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Usefulness of maximum diurnal trunk shrinkage as a continuous water stress indicators of pomegranate (*Punica granatum*) trees

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Abstract. The objective of this research was to assess the feasibility of using maximum diurnal trunk shrinkage (MDS) 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: (i) control (well watered trees); (ii) trees continuously deficit irrigated at 50% of the control regime (SDI); and (iii) trees that had a summer water stress cycle being irrigated at 25% of the control rates only in July and August (RDI). 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 stem water potential (Ψ_{stem}). When water was returned at full dosage, the RDI recovered to MDS and Ψ_{stem} values similar to the control. However, lower MDS for a given 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 Ψ_{stem} . The tree-to-tree variability of the MDS readings was more than four times higher than for Ψ_{stem} .

Keywords. Deficit irrigation – LVDT – Stem water potential.

I – Introduction

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 (ET_c) is estimated using the reference evapotranspiration (ET_o) times the crop coefficient (K_c), according to the procedure suggested by Allen *et al.* (1998). However, K_c values for *Punica granatum* are not listed in FAO water use book by Allen *et al.* (1998). 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 (Ψ_{stem}) 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 to continuously monitoring plant water status. In this sense trunk dendrometers have been widely assessed in fruit trees to monitor plant water status (Férrandez and Cuevas 2010). From trunk diameter variations (TDV) maximum diurnal trunk shrinkage (MDS) can be obtained and it has been shown that MDS has the potential to serve as plant water stress indicator (Férrandez 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.

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

II – Material and methods

1. Experimental orchards

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 x 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, air temperature and humidity and rainfall. Precipitation and reference evapotranspiration (ET_o) during the growing season (April to October) were 111 and 811 mm, respectively.

2. Irrigation 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:

(i) Control, where irrigation was scheduled in order to replace 100% of the estimated crop evapotranspiration (ET_c). Crop evapotranspiration was estimated as product of reference evapotranspiration (ET_o) and crop coefficient (K_c). ET_o was calculated with hourly values by the Penman-Monteith formula as in Allen *et al.* (1998). The K_c 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).

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

(iii) 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% ET_c.

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, a central trees of the middle row were used for data collection.

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 $83 \text{ mV mm}^{-1} \text{ V}^{-1}$. The resolution of trunk diameter measurements including all sources of variation (calibration, non-linearity, excitation and output voltage recording and thermal changes) was about $10 \text{ }\mu\text{m}$. From TDV the maximum daily shrinkage (MDS) was calculated as the difference between the maximum diameter reached early in the morning and the minimum reached normally during the afternoon. 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 8 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 carried out in the Control and SDI treatments. On the other hand, in the RDI trees, Ψ_{stem} was only measured during the RDI cycle and until 45 days after the end of the water restriction period.

4. Data analysis

The effects of the irrigation regime on Ψ_{stem} and MDS was evaluated by analysis of variance using the general linear models "GLM" procedure of the SAS software (version 9.0; SAS Institute, Cary, NC).

III – Results and discussion

The experiment was carried under contrasting evaporative demand regimes. During the summer (till day of the year, DOY 250) daily E_{To} values were around 5 to 6 mm, except for three days, which values were around 7 mm. On the other hand, from DOY 250 onwards, E_{To} had a clear decreasing tendency (Fig. 1A). Over the course of the experiment, rainfall was scarce, and only more noticeable by the end of the experiment (Fig. 1A).

When TDV data collection started, the SDI treatment had already been irrigated at 50% of the Control regime. This explains why the SDI trees since the beginning of the experiment had statistically significant ($P < 0.05$) lower Ψ_{stem} values than the control trees (Fig. 1B). On the other hand, initial differences in MDS, were not statistically significant ($P > 0.05$, Fig. 1C). Differences in Ψ_{stem} and MDS between control trees and SDI ones statistically significant at $P < 0.05$ by the middle of the summer (DOY 190 to 230). At the end of the experiment, there were still statistically significant differences in Ψ_{stem} between SDI and the control trees, but MDS of the SDI trees decreased as the evaporative demand became lower and differences with respect to the MDS value of the control trees were small and not statistically significant ($P > 0.05$).

