Can leaf to air temperature difference substitute for stem water potential in grapevines?

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Abstract

Grapevine (*Vitis vinifera* L.) is a traditional crop around Mediterranean basin where it grows under semi-arid conditions. Water availability during growth season is the most determinant factor of crop productivity and thus, irrigation is a common practice under these conditions. Recently, canopy temperature depression (the cooling ability of a crop canopy through transpiration) was used in various crops to monitor performance under water stress conditions. The aim of this work was to explore the use the non-destructive measurement of leaf (T_l) to air (T_a) temperature difference (ΔT) as a possible substitute of water potential measurements for indirect water status estimation in vineyards. The experiment was conducted during two years in a commercial vineyard planted with cv. Cabernet-Sauvignon onto SO4 and 1103P rootstocks and subjected to three irrigation regimes [full irrigation (FI): 100% of crop evapotranspiration (ET_c), deficit irrigation (DI): 50% ET_c and not-irrigated (NI)]. Vine water status was assessed by midday stem water potential (Ψ_{stem}) measurements using a pressure chamber. Measurements were taken at three growth stages (bunch closure, veraison and harvest). ΔT and Ψ_{stem} were strongly and negatively correlated (ΔT= -1.8235Ψ_{stem} -1.3974, R^2= 0.75, P< 0.001, n= 36) when data were combined across sampling times, rootstocks and irrigation levels and over the two years of experimentation. Our results showed that time-consuming measurements of Ψ_{stem} could be substituted by non-destructive ΔT determinations.

Keywords: *Vitis vinifera* L.; Drought; Leaf (T_l) to air (T_a) temperature difference; Irrigation scheduling

Introduction

Grapevine (*Vitis vinifera* L.) is a traditional crop around Mediterranean basin where it grows under semi-arid conditions. Water availability during growth season is the most determinant factor of crop productivity and thus, irrigation is a common practice under these conditions (Chaves et al. 2010).

On time application of supplemental irrigation with the appropriate amount of water contributes to grape composition and wine quality under water shortage conditions (Koundouras et al. 2006). Water status of the vine is commonly assessed by measuring predawn or midday water potential (Ψ) of leaves using a Scholander pressure chamber (Williams and Araujo 2002). Midday stem water potential (Ψ_{stem}) has been recently proposed as a more reliable indicator of vine water status (Choné et al. 2001). However, measurements of Ψ using a pressure chamber are laborious and time-consuming, suitable at research level but challenging at the grower's level.

Recently, many destructive measurements of physiological traits, especially at field level, have been substituted by non-destructive, indirect and rapid assessments. For example, leaf chlorophyll content is assessed instrumentally using SPAD-502 or CCM-200 in many crops, including grapevine (Fanizza et al. 1991). Leaf Area Index (the ratio of leaf area in m^2 per surface m^2) destructive determination has been substituted by high accuracy instrumental determinations (eg Röver and Koch 1995, Jonckheere et al. 2004, Weiss et al. 2004) or remote sensing technologies (Serrano et al. 2010).

Canopy Temperature Depression (CTD, the temperature difference between canopy and air) is easily estimated by hand-held, remote sensing, standard or infrared thermometers and it expresses the cooling ability of a crop canopy through transpiration (Kumar and Singh 1998). It was found to be a good indicator of plant water status mainly in annual crops (eg Silva et al. 2007, Balota et al. 2008, Lopes and Reynolds 2010). O'Toole et al. (1984) supported that assessment of crop water status *via* leaf (T_l) to air (T_a) temperature difference is quite faster than Ψ measurements. Therefore, measurement of leaf ΔT (T_l-T_a) can provide a potentially rapid and reliable assessment of vine water status and thus, of irrigation timing. Moreover, a substitution of Ψ measurement by an easier determination of water status would be very helpful to vine growers.

The use of leaf to air temperature differences as an approach of water status estimation in woody crops and especially in vines is not widely studied. The aim of this work was to explore the relationship between Ψ_{stem} and ΔT in cv. Cabernet-Sauvignon grafted on two rootstocks (1103P and SO4) and grown under three irrigation regimes (FI: 100% of evapotranspiration, DI: 50% of evapotranspiration and NI: non-irrigated) in central Greece, under typical Mediterranean conditions.

Materials and Methods

A detailed description of the experimentation is given by Koundouras et al. (2008). In brief, the experiment took place, for two growing seasons (2005-2006), in a 10-year-old commercial vineyard located on a deep loamy soil in central Greece (39°48' N, 22°27' E, 190 m). The cv. Cabernet-Sauvignon (*Vitis vinifera* L.) was grafted onto two rootstocks [1103 Paulsen (*V. rupestris*×*V. berlandieri*) and SO4 (*V. riparia*×*V. berlandieri*)].

