Plant water status indicators for detecting water stress in pomegranate trees

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SUMMARY

Measurements obtained by the continuous monitoring of trunk diameter fluctuations were compared with discrete measurements of midday stem water potential (Ψ_{stem}) and midday leaf conductance (g_l) in adult pomegranate trees (*Punica granatum* (L.) cv. Mollar de Elche). Control plants (T0) were irrigated daily above their crop water requirements in order to attain non-limiting soil water conditions, while T1 plants were subjected to water stress by depriving them of irrigation water for 34 days, after which time irrigation was restored and plant recovery was studied for 7 days. T1 plants showed a substantial degree of water stress, which developed slowly. Maximum daily trunk shrinkage (MDS) was identified to be the most suitable plant-based indicator for irrigation scheduling in adult pomegranate trees, because its signal:noise ((T1/T0):coefficient of variation) ratio was higher than that for Ψ_{stem} ((T1/T0):coefficient of variation) and g_l ((T0/T1):coefficient of variation). MDS increased in response to water stress, but when the Ψ_{stem} fell below −1.67 MPa, the MDS values decreased.

Key words: Plant water relations; *Punica granatum*; trunk diameter fluctuations

1. Introduction

Pomegranate (*Punica granatum* L.) is a very interesting fruit tree species because it has drought resistant characteristics [1], being able to thrive well in arid and semiarid areas, even under desert conditions [2]. However, to reach optimal growth, yield and fruit quality, pomegranate trees require regular irrigation, particularly during the dry season [3].

The use of plant-based water status indicators has become very popular for planning precise irrigation, because plant water status may be the ideal method for predicting crop performance under a given irrigation scheduling regime. Since plant water status controls many physiological processes and crop productivity, this information can be highly useful in irrigation scheduling [4]. Measurements of trunk diameter fluctuations (TDF) using trunk diameter sensors provide continuous and automated recording of maximum daily trunk shrinkage (MDS), which has been shown to be suitable for the development of automated irrigation scheduling in fruit trees [5].

In this study, the sensitivity of MDS in comparison with other discretely measured indicators of plant water status in response to a cycle of water deprivation and recovery was studied.

2. Materials and Methods

2.1. Plant material, experimental conditions and treatments

The experiment was carried out in 2009 on a farm located near the city of Murcia (Spain) (37°57' N, 0°56'W). The plant material consisted of own rooted 10-year old pomegranate trees (*Punica granatum* L.) cv. Mollar de Elche, with an average trunk diameter of about 15 cm. Tree spacing followed a 3 m × 6 m pattern, with an average ground cover of about 59 %.

The soil of the orchard was a weakly saline Xeric Torriorthent, with silt loam texture. The

irrigation water had an electrical conductivity of between 1.7 and 2.2 dS m^{-1} and the Cl^- concentration in the irrigation water ranged from 36 to 48 mg l^{-1}.

Control plants (treatment T0) were irrigated above crop water requirements (115 % ETo), using six emitters (each delivering 4 l h^{-1}) per plant. Irrigation in T1 plants was withheld for 34 days (from day of the year (DOY) 209 to 243, second half of rapid fruit growth period). The recovery of plants was ensured by re-irrigation at the levels used in T0 for 6 days (from DOY 244 to 250). Total water amounts applied in the experimental period were 261 and 38 mm for T0 and T1 treatments, respectively.

During the experiment pest control and fertilization practices were those usually used by local growers, and no weeds were allowed to develop within the orchard. Irrigation was carried out daily and during the night using a drip irrigation system with one lateral pipe per tree row.

2.2 Measurements

Meteorological data were collected by automatic weather stations located near the experimental sites. Mean daily air vapour pressure deficit (VPD_m) and daily crop reference evapotranspiration (ETo) were calculated according to Allen et al. [6].