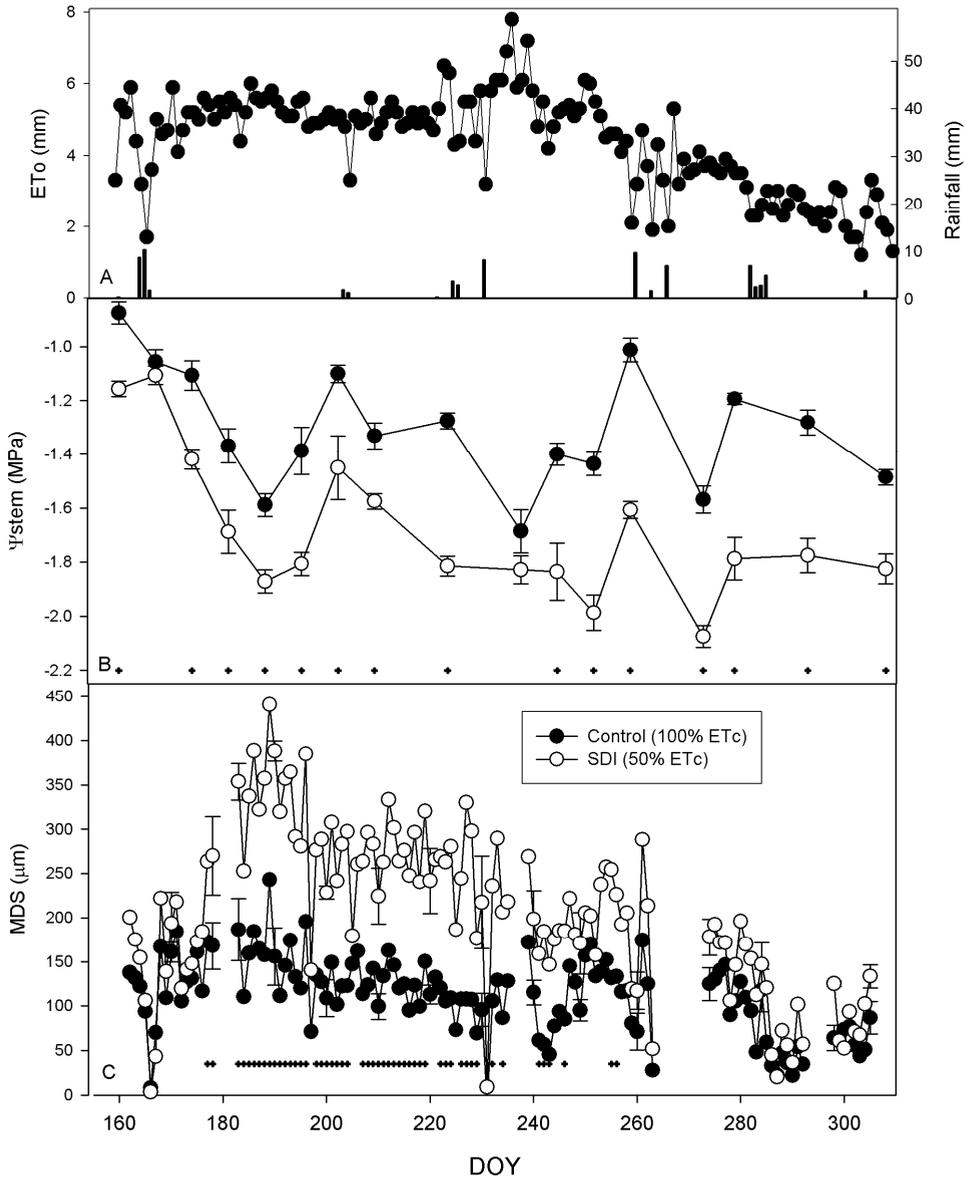


Fig. 1. Seasonal pattern of A) daily reference evapotranspiration (ETo) and rainfall, B) midday stem water potential (Ψ_{stem}), C) maximum diurnal trunk shrinkage (MDS). The error bars indicate the standard error. + denotes statistically significant differences among treatments at $P < 0.05$. DOY, day of the year.

