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Limitations and usefulness of maximum daily shrinkage (MDS) and trunk growth rate (TGR) indicators in the irrigation scheduling of table olive trees

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ABSTRACT

Maximum daily trunk shrinkage (MDS) is the most popular indicator derived from trunk diameter fluctuations in most fruit trees and has been reported to be one of the earliest signs in the detection of water stress. However, in some species such as olive trees (*Olea europaea* L.), MDS does not usually change in water stress conditions and trunk growth rate (TGR) has been suggested as better indicator. Most of this lack of sensitivity to drought conditions has been related to the relationship between the MDS and the water potential. This curvilinear relationship produces an uncertain zone were great variations of water potential do not imply any changes of MDS. The MDS signal, the ratio between measured MDS and estimated MDS with full irrigation, has been thought to be a better indicator than MDS, as it reduces the effect of the environment.. On the other hand, though literature results suggest an effect of environment in TGR values, there are not clear relationship between this indicator and meteorological data. The aims of this work are, on one hand, to study the improvements of the baseline approach in the MDS signal and, on the other, study the influence of several meteorological variables in TGR. Three years' data from an irrigation experiment were used in to carry out the MDS analysis and six years' data for full irrigated trees during pit hardening period were used for TGR study. The comparison between MDS vs. water potential and MDS signal vs. water potential presented a great scattering in both relationships. Values of MDS signal between 1.1 and 1.4 were always identified with moderate water stress conditions (−1.4 to −2 MPa of water potential). However, since this MDS signal values are around the maximum in the curvilineal relationship with water potential, greater values of MDS signal (in the range of 1.1–1.4) were not necessary lower values of water potential. In addition, during low fruit load seasons MDS signal was not an accurate indicator. On the other hand, absolute values of several climatological measurements were not significantly related with TGR. Only daily increments explain part of the variations of TGR in full irrigated trees. In all the data analysed, the daily increment of average vapour pressure deficit was the best indicator related with TGR. The increase of this indicator decreased TGR values. In addition, the agreement between this indicator and TGR was affected for fruit load. Great yield seasons decrease the influence of VPD increment in TGR.

1. Introduction

Trunk diameter fluctuations (TDF) are a daily cycle of shrinking and swelling of the trunk that have been reported since the 60s (Ortuño et al., 2010). The development of sensors and dataloggers during the 90s allowed a re-discovery of the usefulness of these indicators in irrigation scheduling. Research works about drought response of TDF indicators in fruit trees and even automatic irrigation scheduling based on these indicators have been reported (i.e., "Pepista", Huguet et al., 1992).

Several types of indicators can be obtained from the daily TDF curves. The most common and early sign of water stress in most fruit trees is the maximum daily shrinkage (MDS) (Ortuño et al., 2010). The increase of MDS compared to fully irrigated trees was

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reported, from the first works, as an indicator of water stress conditions (Klepper et al., 1971). However, the increase in MDS is also related to the evaporative demand (Herzog et al., 1995). Thus, evaporative demand is an interference of this indicator that reduces its usefulness in commercial orchards. In order to reduce this limitation, Goldhamer and Fereres (2001) suggested the MDS signal: the ratio between measured MDS and MDS with full irrigation. Fully irrigated conditions could be estimated from baseline equations, where MDS is related to a meteorological variable, such as reference evapotranspiration (ETo), vapour pressure deficit (VPD) or temperature (Ortuño et al., 2010; Fernández and Cuevas, 2010).

The usefulness of MDS, however, is not the same in all fruit species. In young olive trees, MDS was not affected by water stress, even when gas exchange was reduced (Moriana and Fereres, 2002). This lack of response has been reported in mature olive trees and in different cultivars and conditions (Moriana et al., 2003; Moriana et al., 2010; Fernández et al., 2011a,b). Moriana et al. (2010) suggested that the absence of response to water stress in MDS is related to the pattern of this indicator during a drought cycle. The relationship between MDS and water potential is curvilinear in all fruit trees, showing an initial increase of MDS with the reduction of the water potential until reaching a maximum value, and then MDS values decrease as the severity of water stress continues to increase (Ortuño et al., 2010). This relationship presented the highest MDS values in olive trees (maximum around 0.8–1 mm) (Moriana et al., 2000) and the first linear phase, until the maximum MSD values, has been considered to be caused by variations in the conditions of the evaporative demand (Pérez-López et al., 2013). Since the MDS values during summer in fully irrigated olive trees were around the maximum, moderate water stress conditions would be in the uncertain zone were clear differences of water potential (between −1.4 MPa and −2 MPa) presented similar MDS values. In addition, Moriana et al. (2013) reported greater values of MDS in fully irrigated conditions for trees which were deficit irrigated in the previous season than in trees with full irrigation. The MDS baseline is likely to reduce the influence of the environment on this indicator but it is not known if it would be a reliable indicator in moderate water stress conditions. Corell et al. (2013) recently reported on a methodology for the estimated MDS baseline at the beginning of the season which could reduce some of the limitations presented above.

