Stem water relations provide new insights on shrinkage–swelling phenomena in olive trees

Cocozza C[1], Marino G[1,3], Giovannelli A[2], Cantini C[2], Centritto M[3], Tognetti R[1]

[1]Dipartimento di Bioscienze e Territorio, Università del Molise, Italy
[2]Laboratorio di Xilogenesi, Istituto per la Valorizzazione Legno e delle Specie Arboree (IVALSA), Consiglio Nazionale delle Ricerche, Italy
[3]Istituto per la protezione delle Piante (IPP), Consiglio Nazionale delle Ricerche, Italy

Introduction

Environment affects the timing, rate and dynamics of tree growth. Monitoring how stem radius varies during circadian cycles can provide insight into plant growth dynamics, as well as on soil water availability. Simultaneous measurements of sap flow and evaporative demand may further improve the understanding of impacts on tree physiology and growth processes, namely drought and temperature stress in Mediterranean environments. Continuous stem water relations (sap flux and radial variation) and soil moisture, diurnal and seasonal trends of leaf photosynthesis (A), stomatal conductance (gs) and leaf water potential (Ψl) and evaporative demand were monitored in an olive orchard under two different irrigation regimes in central Italy. The long-term hydraulic acclimation of olive trees to deficit irrigation is well documented. The main objective of this research was to describe the seasonal patterns of plant dynamics and to couple these processes in a framework suitable for application in modelling schemes.

Materials and Methods

The experiment was conducted during the year 2011 at the Santa Paolina experimental farm of CNR- IVALSA, located in Follonica (GR), Toscana, central Italy (42°55'58''N, 10°45'51''E, 17 m a.s.l.), in a olive orchard of 10-year-old trees (*Olea europaea* L., cv. Leccino), under rainfed and irrigated (well-watered, control), cultivated at single-trunk free canopy at a spacing of 4 m × 4 m.

Meteorological data: standard meteorological digital station (Fig. 1).

Soil water content: soil moisture sensors (model PS-0077-DD, Netsens s.r.l, Florence, Italy).

Leaf water potential: Scholander-type pressure chamber (SKPM 1400, Skye Instruments, Llandrindod Wells, UK).

Gas exchange measurements: leaf chamber fluorometer (LI-6400-40, Li-Cor, Inc., Nebraska, USA) (Fig. 2).

Stem radius variations: automatic point dendrometers (Label et al. 2000) (Fig. 3).

Sap flow measurements: Granier-type sensors (Fig. 4).

Time series comparison of hourly stem radius variations were statistically analysed with the Time Series Analysis Programme (TSAP) software package (Frank Rinn, Heidelberg, Germany), which was originally developed as a tool for cross-timing of tree-ring series.

Mathematical analysis: OriginPro software package (OriginLab, Massachusetts, USA).

The derivative of the function at a chosen input value describes the best linear approximation with respect to time of the function near that input value.