The region has a semi-arid climate with less than 60 mm rainfall in summer. The average midday temperature and air humidity from June to August were 32.2°C and 35%, respectively. Beginning at berry set and ending at harvest, three irrigation levels [full irrigation (FI): 100% of crop evapotranspiration (ET_c), deficit irrigation (DI): 50% ET_c and not-irrigated (NI)] were applied. ET_c was estimated from the potential evapotranspiration (calculated by the Penmann-Monteith method) when the crop coefficients were adapted accordingly (Williams et al. 2003). Water was supplied by a drip irrigation system and the total amount for the season was approximately 300 mm for the FI treatment and 150 mm for DI. The six treatments (two rootstocks × three irrigation levels) were triplicated in randomized blocks, with three rows (70 m long) per plot. In each plot, only the central 4 vines of the middle row were used for measurements and the others served as borders.

Vine water status was assessed by stem water potential (Ψ_{stem}) measurements using a pressure chamber (Scholander et al. 1965). Measurements were conducted at three growth stages: bunch closure, (approximately 15 days after the beginning of irrigation), veraison and harvest. In each occasion, four leaves of the inside part of the canopy were enclosed in plastic bags and covered with aluminium foil for at least 1h 30 before measurement, to allow equilibration of Ψ_{stem}. Measurement of Ψ_{stem} was performed at solar noon (12h 30 to 13h 30) on cloudless days.

On the same days, LC_i portable system (ADC BioScientific Ltd, Hoddesdon, UK) was used for gas exchange measurements [net assimilation rate (*A*), stomatal conductance (g_s), evaporation (*E*), intercellular CO_2 concentration (C_i), leaf (T_l) and air temperature (T_a)] simultaneously with Ψ_{stem} determinations. Leaf ΔT was estimated as T_l-T_a. Measurements were taken on 4 fully-expanded, sun-lit leaves (photosynthetic photon flux density> 1200mmol m^{-2} s^{-1}) per plot and adjacent to those used for Ψ_{stem} determinations.

Data of both Ψ_{stem} and ΔT were subjected to four-factor (year, sampling time, rootstock and irrigation level) ANOVA using MSTAT-C (version 1.41, Crop and Soil Sciences Department, Michigan State University, USA) and the means were compared with LSD test at $P< 0.05$.

Results and Discussion

Year did not affect neither Ψ_{stem} (2005: -0.95MPa, 2006: -1.00MPa) nor ΔT (2005: 0.41ºC, 2006: 0.36ºC). On the contrary, the other factors (sampling times, rootstocks, irrigation levels) affected significantly both parameters (Table 1).

Ψ_{stem} decreased significantly with the progress of the season (bunch closure: -0.78MPa, veraison: -0.99MPa, harvest: -1.16MPa) while ΔT increased significantly only at the end of the season (bunch closure: 0.17ºC, veraison: 0.15ºC, harvest: 0.82ºC). 1103P had higher Ψ_{stem} (-0.95MPa) and respectively, lower ΔT (0.27ºC) compared to SO4 (Ψ_{stem}: -0.95MPa, ΔT: 0.49ºC). ΔT revealed more interactions between the factors compared to Ψ_{stem} indicating a higher response to factors' inter-seasonal changes (Table 1).

Ψ_{stem} is accepted as an accurate indicator of vine water status and it is widely used at both research and practice level (Choné et al. 2001). However, it is a destructive method which requires a time-consuming preparation before measurement; a putative restrictive factor when it is practiced by growers. Thus, a more rapidly and easily applicable measurement could be appreciably accepted as a substitute for it.

Table 1. ANOVA for stem water potential (Ψ_{stem}) and leaf ΔT determined during two growing seasons (2005, 2006), at three sampling times (bunch closure, veraison and harvest), on Cabernet-Sauvignon vines grafted onto two rootstocks (1103P and SO4) and subjected to three irrigation levels (full irrigation: 100% of crop evapotranspiration, deficit irrigation: 50% and non-irrigated).

		Ψ_{stem}		ΔT	
	df	***F*-value**	***p***	***F*-value**	***p***
Blocks	2	5.03	**	1.08	ns
Years (Y)	1	3.79	ns	0.70	ns
Samplings (S)	2	69.03	***	53.47	***
Y×S	2	3.54	*	7.86	***
Rootstocks (R)	1	4.99	*	12.93	***
Y×R	1	0.38	ns	0.35	ns
S×R	2	1.43	ns	4.10	*
Y×S×R	2	1.96	ns	2.54	ns
Irrigation (I)	2	135.16	***	97.64	***
Y×I	2	4.76	*	9.18	***
S×I	4	5.61	***	7.05	***
Y×S×I	4	1.07	ns	3.69	**
R×I	2	2.71	ns	2.34	ns
Y×R×I	2	1.12	ns	1.40	ns
S×R×I	4	0.87	ns	1.29	ns
Y×S×R×I	4	0.40	ns	0.40	ns