Midday (12 h solar time) stem water potential (Ψ_{stem}) was measured on the south facing side and the middle third of the trees, in two fully developed leaves per tree of each replicate, enclosing leaves in small black plastic bags covered with aluminium foil for at least 2 h before measurements in the pressure chamber (model 3005, Soil Moisture Equipment Co., Santa Barbara, CA, USA). Midday leaf conductance (g_l) in attached leaves was measured with a steady-state porometer (LI-1600, LICOR Inc., Lincoln, USA) on the abaxial surface of the leaves and in a similar number and type of leaves as used for the Ψ_{stem} measurements

The micrometric trunk diameter fluctuations (TDF) were measured throughout the experimental periods in four trees per treatment, using a set of linear variable displacement transducers (LVDT) as indicated by Moriana et al. [5]. MDS was calculated as the difference between the daily maximum diameter and the minimum diameter.

To compare the sensitivity of the plant-based indicators for use as water stress indicators it is more suitable to compare their values relative to those of the control trees. For this, the signal intensity of both continuous and discrete plant water status measurements were defined as the relative values (T1/T0 or T0/T1), while variability or noise was defined as the coefficient of variation of the mean. Thus, the signal:noise ratio integrates both the indicator strength and its variability, and is important for assessing the usefulness of plant-based water stress indicators for irrigation scheduling.

2.3 Statistical analysis

The design of the experiment was completely randomized with four replications. Data were analyzed using SPSS software [7]. Analysis of variance was performed and means values were compared by an $LSD_{0.05}$ test. Values for each replicate were averaged before the mean and the standard error of each treatment were calculated.

3. Results and Discussion

During the experimental period, average daily maximum and minimum air temperatures were 32.5 and 20.2 ºC, respectively. VPD_m ranged from 0.98 to 2.84 kPa, and accumulated ETo was 226 mm. There was no rainfall during the experimental period.

The high Ψ_{stem} and g_l values in T0 plants throughout both experimental periods (Figure 1A and B) suggested that control pomegranate plants were under non-limiting soil water conditions. Despite that T1 plants at the end of the water withholding period pointed to a relatively strong water stress situation, the decrease in Ψ_{stem} values at a rate of around 0.025 MPa d^{-1} indicates that the water stress developed quite slowly (Figure 1A and B).

MDS values showed substantial fluctuations during the experimental period (Figure 1C). Differences between T0 and T1 treatments were evident as early as four days after the imposition of water stress, due to the MDS increase in T1 plants (Figure 1C). When T1 plants were rewatered, MDS values fell and were similar in both treatments during the recovery period.

The fact that MDS signal:noise ratio was higher than that for Ψ_{stem} and g_l for all the intervals of time considered (Table 1) suggested that MDS is the most suitable indicator for pomegranate irrigation scheduling. In this sense, Ortuño et al. [8] showed that continuously measured plant water status indicators were more immediate and sensitive than discretely measured indicators. Moreover, Remorini and Massai [9]

indicated that trunk diameter fluctuations differed between irrigation treatments even in the absence of differences in Ψ_{stem}, and Goldhamer et al. [10] indicated that MDS responded sooner than Ψ_{stem} to water stress.