Fig. 1


Fig. 2


Fig. 3

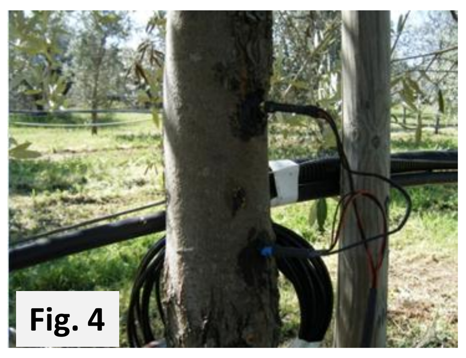


Fig. 4

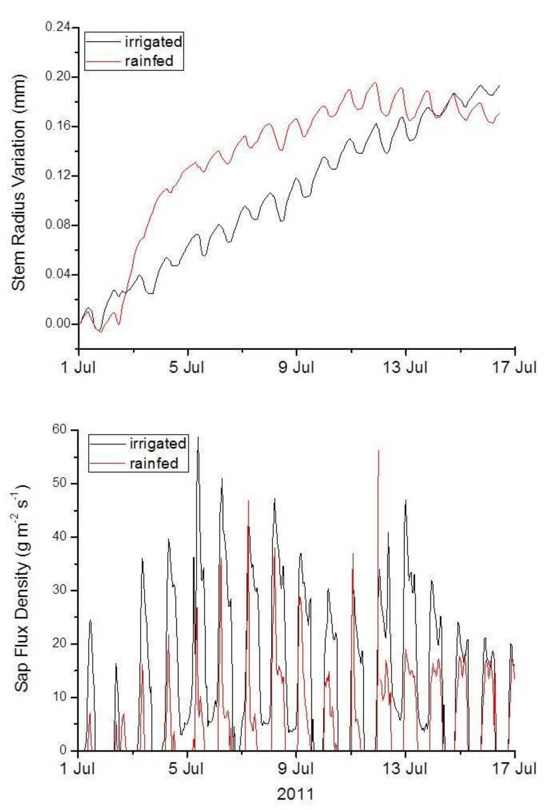


Fig. 7. Variations of stem diameter and sap flow density in a representative period. A strong similarity between comparison coefficients was found for patterns of the time series of stem radius variation in irrigated and rainfed conditions, whereas, low similarity coefficients were for sap flux series.
Dendrometer series: Glk = 55 ÷ 89; GSL = ***; TVBP = 100; Sap flux density series: Glk = 48 ÷ 71; GSL = * / ***; TVBP = 1.1 ÷ 20.1.

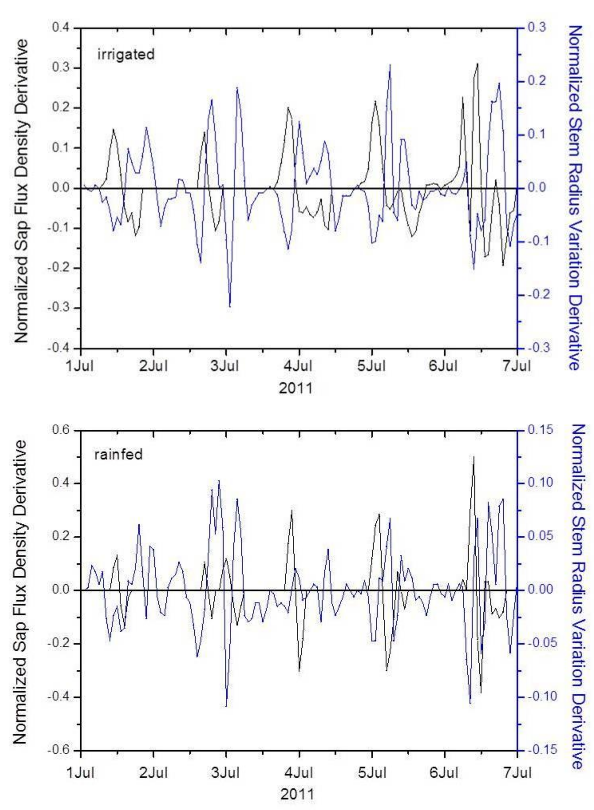


Fig. 8. Normalized derivatives of sap flow density and stem radius variation in a representative period.
The derivative of the function at a chosen input value describes the best linear approximation with respect to time of the function near that input value.

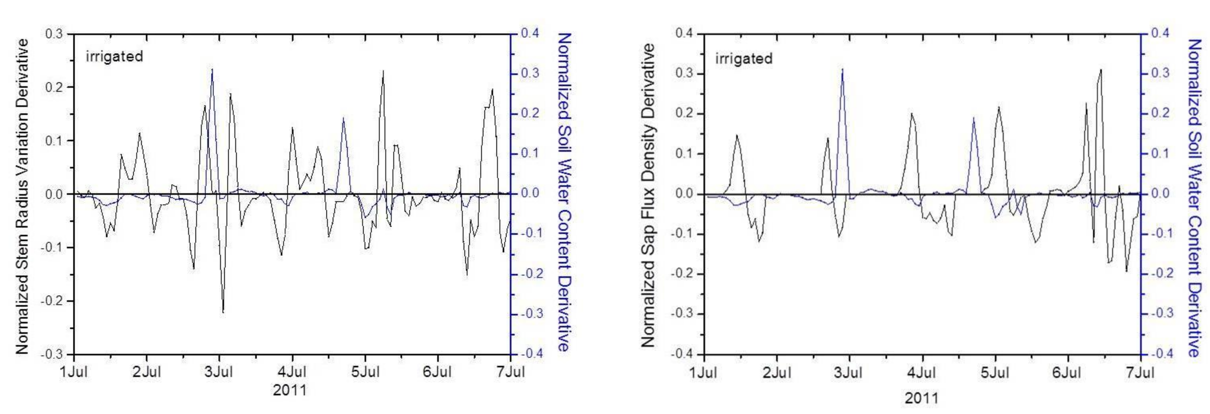


Fig. 9. A representative synchronization of the normalized derivatives of stem radius and sap flow density with soil water content in irrigated plant in July.

