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Changes in the physiological response between leaves and fruits during a moderate water stress in table olive trees

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ABSTRACT

Pit hardening period is the phenological stage when water stress is recommended in regulated deficit irrigation (RDI) in olive trees. In table olive trees, fruit growth is a very important process which could affect the final profit of the yield. RDI scheduling based on water status measurements could improve water management, but accurate threshold values are needed. Previous works in low fruit load conditions suggested −1.8 MPa of midday stem water potential as "first step" of water stress level where no variations of fruit growth have been detected. The aim of this work is to describe the physiological response of table olive trees with a significant yield in a moderate water stress conditions during pit hardening period. Water relations of Control (no water stress) trees and Stressed trees were studied in a mature table olive orchard in Seville (Spain). Control trees were irrigated with 100% of ET_c and values around field capacity were measured. Irrigation in Stressed trees was withdrawn during pit hardening period, and they were irrigated as Control in the rest of the experiment. Fruit growth was not affected until the last days of the deficit period, though midday stem water potential and maximum leaf conductance measurements reached minimum values a few days after the beginning of the water stress period. Such responses suggest two phases in the water stress period. At the beginning of the experiment, the physiological response of the trees (osmotic adjustment and trunk dehydration in the present work) compensated the decrease in water potential. In this phase, leaves and fruits are similar water sink in the shoots. During the last days of the drought period, the reduction of the osmotic adjustment and the greater decrease of fruit water potential transform fruits in more strength water sink than leaves. These changes produced a decrease in the fruit growth. The recovery, though it was not complete, increase fruit size as the same level than Control.

1. Introduction

Regulated deficit irrigation (RDI) in olive trees is scheduling with a water deficit period during pit hardening (Goldhamer, 1999). This phenological stage is a dynamic period which can change in length with the water status of the tree (Hammani et al., 2013). In addition, in conditions of significant fruit load in the tree, vegetative growth is stopped (Rallo and Suarez, 1989) and water relations are clearly changed in comparison with low fruit load conditions (Martin-Vertedor et al., 2011). Therefore, pit hardening is a complex phenological stage from the point of view of water relations.

Irrigation scheduling in deficit conditions has been changed in recent decades and there are several works that suggest water status measurements as a more efficient tool than the traditional water balance (i.e. Goldhamer and Fereres, 2001). But all the parameters related directly to the plant physiology could be altered by the drought adaptation process. In olive trees, osmotic adjustment has been suggested as one of the first responses of trees to drought conditions (Dichio et al., 2006). Great dehydration capacity has also been reported as a physiological respond to water stress (Fereres, 1984). Midday stem water potential has been considered the best indicator even in low water stress level (Moriana et al., 2010).

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Moriana et al. (2012) suggested −1.4 MPa as an adequate threshold value midday stem water potential during the pit hardening period in no water stress conditions. Dell'Amico et al. (2012) in table olive trees reported no decrease in fruit volume in low water stress conditions with minimum values around −1.8 MPa. The low fruit load in this latter experiment is likely to have limited the level of water stress. According to the literatures, such values of water potential are too high for deficit irrigation in olive trees. No clear reduction of fruit yield has been reported with values around −3.5 MPa during pit hardening (Moriana et al., 2003; Iniesta et al., 2009), though fruit growth has been reduced with values higher than −3.0 MPa (Moriana et al., 2013).

The aim of this work is to describe the physiological response of table olive trees in moderate water stress conditions during the pit hardening period. This is the first step to establish a more accurate threshold values or indicators of water potential for irrigation scheduling. We hypothesize that a significant fruit load on the tree will control the process and that shoots water relations would tend to allow fruit growth during the water deficit period.

2. Materials and methods

2.1. Description of the experiment

Experiments were conducted at La Hampa, the experimental farm of the Instituto de Recursos Naturales y Agrobiología (CSIC). This orchard is located at 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 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. The experiment was performed on 44-year-old table olive trees (*Olea europaea* L cv Manzanillo) during 2012. Tree spacing followed a 7 m × 5 m square pattern. Pest control and fertilization practices were those commonly used by 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 8 $L\ h^{-1}$ each and spacing 1 m. Irrigation requirements were determined according to daily reference evapotranspiration (ET_o) and a crop factor based on the time of year and the percentage of ground area shaded (40%) by the tree canopy ($Kr = 0.8$). The crop coefficient values (Kc) considered were 0.76 in May, 0.70 in June, 0.63 in July and August, 0.72 in September and 0.77 in October (Fernández et al., 2006).