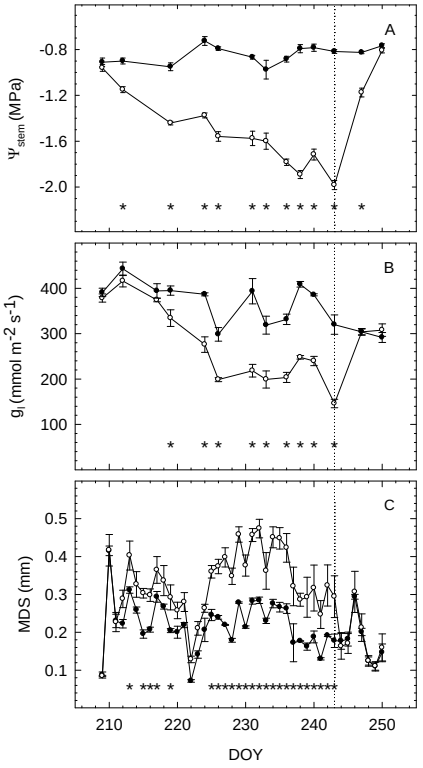

Figure 1. *Midday stem water potential (Ψ_{stem}) (A), midday leaf conductance (g_l) (B) and maximum daily trunk shrinkage (MDS) (C) in T0 (closed symbols) and T1 (open symbols) plants during the 2009 experimental period. Bars on data points are ± S.E. of the mean (not shown when smaller than symbols). Vertical dotted line indicated the time at which irrigation was restored. Asterisks indicate statistically significant differences by least significant difference at 5% level ($LSD_{0.05}$) range test. Each point is the mean of four values*

Taking into consideration the Ψ_{stem} values obtained during the experimental period and the MDS values taken at the same times, a polynomial relationship between both parameters (MDS (mm) = 0.419 + 0.979Ψ_{stem} (MPa) + 1.118Ψ_{stem}^2 (MPa) + 0.331Ψ_{stem}^3 (MPa), r^2 = 0.685, MSE = 0.003) was evident in the range of water stress studied (Ψ_{stem} values from –0.72 to –1.98 MPa) (Figure 2).

Table 1. Mean signal intensity, mean noise, and signal:noise ratio of maximum daily trunk shrinkage (MDS), midday stem water potential (Ψ_{stem}) and midday leaf conductance (g_l) at different intervals of the 2009 water stress period. For each interval, mean signal or mean noise values that do not have a common letter are significantly different according to the $LSD_{0.05}$ range test.

DOY		Mean signal	Mean noise	Signal: noise
209-217	MDS	1.24a	0.17a	7.31
	Ψ_{stem}	1.27a	0.21a	6.16
	g_l	1.04a	0.15a	6.93
209-224	MDS	1.31ab	0.17b	7.84
	Ψ_{stem}	1.46a	0.23a	6.27
	g_l	1.15b	0.15b	7.73
209-231	MDS	1.37ab	0.17b	7.95
	Ψ_{stem}	1.59a	0.22ab	7.13
	g_l	1.29b	0.24a	5.34
209-238	MDS	1.41b	0.17b	8.24
	Ψ_{stem}	1.72a	0.23a	7.39
	g_l	1.40b	0.23a	6.07
209-243	MDS	1.46b	0.18b	8.31
	Ψ_{stem}	1.81a	0.24a	7.63
	g_l	1.49b	0.26a	5.82

This relationship was characterized by two different phases. Above Ψ_{stem} values of -1.67 MPa, MDS values increased sharply as Ψ_{stem} decreased, and when Ψ_{stem} values were below this threshold value the relationship changed and any further reduction in Ψ_{stem} was associated with a decrease in MDS. This is the behaviour more frequent in most species values [11]. However, Intrigliolo et al. [12], suggested that the best fit between MDS and Ψ_{stem} in pomegranate trees was obtained with a linear regression, and that there was not a single unique relationship between both variables valid for the whole season due to changes in fruit growth pattern and fruit removal. In this sense, our data also revealed the possibility of presenting the relationship between MDS and Ψ_{stem} by means of a first-order fit (MDS (mm) = 0.056 - 0.168Ψ_{stem} (MPa), r^2 = 0.587, MSE = 0.004) but the correlation obtained was worse than for the polynomial regression model (Figure 2). In our opinion, to clarify the model that defines the relationship between both variables, a higher number of MDS data points corresponding to Ψ_{stem} values below -1.67 MPa would have been necessary.

