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Approach for using trunk growth rate (TGR) in the irrigation scheduling of table olive orchards

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ABSTRACT

The management of regulated deficit irrigation with a continuous measurement of the water status would allow obtaining an accurate estimation of the water needs. However, although different types of sensors are available, the threshold and daily management of these data are not clearly defined. Trunk diameter fluctuations are a good example of these type of data. The trunk growth rate (TGR) is considered an early indicator in olive trees. However, the daily TGR values are very changeable, and only cumulative values of TGR show a clear trend. The number of irrigation works using this indicator is scarce. The TGR thresholds considered in these papers are the average of values over a period, and this makes it difficult to use when preparing a daily schedule. The aim of this work is to present an approach that allows using daily TGR data.

During the 2015 season, an irrigation experiment was carried out in the Doña Ana farm, a table olive orchard near Seville (Spain). The trees were 30 years old with a space of 7 × 4 m and they were irrigated using two drip lines with a flow rate of 2.5 l h^{-1}. The experiment began in spring and involved three treatments. Control trees were irrigated to maintain the midday stem water potential values at around −1.2 MPa before pit hardening started and at −1.4 MPa after this point. The trees under a mild water stress treatment (MI) were irrigated in the same was as the Control trees, except from DOY (day of the year) 161, the beginning of pit hardening, to DOY 237, when threshold value decreased to −2.0 MPa. The Moderate water stress trees (MO) were irrigated in the same way as the Control trees, except in the same period that MI, but with a threshold value of −4.0 MPa. The midday water potential pattern and leaf conductance pattern suggested that the level of water stress in both treatments was low, slightly higher in MO than in MI at the end of the water stress period. The shoot elongation suggested a period of water stress before DOY 161 in MO trees that the midday stem water potential and leaf conductance did not detect. The maximum daily shrinkage (MDS) signal indicated water stress conditions during the drought period, but both treatments presented similar values. The trunk growth rate (TGR) indicator was useful when maximum perimeter curves, average TGR and daily TGR were used together. All the periods of water stress identified by other indicators were detected when the three TGR data were used. An approach to use these three sets of data is discussed herein.

1. Introduction

Water resources are progressively scarcer in most semi-arid regions. In addition, although agriculture still involves the greatest water consumption, other social uses are also increasing their demand (Fereres and Evans, 2006). Therefore, irrigation management needs to improve the accuracy of the tools involved in the

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scheduling. In the last decades of the 20th century, the development of sensors began and old indicators, such as trunk diameter fluctuations (Klepper et al., 1971), were recovered and used as continuous plant measurement for irrigation scheduling of fruit trees (e.g. Huguet et al., 1992). Since then, the capacity to store, send and measure different data of the soil-plant-air system has been improving. During this period, fruit tree irrigation has changed from regulated deficit irrigation, a scheduling method promoting the control of water applied according to the phenological stage (Chalmers and Wilson, 1978), to smart irrigation, an accurate and continuous estimation of water needs (Fernández, 2016). However, although the technology is available, the management of deficit irrigation based on these indicators is difficult and not even clear in scientific papers (Fernández, 2014). Most of these shortcomings are related to the low amount of works studying the threshold values of these indicators or the even lower amount of works using these indicators as the main tool for irrigation scheduling.

Trunk diameter fluctuations are daily cycles of shrinkage and swelling of the trees, described in the 60's (Klepper et al., 1971) and strongly suggested as irrigation tools 40 years later (Goldhamer and Fereres, 2001). In olive trees, two main indicators derived from daily curves are commonly suggested, maximum daily shrinkage (MDS) and trunk growth rate (TGR) (Moriana and Fereres, 2002). The response of these indicators to water stress conditions is different in other fruit trees such as peach or almond trees (Ortuño et al., 2010). MDS is not a reliable water stress indicator in olive trees (Moriana and Fereres, 2002; Cuevas et al., 2012; Moriana et al., 2010), but it is the most sensitive in other fruit trees (e.g. peaches, Goldhamer et al., 1999). Such differences are related to the physiology of olive trees, an extremely dehydration resistant species (Moriana et al., 2003). MDS increases faster in olive trees than in other fruit trees, and reaches maximum values close to 1 mm with a relatively low water potential, around −1.4 MPa (Ortuño et al., 2010) with a subsequent decrease when the water stress increases (Moriana et al., 2000). This means that fully irrigated trees show a similar MDS to those with a moderate water stress in a range of water potential between −1.4 and −2.0 MPa (Girón et al., 2016). Girón et al. (2016) suggested that the use of the MDS signal, the ratio between measured and fully irrigated estimated MDS, could be used even in this range of water stress level. However, the MDS signal will only reflect water stress conditions but not the water stress level (Girón et al., 2016). On the other hand, the trunk growth rate (TGR) has been described as a very sensitive water stress indicator in olive trees (Moriana and Fereres, 2002). The great daily variations measured in TGR prompted the presentation of maximum daily curves in most works, in order to increase the clarity of the results, although the rate of this curve (the TGR) were the real data analysed (Moriana et al., 2013; Girón et al., 2015). As far as we know, only two works suggest values of TGR for olive trees: Moriana et al. (2013) a threshold of $-5\ \mu\text{m day}^{-1}$ of average TGR and Girón et al. (2015) a threshold of $-10\ \mu\text{m day}^{-1}$ of average TGR, both during pit hardening. Both works were carried out in the same olive orchard, limiting the scope of the recommendations. On the other hand, Girón et al. (2016) reported that the daily TGR in fully irrigated conditions is affected by the increase in the vapour pressure deficit (VPD): an increase in the average VPD from day "n" to day "n + 1" was linked to a decrease in the TGR of day "n + 1". Such response could partially explain the great variations in daily TGR values and the latter work suggested the use of an average TGR for a period and the curve of maximum values to identify trends (Girón et al., 2016). This recommendation limits using a continuous management of TGR, which is the main advantage of this measurement.

