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Usefulness of trunk diameter variations as continuous water stress indicators of pomegranate (*Punica granatum*) trees

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ABSTRACT

Pomegranate trees (*Punica granatum* L.) is a deciduous fruit tree included in the so-called group of minor fruit tree species, not widely grown but of some importance in the south east of Spain. Pomegranate trees are considered as a culture tolerant to soil water deficit. However, very little is known about pomegranate orchard water management. The objective of this research was to asses the feasibility of using trunk diameter variation (TDV) indexes, obtained by means of LVDT sensors, as a plant water stress indicators for pomegranate trees. The experiment was carried out with mature trees grown in the field under three irrigation regimes: control well watered trees; trees continuously deficit irrigated at 50% of the control regime (SDI); and trees that had a summer water stress cycle being irrigated at 25% of the control rates only in July and August (RDI). The seasonal variations of maximum diurnal trunk shrinkage (MDS) and trunk growth rates (TGR) were compared with midday stem water potential (Ψstem) measurements. During the course of the entire season, control trees maintained lower MDS values than the SDI ones. In the RDI treatment, as water restrictions began, there was a slow increase in MDS, in correspondence with a decrease in Ψstem. When water was returned at full dosage, the RDI quickly recovered to MDS and Ψstem values similar to the control. However, lower MDS for a given Ψstem values were observed as the season advanced. The magnitude of differences between well watered and deficit irrigated trees was much larger in the case of MDS than for Ψstem. However, the tree-to-tree variability of the MDS readings was more than four times higher than for Ψstem; average coefficient of variation of 7.5 and 36% for Ψstem and MDS, respectively. On the other hand, TGR did not clearly reflect differences in tree water status. Overall, results reported indicated that MDS is a good indicator of pomegranate tree water status and it can be further used for managing irrigation. However, the seasonal changes in the MDS-Ψstem relationship should be taken into account when attempting to use threshold MDS values for scheduling irrigation.

1. Introduction

Pomegranate trees (*Punica granatum* L.) belongs to the family Lythraceae. It is a deciduous fruit tree native of central Asia included in the so-called group of minor fruit tree species. At present, the cultivated surface in Spain is more than 3.000 ha. Nowadays, pomegranate culture is steadily increasing because of the high fruit commercial value. Fruit consumption interest is mainly due to the organoleptic characteristics of the arils (i.e. the seeds) and to the beneficial effects on health.

Pomegranate trees are considered as a culture crop tolerant to soil water deficit (Holland et al., 2009). Because of this, in Spain, its culture is concentrated in the south east, where fresh water available for agriculture is very scarce. Nowadays, irrigation scheduling is often based on the FAO method where crop evapotranspiration (ETc) is estimated using the reference evapotranspiration (ETo) times the crop coefficient (Kc), according to the procedure suggested by Allen et al. (1998). However, Kc values for *Punica granatum* are not listed in FAO water use book by Allen et al. (1998). Only recently Bhantana and Lazarovitch (2010) reported water use values of young trees grown in lysimeters in Israel under different soil water electrical conductivity values. Intrigliolo et al. (2011) suggested tentative water needs values for mature field grown trees. However to date no specific studies have investigated

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pomegranate water needs in the field. Hence, alternative methods need to be applied for an efficient irrigation scheduling of *Punica granatum*.

Plant water status information can be used to determine when to irrigate. Recently Intrigliolo et al. (2011) evaluated the usefulness of stem water potential (Ψstem) and leaf gas exchange as water stress indicators for pomegranate trees. However, because this measurements cannot be easily automated there is a need to look for other tools for continuously monitoring plant water status. In this sense trunk dendrometers have been widely assessed in fruit trees to monitor plant water status (Ortuño et al., 2010). From trunk diameter variations (TDV) two indexes are normally obtained, the maximum diurnal trunk shrinkage (MDS) and the trunk growth rate (TGR). Particularly MDS has been shown to have the potential to serve as plant water stress indicator (Fernández and Cuevas, 2010). This is because MDS is normally higher in plants with soil water deficit than in well irrigated trees. However, before using MDS as a parameter to schedule irrigation, its usefulness as water stress indicator for pomegranate trees must be evaluated. This is because despite in many woody crops like citrus (Ortuño et al., 2004), peach (Marsal et al., 2002), apple (Doltra et al., 2007), plum (Intrigliolo and Castel, 2006), almond (Goldhamer and Fereres, 2001) and persimmon Kaki (Badal et al., 2010) MDS was found to be a reliable water stress indicator, there is also some evidence than in other woody perennials such as olive (Moriana and Fereres, 2002) and grapes (Intrigliolo and Castel, 2007) MDS was not always useful for detecting soil water deficit.