At the beginning of the experiment, the RDI trees had surprisingly higher Ψ_{stem} than the control trees (Fig. 2A), but similar MDS (Fig. 2B). Only two weeks after restrictions started, the RDI trees water status became significantly lower than the control. A decrease in Ψ_{stem} was associated with a progressive increase in MDS. However statistically significant differences

among treatments could be detected earlier for Ψ_{stem} than for MDS (Fig. 2). On the other hand, once the water stress cycle was ended, the RDI trees very quickly recovered to values similar to the control ones (Fig. 2).

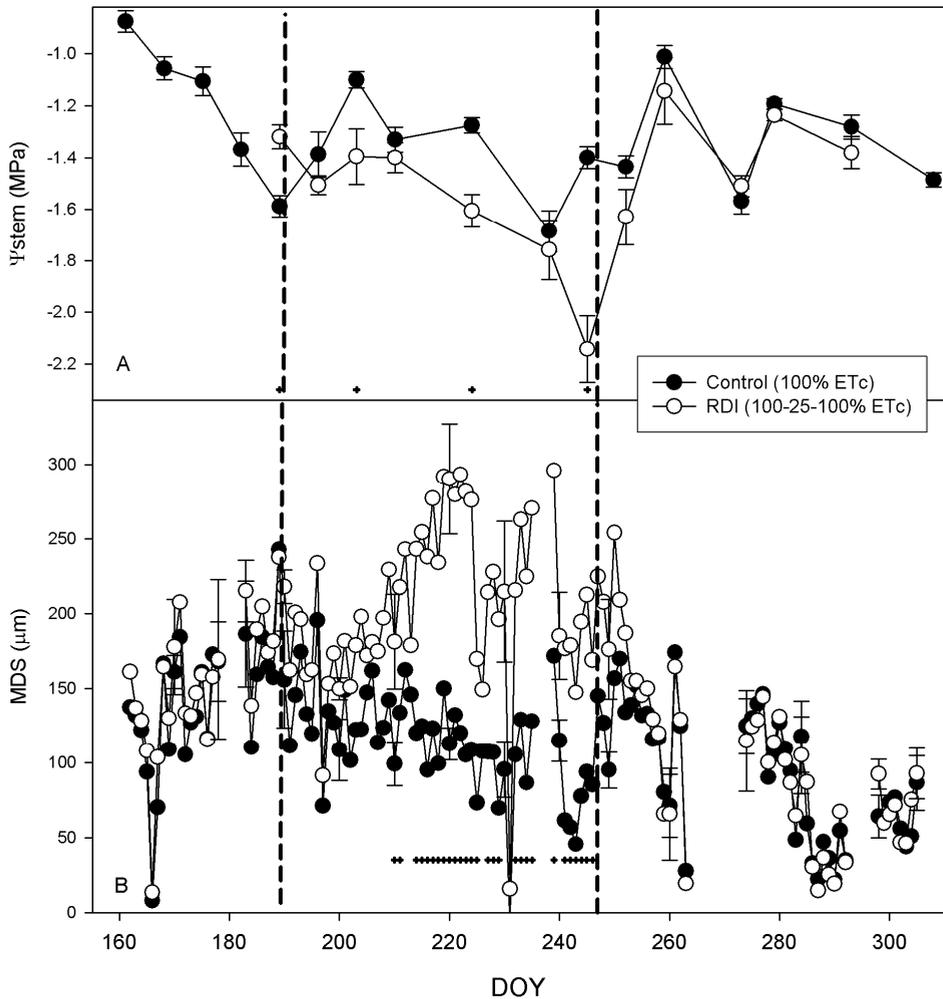


Fig. 2. Seasonal pattern of A) midday stem water potential (Ψ_{stem}) and B) maximum diurnal trunk shrinkage (MDS). The error bars indicate the standard error. + denotes statistically significant differences among treatments at $P < 0.05$. The vertical dotted lines enclosed the period when RDI trees were irrigated at 25% of the control regime. DOY, day of the year.