These limitations in the usefulness of MDS in olive trees have produced that other indicators such as trunk growth rate (TGR) have been considered for irrigation scheduling (Moriana et al., 2013). TGR is clearly affected for the fruit load and during pit hardening period in mature trees almost no growth is detected (Moriana et al., 2003). However, even in these conditions, TGR in full irrigated olive trees is very variable and extremely negative values are measured (Moriana et al., 2013). Such response suggests an environmental effect which has been poorly described in olive trees.

The aim of this work is studied possible solutions of the limitations described above in MDS and TGR indicators. In one way, a three year data set of MDS and MDS signal were compared with water potential and soil moisture in order to check if the baseline approach could reduce the uncertain zone of this indicator in moderate water stress conditions. TGR data in the period of pit hardening were compared with climatic data of 6 years in order to obtain a relationship that, at least, described partially the daily pattern of this indicator.

2. Materials and methods

2.1. Experimental orchard description

Experiments were conducted at La Hampa, the experimental farm of the Instituto de Recursos Naturales y Agrobiología (IRNAS-CSIC). This orchard is located in Coria del Río, near Seville (Spain) (37°17″N, 6°3′W, 30 m altitude). 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 the saturation point, 0.21 $m^3 m^{-3}$ at field capacity and 0.1 $m^3 m^{-3}$ at the permanent wilting point, and a bulk density of 1.30 (0–10 cm) and 1.50 (10–120 cm) g cm^{-3}. The experiment was performed on 43-year-old table olive trees (*Olea europaea* L., cv Manzanillo) from the 2008 to the 2014 seasons. 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 row of trees and five emitters per plant, delivering 8L h^{-1} each. The irrigation requirements were determined according to the daily reference evapotranspiration (ET_o) and a crop factor based on the time of year and the percentage of ground area shaded by the tree canopy (Fernández et al., 1997).

Maximum daily shrinkage (MDS) study was performed only with data of the seasons from 2011 to 2013. Trunk growth rate (TGR) data were obtained from seasons 2008, 2010, 2012, 2013 and 2014 of this orchard and only in 2012 also in a contiguous orchard with the same age and cultivar but 7 × 7 m spaced. The study of both indicators was performed only in the period of pit hardening.

2.2. Treatment description

Full irrigated Control trees from 2008 to 2014 were used to obtain relationship between TGR and environmental variables. Control trees were irrigated with 100% of crop evapotranspiration (ETc) in order to obtain non-limiting soil water conditions during the entire season. MDS data were obtained from three different irrigation treatments performed from 2011 to 2013 seasons, one the Control described above and two regulated deficit irrigation (RDI) treatments. RDI considered the phenological stage of the trees in the water stress conditions. The beginning of pit hardening, the most resistant to water stress phenological stage, was determined according to Rapoport et al. (2013) and the recovery phase started in the last week of August (three weeks before harvest). The RDI scheduling was performed according to the trunk diameter variation indicators (Maximum Daily Shrinkage, MDS, and Trunk Growth Rate, TGR). The threshold values used in the present work were selected from previous data (Moriana et al., 2013). The treatments were:

- Control: trees were irrigated with 100% of crop evapotranspiration (ET_c) in order to obtain non-limiting soil water conditions during the entire season.
- Regulated deficit irrigation 2 (RDI 2). The objective of this treatment was to create a moderate water stress during the pit hardening and then a slow recovery. Irrigation was scheduled taking into account the maximum daily shrinkage (MDS) and the trunk growth rate (TGR) indicators. Before the period of massive pit hardening (from April to late June) water was supplied only when TGR was lower than 20 μm day^{-1}. During the pit hardening, irrigation was supplied only when the MDS signal was lower than 0.9. Finally, the recovery started during the last week of August and in this period, water was supplied when TGR was lower than −5 μm day^{-1}. This schedule was used during 2011 and 2012 seasons but the water status during pit hardening of this treatment and the next one were similar in these seasons (data not shown). For this reason, RDI 2 was changed during the 2013 season, and during the pit hardening water was supplied when TGR was lower than −10 μm day^{-1}.
- RDI 12. The objective of this treatment was to create a moderate water stress before the pit hardening, a severe water stress during pit hardening and a slow recovery. Before the pit hardening, water