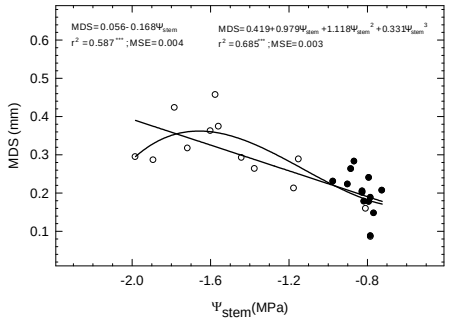

Figure 2. *Relationship between and maximum daily trunk shrinkage (MDS) and stem water potential (Ψ_{stem}) in T0 (closed symbols) and T1 (open symbols) plants during the 2009 water stress period. Each value is the mean of four measurements*

4. Conclusions

The results indicated that MDS is a reliable plant-based water stress indicator in adult pomegranate trees. In addition, the fact that LVDT sensors used in the experiment did not have to be repositioned, together with other operational advantages over discretely measured indicators, such as the low labour costs involved and the possibility of connection to remotely operated irrigation controllers, confirm that MDS is a suitable plant-based indicator for precise irrigation scheduling practices based on plant water status measurements.

5. Acknowledgements

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6. References

[1] Rodríguez, P., Mellisho, C.D., Conejero, W., Cruz, Z.N., Ortuño, M.F., Galindo, A., Torrecillas, A., 2012. Plant water relations of leaves of pomegranate trees under different irrigation conditions. Environ. Exp. Bot. 77: 19-24.

[2] Sarkhosh, A., Zamani, Z., Fatahi, R.. Ebadi, A., 2006. RAPD markers reveal polymorphism among some Iranian pomegranate (*Punica granatum* L.) genotypes. Sci. Hort. 111: 24–29.

[3] Holland, D., Hatib, K., Bar-Yàakov, I., 2009. Pomegranate: botany, horticulture, breeding. Hortic. Rev. 35: 127–191.

[4] Fernández, J.E., Cuevas, M.V., 2010. Irrigation scheduling from stem diameter variations: a review. Agric. For. Meteorol. 150: 135-151.

[5] Moriana, A., Girón, I.F., Martín-Palomo, M.J., Conejero, W., Ortuño, M.F., Torrecillas, A., Moreno, F., 2010. New approach for olive trees irrigation scheduling using trunk diameter sensors. Agric. Water Manage. 97: 1822-1828.

[6] Allen, R.G., Pereira, R.S., Raes, D., Smith, M., 1998. Crop evapotranspiration-guidelines for computing crop water requirements. FAO Irrigation and Drainage paper No 56. Rome, Italy, pp 15–27.

[7] SPSS Inc., 2002. SPSS Professional Statistics. Business Intelligence Division, v. 12, Chicago

[8] Ortuño, M.F., García-Orellana, Y., Conejero, W., Ruiz-Sánchez, M.C., Alarcón, J.J., Torrecillas, A., 2006 Stem and leaf water potentials, gas exchange, sap flow and trunk diameter fluctuations for detecting water stress in lemon trees. Trees 20: 1–8.

[9] Remorini, D., Massai, R., 2003. Comparison of water status indicators for young peach trees. Irrig. Sci. 22: 39–46.

[10] Goldhamer, D.A., Fereres, E., Mata, M,. Girona, J., Cohen, M, 1999. Sensitivity of continuous and discrete plant and soil water status monitoring in peach trees subjected to deficit irrigation. J. Am. Soc. Hortic. Sci. 124: 437-444.

[11] Ortuño, M.F., Conejero, W., Moreno, F., Moriana, A., Intrigliolo, D.S., Biel, C., Mellisho, C.D., Pérez-Pastor, A., Domingo, R., Ruiz-Sánchez, M.C., Casadesus, J., Bonany, J., Torrecillas, A., 2010. Could trunk diameter sensors be used in woody crops for irrigation scheduling? A review of current knowledge and future perspectives. Agric. Water Manage. 97: 1-11.

[12] Intrigliolo, D.S., Puerto, H., Bonet, L., Alarcón, J.J., Nicolás, E., Bartual, J., 2011b. Usefulness of trunk diameter variations as a continuous water stress indicators of pomegranate (*Punica granatum*) trees. Agric. Water Manage. 98: 1462-1468.