Where df: degrees of freedom, ns: not significant, *,**,***: significant at $P< 0.05, 0.01, 0.001$

Canopy temperature depression (CTD) is widely used to assess mainly the performance of annual crop genotypes under water stress conditions (e.g. Royo et al. 2002, Silva et al. 2007, Balota et al. 2008, Lopes and Reynolds 2010). The concept behind this is that genotypes having a better access to soil water due to a deeper and/or denser rooting system transpire more and thus, they have a cooler canopy and perform better at a physiological level. Strong relationships between CTD and plant water status have already reported (e.g. Royo et al. 2002, Guilioni et al. 2008, Fanaei et al. 2009). The main advantage of using CTD to assess water status is the limited time needed (O'Toole et al. 1984).

Figure 1 presents a strong, negative correlation between Ψ_{stem} and ΔT ($\Delta T = -1.8235\Psi_{stem} - 1.3974$, $R^2 = 0.75$, $p< 0.001$, n= 36) when data were combined across years, samplings, rootstocks and irrigation levels. T_l values become higher than T_a at Ψ_{stem} lower than -0.6 MPa, which, according to water deficit thresholds by van Leeuwen *et al.* (2008), corresponds to the first stages of vine water deficit. On the other hand, ΔT values superior to 1.0ºC are indicative of severe water stress (Ψ_{stem}< -1.4 MPa).

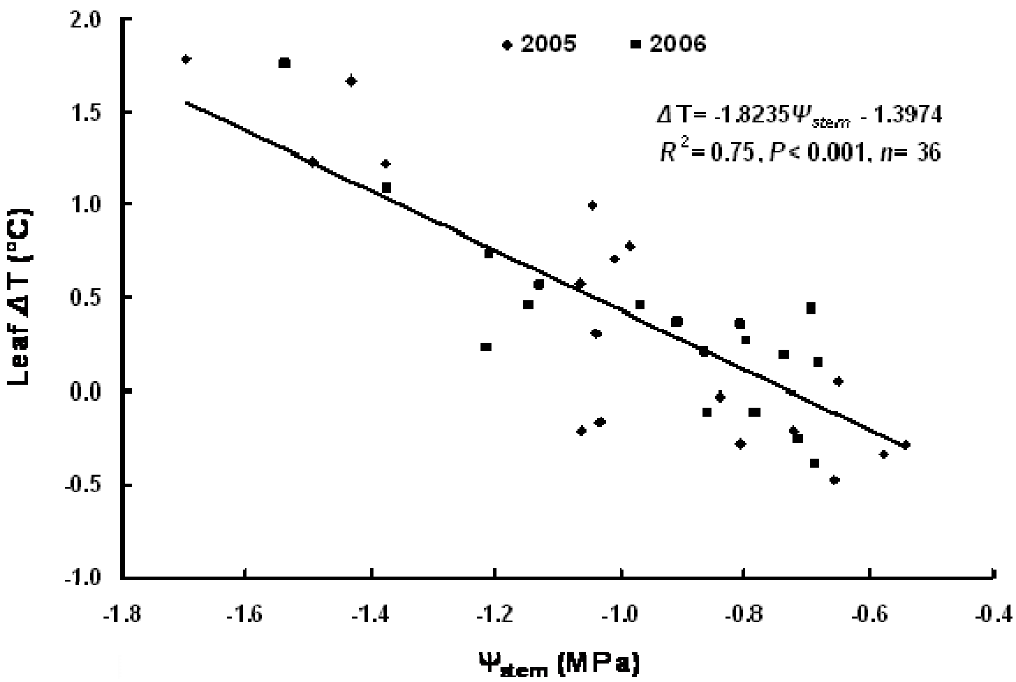

Figure 1. Correlation between stem water potential (Ψ_{stem}) and leaf ΔT across sampling times, rootstocks and irrigation levels and over the two years of experimentation.

The ΔT measurement at leaf level seemed to be a reliable substitute for Ψ_{stem} and thus, for the assessment of vine water status. Its determination can be conducted easily and rapidly using commercially available or new developed low-cost thermometers (Mahan and Yeater 2008).