Taking into consideration SDI and control trees, in general, the signal intensities (stress/control) was almost double for MDS than for Ψ_{stem} (Fig. 3). In fact, maximum signal values obtained for Ψ_{stem} were around 1.5; while for MDS they reached up to 3.2 (Fig. 3). However, by the end of the experiment, under lower evaporative demand and with some rainfall events (Fig. 1A) the MDS signal intensity decreased to similar Ψ_{stem} signal intensity values (Fig. 3).

Considering MDS and Ψ_{stem} values obtained in the RDI and control trees, there was a progressive increase in the MDS signal during the restriction period (Fig. 3). Immediately after restriction ended signal values returned to values close to 1.

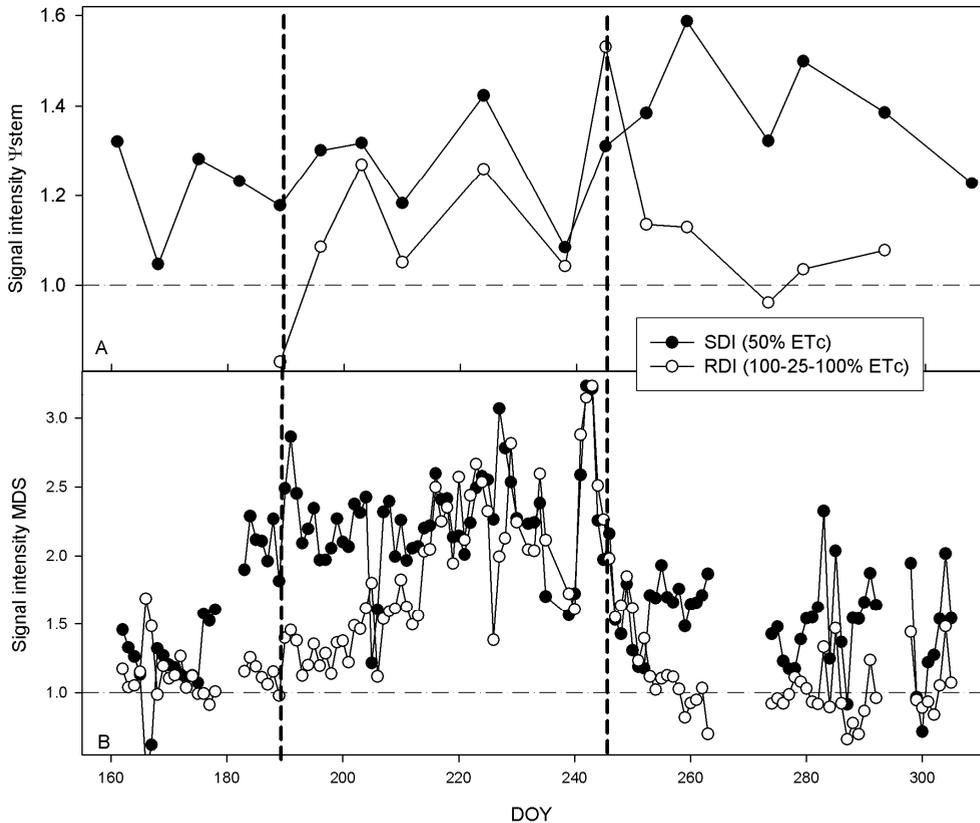


Fig. 3. Seasonal pattern of the signal intensity (stress:control) for midday stem water potential (Ψ_{stem}) and maximum diurnal trunk shrinkage (MDS). The vertical dotted lines enclosed the period when RDI trees were irrigated at 25% of the Control regime. DOY, day of the year. The SDI trees were always irrigated at 50% of the Control water applications. Data shown are average of 12 and 6 determinations per treatment for Ψ_{stem} and MDS, respectively.

The results presented showed that MDS can be considered as a sensitive indicator of Pomegranate plant water status. As water was restricted, trunk shrinkage appeared to be a good indicator of the onset of plant water stress. However, it is important to note that statistically significant differences between irrigation regimes could be detected earlier for Ψ_{stem} than for MDS. This is probably due to the high MDS tree-to-tree variability that precluded to detect with statistical significance small differences between treatments. Contrarily, previous reports in plum (Intrigliolo and Castel 2004) and peach (Remorini and Massai 2003) trees showed how MDS was able to detect differences in plant water status between trees under different irrigation regimes earlier than Ψ_{stem} .