Trees were irrigated with 100% of crop evapotranspiration (ET_c) in order to obtain non-limiting soil water conditions until the beginning of pit hardening (Phase I). The beginning of the pit hardening was estimated according to Rapoport et al. (2013) around day of the year (DOY) 173. From this date until DOY 233 irrigation was withdrawn in a Stressed treatment (Phase II). All measurements were made in 6 olives irrigated at 100% ET_c throughout the experiment (Control trees) and 6 olives where irrigation was withdrawn (Stressed trees). After DOY 233 trees were irrigated with the same amount of water as Control trees (Recovery). The experiment was stopped at DOY 256 because the harvest had taken place.

2.2. Measurements

Micrometeorological 30 min data, namely air temperature, solar radiation, relative humidity of air 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 (ET_o) was calculated using the Penman–Monteith equation (Allen et al., 1998).

Soil moisture was measured with a portable FDR sensor (HH2, Delta-T, U.K.) with a calibration obtained in previous works (Fernández and Díaz, unpublished data). This calibration was performed according to the instructions of the sensor and compared the soil moisture measured gravimetrically and the output voltage of the sensor (Eq. (1)). Eq. (1) permits the estimation of the dielectric constant.

$$\theta = 0.4437 \times \text{Volt} - 0.1697\,(1); \quad \left(r^2 = 0.76{*}{*}{*};\ n = 59;\ \text{RMSE} = 0.017\right) \tag{1}$$

where θ: soil moisture measured gravimetrically; Volt: output voltage of the sensor.

The measurements were made in four plots per treatment (one access tube per plot). The access tubes for the FDR sensor were placed in the irrigation line around 30 cm from an emitter. The data were obtained at 1 m depth with a 10 cm interval.

The drought cycle was characterized by weekly measurements of maximum leaf conductance (g) and midday stem water potential (ψ_{stem}). Abaxial leaf conductance was measured in two full expanded and well illuminated leaves per tree in each treatment with a steady state porometer (LICOR-1600, LICOR, UK) around 10:00 GMT, when maximum values are expected (Xiloyannis et al., 1988). Midday stem water potential in one leaf per tree was measured with a pressure chamber (Model 1000, PMS, USA) around 13:00 GMT. Leaves near the main trunk for ψ_{stem} measurements were covered with aluminium foil 2 h before measuring. After the leaf excision, two small cuts parallel to the main nerve were done. These cuts permitted more length in the leaf base to insert in the pressure chamber and increase the grip with the rubber.

In order to describe the cumulative effect of the water deficit, the water stress integral was calculated from the Ψ_{stem} data (Myers, 1988) during the period of water stress (Eq. (2)). In this publication, the integral is estimated with the sum of the surfaces calculated as the average Ψ of two consecutive dates multiplied by the number of days between this dates (Eq. (2)). Myers (1988) referred the surface to the maximum Ψ measured during the experiment (Eq. (2), "c"). Moriana et al. (2012) suggested −1.4 MPa of midday stem water potential as reference value in olive trees during pit hardening period. Stress integral was calculated with both reference values in order to compare the usefulness of the Moriana et al. (2012) reference. All the values higher than the reference were considered as equal to this. The expression used was:

$$S\varphi = \left|\Sigma\,(\Psi - c) \times n\right| \tag{2}$$

where $S\varphi$ is the stress integral; Ψ is the average midday stem water potential for any interval; c is the maximum value of midday stem water potential in the experiment (traditional use) or the value −1.4 MPa.; n is the number of the days in the interval.

The water relations of the leaves and fruits were measured around the time of maximum leaf conductance. Two fully expanded and shaded leaves per tree were randomly cut. Leaf water potential (ψ_{leaf}) was measured with the pressure chamber (Model 1000, PMS, USA) in one of them. This leaf was then covered with aluminium foil and immediately frozen in liquid nitrogen and stored at −80 °C. This sample was used to measure actual osmotic potential (ψ_π). The second leaf was put in a test tube with distilled water, in which only the petiole was in contact with the water. The test tube was covered with aluminium foil and put into a portable freezer until arrival at the laboratory. Then the test tubes were kept in the dark for 24 h at 6–8 °C and then frozen in liquid nitrogen and stored at −80 °C. This sample was used to measure leaf saturated osmotic potential. Fruit water potential was measured with the pressure chamber (Model 1000, PMS, USA) in one fruit per tree in the same shoot where leaf