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References

1. Balota, M., Payne, W.A., Evett, S.R. and Peters, T.R., 2008. Morphological and physiological traits associated with canopy temperature depression in three closely related wheat lines. Crop Science 48, 1897-1910.
2. Chaves, M.M., Zarrouk, O., Francisco, R., Costa, J.M., Santos, T., Regalado, A.P., Rodrigues, M.L. and Lopes, C.M., 2010. Grapevine under deficit irrigation: hints from physiological and molecular data. Annals of Botany 105, 661-676.
3. Choné, X., van Leeuwen, C., Dubourdieu, D. and Gaudillère, J.P., 2001. Stem water potential is a sensitive indicator of grapevine water status. Annals of Botany 87, 477-483.
4. Fanaei, H.R., Galavi, M., Kafi, M. and Ghanbari Bonjar, A., 2009. Amelioration of water stress by potassium fertilizer in two oilseed species. International Journal of Plant Production 3, 41-54.
5. Fanizza, G., Della Gatta, C. and Bagnulo, C., 1991. A non-destructive determination of leaf chlorophyll in *Vitis vinifera*. Annals of Applied Biology 119, 203-205.
6. Guilioni, L., Jones, H.G., Leinonen, I. and Lhomme, J.P., 2008. On the relationships between stomatal resistance and leaf temperatures in thermography. Agricultural and Forest Meteorology 148, 1908-1912.
7. Jonckheere, I., Fleck, S., Nackaerts, K., Muys, B., Coppin, P., Weiss, M. and Baret, F., 2004. Review of methods for in situ leaf area index determination. Part I. Theories, sensors and hemispherical photography. Agricultural and Forest Meteorology 121, 19-35.
8. Koundouras, S., Marinos, V., Gkoulioti, A., Kotseridis, Y. and van Leeuwen, C., 2006. Influence of vineyard location and vine water status on fruit maturation of nonirrigated cv. Agiorgitiko (*Vitis vinifera* L.). Effects on wine phenolic and aroma components. Journal of Agricultural and Food Chemistry 54, 5077-5086.
9. Koundouras, S., Tsialtas, I.T., Zioziou, E. and Nikolaou, N., 2008. Rootstock effects on the adaptive strategies of grapevine (*Vitis vinifera* L. cv. Cabernet-Sauvignon) under contrasting water status: Leaf physiological and structural responses. Agriculture Ecosystems and Environment. 128, 86-96.
10. Kumar, A. and Singh, D.P., 1998. Use of physiological indices as a screening technique for drought tolerance in oilseed *Brassica* species. Annals of Botany 81, 413-420.

11. Lopes, M.S. and Reynolds, M.P., 2010. Partitioning of assimilates to deeper roots is associated with cooler canopies and increased yield under drought in wheat. Functional Plant Biology 37, 147-156.
12. Mahan, J.R. and Yeater, K.M., 2008. Agricultural applications of a low-cost infrared thermometer. Computers and Electronics in Agriculture 64, 262-267.
13. O'Toole, J.C., Turner, N.C., Namuco, O.P., Dingkuhn, M. and Gomez, K.A., 1984. Comparison of some crop water stress measurement methods. Crop Science 24, 1121-1128.
14. Röver, A. and Koch, H.-J., 1995. Indirect determination of leaf area index of sugar beet canopies in comparison to direct measurement. Journal of Agronomy and Crop Science 174, 189-195.
15. Royo, C., Villegas, D., García del Moral, L.F., Elhani, S., Aparicio, N., Rharrabti, Y. and Araus, J.L., 2002. Comparative performance of carbon isotope discrimination and canopy temperature depression as predictors of genotype differences in durum wheat yield in Spain. Australian Journal of Agricultural Research 53, 561-569.
16. Scholander, P.F., Hammel, H.J., Bradstreet, A. and Hemmingsen, E.A., 1965. Sap pressure in vascular plants. Science 148 339-346.
17. Serrano, L., González-Flor, C. and Gorchs, G., 2010. Assessing vineyard water status using the reflectance based Water Index. Agriculture Ecosystems and Environment 139, 490-499.
18. Silva, M.A., Jifon, J.L., da Silva, J.A.G. and Sharma, V., 2007. Use of physiological parameters as fast tools to screen for drought tolerance in sugarcane. Brazilian Journal of Plant Physiology 19, 193-201.
19. van Leeuwen, C., Tregoat, O., Choné, X., Gaudillère, J.P. and Pernet, D., 2008. Different environmental conditions, different results-the role of controlled environmental stress on grape quality potential and the way to monitor it. P. Australian Wine Industry Technical Conference 13, 39-46.
20. Weiss, M., Baret, F., Smith, G.J., Jonckheere, I. and Coppin, P., 2004. Review of methods for in situ leaf area index (LAI) determination. Part II. Estimation of LAI, errors and sampling. Agricultural and Forest Meteorology 121, 37-53.
21. Williams, L.E. and Araujo, F.J., 2002. Correlations among predawn leaf, midday leaf, and midday stem water potential and their correlations with other measures of soil and plant water status in *Vitis vinifera*. Journal of the American Society for Horticultural Science 127, 448-454.

22. Williams, L.E., Phene, C.J., Grimes, D.W. and Trout, T.J., 2003. Water use of mature Thompson seedless grapevines in California. Irrigation Science 22, 11-18.