria del Río near Seville (Spain) (37°17′′N, 6°3′W, 30 m altitude). The experiment was performed on 40-year-old table olive trees (*Olea europaea* L. cv Manzanillo) from the 2011 to the 2013 seasons. Tree spacing followed a 7 m × 5 m square pattern. Age and density of the experimental orchard is the common of the zone in commercial orchards. The sandy loam soil (about 2 m deep) of the experimental site was characterised 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, only in the last season no pruning was performed. Drip irrigation was carried out at night using one lateral pipe per row of trees and five emitters per plant, spaced 1 m and delivering $8\ L\ h^{-1}$ each. Micrometeorological data were obtained using an automatic weather station located around 40 m from the experimental site. Although some recent works suggest simple approaches for estimated daily reference evapotranspiration (ET_0) (i.e., Valipour 2014, 2015), daily reference evapotranspiration (ET_0) was calculated using the Penman–Monteith equation (Allen et al., 1998).

The experimental design was a completely randomized block experiment with 3 blocks and 3 irrigation treatments. Each treatment was carried out in a plot with two trees located in a single row and 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 was 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. Therefore, 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. The typical date of the beginning of postharvest is the beginning of October.

2.3. Treatment description

The water stress levels were estimated according to the trunk diameter fluctuation indicators. 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 in day "*n* + 1" minus that in day "*n*" (Cuevas et al., 2010).

Severe water stress conditions reduce MDS in comparison to fully irrigated trees (Moriana et al., 2000). Therefore, MDS was used only during Phase II. Since MDS is strongly related with evaporative demand, the parameter considered was the MDS signal, which is the ratio between the measured MDS and the MDS in fully irrigated conditions (Goldhamer and Fereres, 2001). Moriana et al. (2011) reported that the maximum temperature is the best meteorological measurements in order to estimate the seasonal baseline in olive trees. The fully irrigated MDS was estimated from a baseline obtained with the Corell et al. (2013) approach. Corell et al. (2013) suggested that seasonal changes in the baseline are in the *y*-interception, while the slope is similar for different years. Therefore, a small numbers of MDS data at the beginning of the irrigation