Indeed, the good sensitivity of MDS as a water stress indicator makes it a suitable parameter for scheduling irrigation in this crop. Data reported in Fig. 1C, clearly show that in control trees

MDS was always lower than 150-175 μm . These values could be adopted as a threshold for detecting the onset of mild water stress.

Pooling data from the entire experiment the relationship between MDS and Ψ_{stem} was weak ($r^2=0.30^{**}$). When data were separated according to different periods (from DOY 168 to DOY 224 and from DOY 225 onwards) there was a statistically significant difference ($P<0.05$) in the slopes of the MDS- Ψ_{stem} relationships (Fig. 6). Within each single period, the relationship was tighter than with the entire data set, particularly for data corresponding with the last part of the season.

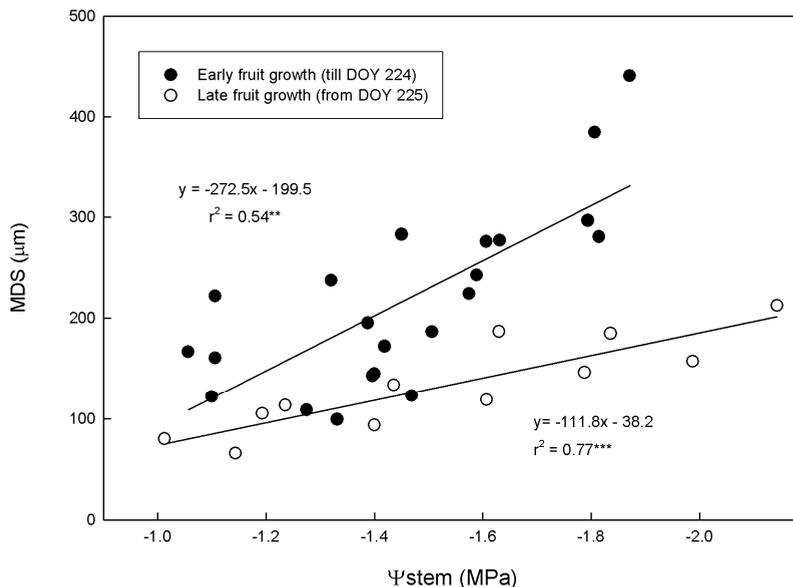


Fig. 4. Relationship between maximum diurnal trunk shrinkage (MDS) and midday stem water potential (Ψ_{stem}). Data are average treatment of 12 and 6 determinations for Ψ_{stem} and MDS, respectively. Values are separated according to two periods: from day of the year (DOY) 168 to DOY 224 and from DOY 225 onwards. *** and ** indicates statistically significance at $P<0.001$ and $P<0.01$, respectively. DOY, day of the year.

This suggest that there was not a single unique relationship between MDS and Ψ_{stem} valid for the whole period. This behavior is similar to other cases, such plum (Intrigliolo and Castel 2006) where the relationship between MDS and Ψ_{stem} changed in concordance with some changes in the fruit growth pattern or fruit removal. In the present experiment, fruit were present during all the course of the experiment, but fruit growth rates were higher till DOY 224 than later on (results not-shown). It is also possible that the different relationship obtained between MDS and Ψ_{stem} during the seasons is due to changes in tissue elasticity. It is generally accepted that tissue age affects its elasticity, older tissues being less elastic (higher resistance to shrinkage; Tyree and Jarvis 1982). Therefore, the lower MDS for a given Ψ_{stem} value obtained late in the season may be due to less elastic, older tissues.

IV – Conclusions

Results presented indicate that MDS could be used in commercial orchards for detecting plant water stress; however, a large number of trees need to be monitored and occasional determinations of plant water status need to be carried out in order to complement the on-line continuous monitoring plant water status obtained by MDS. This is particularly important considering the change in the relationship between MDS and Ψ_{stem} reported.

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