Results and Discussion

	SWC (%)					
Time	*28 March*	*22 June*	*21 July*	*24 August*	*28 September*	*16 November*
10 cm depth						
Control	26.18 ± 0.35	32.13 ± 0.43	34.24 ± 0.45	34.84±0.47	33.51 ± 0.45	33.73 ± 0.41
Rainfed	18.70 ± 0.25 ***	9.67 ± 0.13 ***	18.36 ± 0.24 ***	16.20 ± 0.22 ***	14.95 ± 0.20 ***	30.76 ± 0.45 **
30 cm depth						
Control	24.21 ± 0.32	33.20 ± 0.44	29.78 ± 0.40	27.74 ± 0.37	20.51 ± 0.27	28.84 ± 0.39
Rainfed	23.43 ± 0.31	10.90 ± 0.44 ***	15.61 ± 0.21 ***	13.70±0.18 ***	12.56 ± 0.17 ***	29.38 ± 0.38

Table 1. Volumetric soil water content (SWC) measured at the soil depths of 10 cm and 30 cm during the growing season. Data are mean of four blocks per treatment ± 1 SEM. Asterisks indicate statistically significant differences between the two treatments (*** = P < 0.001, ** = P < 0.01).

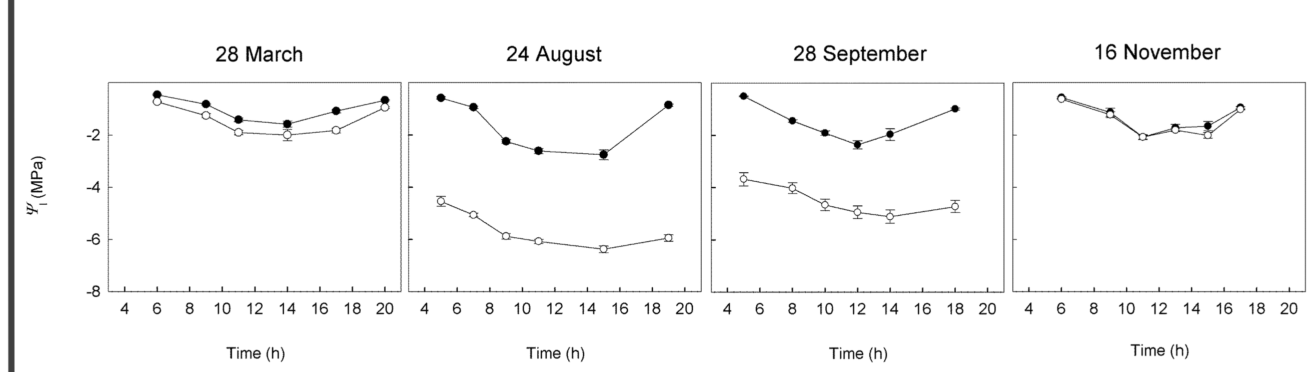
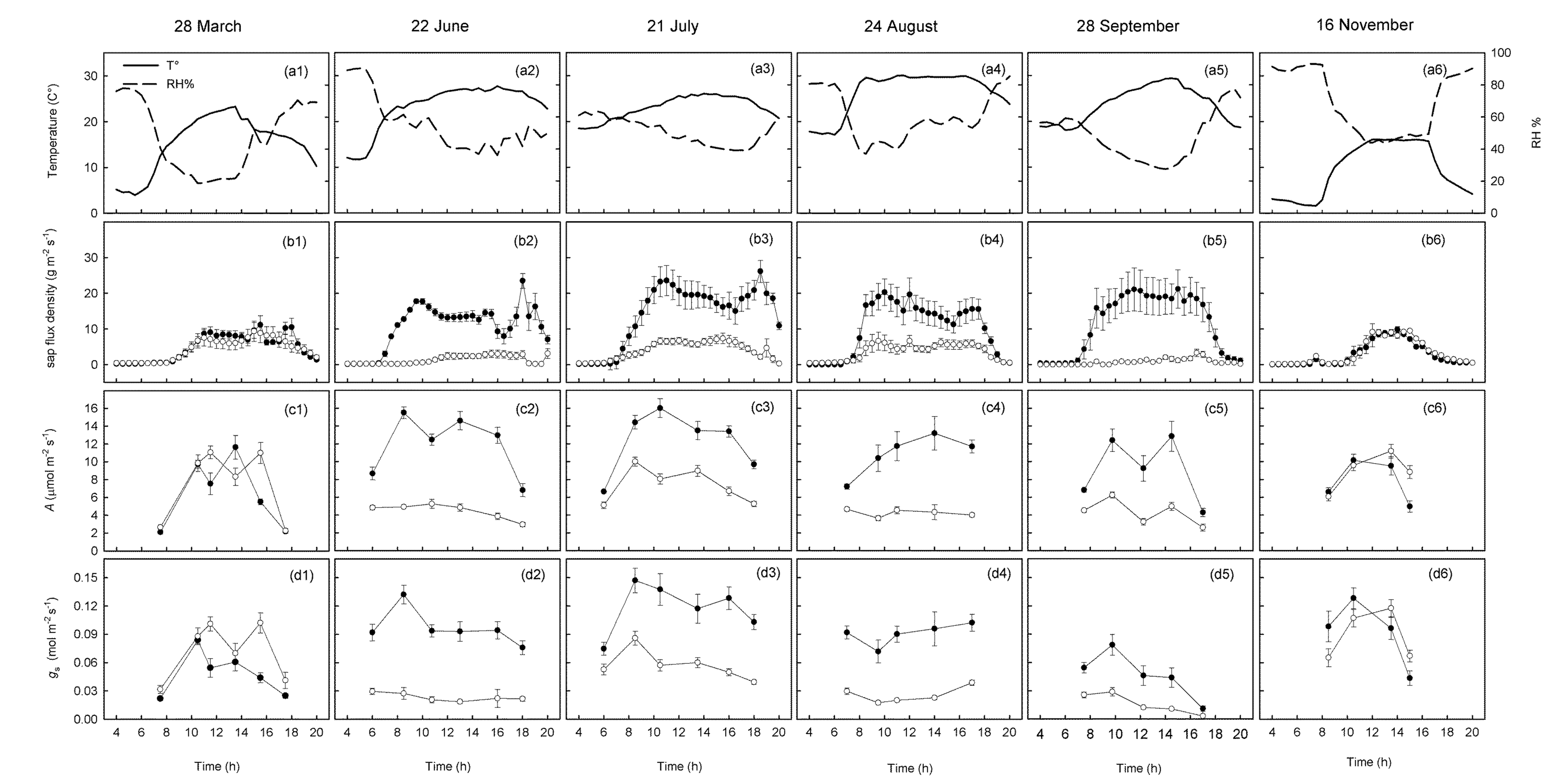