In addition to MDS, TGR has been proposed as a water stress indicator, since particularly in young trees a decrease in trunk growth was found as one of the earliest signals of plant water stress development (Moriana and Fereres, 2002; Nortes et al., 2005). However, it is already known that other factors such as phenological stage and crop load (Berman and DeJong, 2003) can affect trunk growth independently of plant water status.

The objective of the experiment was to asses, for the first time for pomegranate trees, the usefulness of both MDS and TGR as a water stress indicators. In trees under three irrigation regimes, seasonal variations of MDS and TGR were compared with midday stem water potential measurements.

2. Materials and methods

2.1. Experimental plot

The experiment was performed during the 2010 season in a commercial mature pomegranate tree orchard (*Punica granatum*, L cv. 'Mollar de Elche') at Elche, Alicante, Spain (38°N, elevation 97 m). The soil was sandy-loam with an effective depth over 120 cm. Trees were planted in 2000 at a spacing of 5 m × 4 m and average tree shaded area was 48% of the soil allotted per tree. Average trunk diameter was 18.2 cm.

Trees received 100, 40 and 80 kg ha^{-1} year^{-1} of N, P2O5 and K2O, respectively. Agricultural practices followed were those common for the area. Weather was recorded at an automated weather station near the orchard. Meteorological variables measured included, solar radiation, air temperature, air humidity, wind speed and direction, and rainfall. Precipitation and reference evapotranspiration (ETo) during the growing season (April to October) were 111 and 811 mm, respectively.

2.2. Treatments

Drip irrigation was applied with eight emitters per tree delivering 4.0 L h^{-1} each and were located in a single line parallel to the tree row. Irrigation treatments were:

Control, where irrigation was scheduled in order to replace 100% of the estimated crop evapotranspiration (ETc). Crop evapotranspiration was estimated as product of reference evapotranspiration (ETo) and crop coefficient (Kc). ETo was calculated with hourly values by the Penman–Monteith formula as in Allen et al. (1998). The Kc values increased from an initial value of 0.27 used in March to a maximum value of 0.77 used in July, August and September according to previous recent findings obtained in the same plot (Intrigliolo et al., 2011).

Sustained deficit irrigation (SDI), where water was constantly applied at 50% of control regime.

Regulated deficit irrigation (RDI) where irrigation was applied at 25% of the control irrigation from July 9 (day of the year DOY 190) to September 3 (DOY 246) coincident with a linear fruit growth phase. During the rest of the season, irrigation was applied at 100% ETc. This RDI regime was chosen in order to start restrictions once fruit drop had finished and fruit had still time, before harvest, to compensate growth once water restrictions ended.

The reductions in the amount of water applied during the deficits were achieved by reducing irrigation duration, while frequency of irrigation was always the same for all treatments. Irrigation frequency changed over the season with all treatments irrigated once a week in early spring and autumn and five times a week during summer.

The experimental design was a randomized complete block, with four replicates per treatment. Each plot had three rows, with 8 trees per row. In each experimental unit, 1–2 central trees of the middle row were used for data collection.

2.3. Determinations

Trunk diameter variations were measured with six linear variable differential transformers (LVDT, Schlumberger Mod. DF-2.5) per treatment. On each experimental tree a sensor was fixed to the main trunk by a metal frame of Invar (a metal alloy with a minimal thermal expansion) located about 20 cm from the ground on the north side. Prior to installation the transformers were individually calibrated by means of a precision micrometer (Verdtech SA, Spain). The typical output coefficient was about 83 mV mm^{-1} V^{-1}. The resolution of trunk diameter measurements including all sources of variation (calibration, non-linearity, excitation and output voltage recording and thermal changes) was about 10 μm. Following protocols explained in Ortuño et al. (2010), from TDV two different indexes were calculated, trunk growth rate (TGR), and maximum daily shrinkage (MDS), the latter obtained as the difference between the maximum diameter reached early in the morning and the minimum reached normally during the afternoon. Daily growth rates were obtained as the difference between the maximum diameter during two consecutive days, and then averaged over ten consecutive days. All sensor data were automatically recorded every 30 s using a data logger (model CR1000 connected to an AM16/32 multiplexer programmed to report mean values every 30 min). The system was powered by batteries. Data collection lasted from June 11 (DOY 162) till November 1 (DOY 305). However, during the experiment there were three periods (June 28 to July 1, August 24 to August 26 and September 21 to September 30) when data were not obtained due to battery power failures.

Stem water potential was measured in the same trees instrumented with LVDT sensors with a pressure chamber, following the procedures described by Turner (1981), in two leaves per tree (total of 12 leaves per treatment). Mature leaves from the north face near the trunk, were enclosed in plastic bags covered with silver foil at least two hours prior to the measurements, which were carried out between 12:00 and 13:00 h solar time, approximately every week. During the course of the entire experiment determinations were