The great variability on trunk diameter data in different days, even for the same tree, makes it very difficult to use in commercial orchards. Previous works suggested average values for a period, but a continuous measurement requires daily decisions. The aim of the current work was to validate previous results of MDS signal and TGR in order to facilitate the decision making in the day to day irrigation scheduling. These validations would allow identifying false water stress measurements linked to the environment and improving the continuous monitoring of the trees water status.

2. Material and methods

2.1. Orchard description and experimental design

The experiment was carried out at the Doña Ana farm, a private farm located in Dos Hermanas, near Seville (Spain) (37° 25′ N, 5° 95′ W). The loam soil (more than 1 m deep) of the experimental site was characterized by a volumetric water content of $0.31\text{m}^3\ \text{m}^{-3}$ at field capacity and $0.14\text{m}^3\ \text{m}^{-3}$ at the permanent wilting point, as well as a bulk density of $1.4\ \text{g cm}^{-3}$ (0–30 cm) and $1.35\ \text{g cm}^{-3}$ (30–90 cm). Trees were 30-year-old table olive trees (*Olea europaea* L cv Manzanillo) during the 2015 season. The tree spacing followed a 7 × 4 m square pattern. Pest control, pruning and fertilization practices were those commonly used by growers, and weeds were chemically removed in the orchard. Irrigation was carried out during the night by drip, using two lateral pipes per row of trees and twenty-six emitters per plant, split between the two rows, delivering $2\ \text{l h}^{-1}$ each. Micrometeorological data, namely air temperature, solar radiation, relative humidity of air and wind speed at 2 m above the soil surface, were recorded every 30 min by an automatic weather station located some 10Km from the experimental site, at a similar altitude. The daily reference evapotranspiration (ETo) was calculated using the Penman-Monteith equation (Allen et al., 1998). The mean daily vapour pressure deficit (VPD) was calculated from the mean daily vapour pressure and relative humidity. The experimental design was a completely randomized block experiment with 4 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. The experiment was performed from spring, day of the year (DOY) 60, until harvest, DOY 249 (end of summer) with three different irrigation treatments. In Control trees, irrigation was performed to avoid any water stress. The irrigation scheduling in this treatment involved using the pressure chamber technique and the threshold values of midday stem water potential were −1.2 MPa before the period of pit hardening and −1.4 MPa after the period of pit hardening (Moriana et al., 2012). The beginning of the pit hardening period was considered as the moment when the rate of longitudinal fruit growth decreased (Rapoport et al., 2013). A second treatment established a Mild water stress (MI) conditions during pit hardening. In these trees, irrigation was scheduled in the same way as for the Control treatment, but during pit hardening (from DOY 161 to 237) the threshold value changed to −2 MPa. Finally, Moderate water stress (MO) conditions were also applied. In this treatment, irrigation was scheduled in the same way as for the Control treatment, but during pit hardening (from DOY 161 to 237) the threshold value changed to −4 MPa. Since values lower than −4 MPa were not measured, this treatment was rainfed for the entire period.

The irrigation scheduling was applied weekly in each plot. Water was applied to obtain a water status around the threshold selected and it was measured in each plot with a water meter. Therefore, the irrigation amount was calculated as a percentage of the maximum daily crop evapotranspiration throughout the season ($4\ \text{mm day}^{-1}$) based on the difference between the midday water potential measured and the threshold (Moriana et al., 2012). No irrigation was provided when the measured water potential was higher than the threshold. When the differences were lower than 10%, only $1\ \text{mm day}^{-1}$ was applied. If these differences were between 10 and