Fig. 5. Daily course of leaf water potential (Ψl) measured in well-watered (●) and rainfed (○) plants during the growing season. Data are mean of three plants per treatment (five leaves per tree) ± 1 SEM.

Fig. 6. Daily course of air temperature and relative humidity (a1,6), sap flux density (b1,6), photosynthetic rate (A) (c1,6) and stomatal conductance (gs) (d1,6) in well-watered (●) and rainfed (○) plants in representative days of the growing season 2011. Data are mean of three plants per treatment ± 1 SEM.



In the daily course, the good correspondence between gs, Ψl and SWC across treatments (Table 1, Fig. 5, Fig. 6) suggested that olive trees were able to restrict, at least partially, water loss by closing stomata. The difference between predawn and midday Ψl tended to increase with decreasing soil water availability (and soil water potential) because of a combination of moderate stomatal regulation of transpiration rate and the usually higher transpiration demand in drier periods. Indeed, these olive trees presented anisohydric behaviour in relation to soil drought.

In the continuous monitoring (Fig. 7), the mathematical approach (Fig. 8, Fig. 9) was adopted to synchronize tree functions and environmental parameters was proved useful to test plant acclimation and resilience to stress in field conditions (Cocozza et al. 2009, J Exp Bot 60, 3655–3664; Cocozza et al. 2012, Agr For Meteorol 161, 80– 93), providing insights on shrinkage–swelling and water fluxes phenomena at the trunk level in relation to irrigation cycles, which are difficult to detect with empirical variation records. This type of analysis allows the rate of variation of a function to be emphasized; when the derivative is found to be positive, the input function is increasing, while when it is negative the function is decreasing. Moreover, the higher value of the derivative the faster is the change in the value of the function. The intersection of the derivative curve with the x-axis, i.e. the null value of the derivative, corresponds to an extreme of the input function. A positive (negative) derivative that intersects the x-axis indicates a local maximum (minimum) of the input function. Seasonal trend of soil water content was regular, considering long term records for the area, which represented a regular signal explaining the relationship between environmental conditions and plant functionality.

Conclusions

This experiment on olive trees is the first to our knowledge that combines diurnal and seasonal trends of leaf gas-exchange, stem radius variation and sap flow trends. This study further showed that the cross-correlation approach might be conveniently applied to examine time lags in term of water storage-transport capacities and associated environmental drivers to monitor sap flow dynamics within a tree and to model plant water relations. Long-lasting experiments are, however, required to infer tree resilience to extreme events in Mediterranean environments. Continuous stem diameter and sap flow measurements on model tree species (e.g., olive tree for Mediterranean-type agro-ecosystems) throughout the growing season have the potential to provide important information on growth pattern and water balance, and thus on elastic properties of wood and plant sensitivity to drought.

Acknowledgements

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