EFFECTS OF THE ATMOSPHERIC VAPOUR PRESSURE DEFICIT AND SOIL WATER AVAILABILITY ON THE DIURNAL PATTERN OF GRAPEVINE STEM WATER POTENTIAL

LES EFFECTS DU DEFICIT DE PRESSION DE VAPEUR DE L'AIR ET LA FRACTION D'EAU DISPONIBLE SUR L'EVOLUTION JOURNALIÈRE DU POTENTIEL DE TIGE DE LA VIGNE

João Gouveia[1], Pedro Rodrigues[1,2], Vanda Pedroso[3], Francisco Marques[1], Isabel Alves[2,5]. Carlos M. Lopes[2,6]

1. Escola Superior Agrária de Viseu, Instituto Politécnico de Viseu, Quinta da Alagoa, Ranhados, 3500-606 VISEU, Portugal.
2. Instituto Superior de Agronomia/Universidade Técnica de Lisboa, Tapada da Ajuda, 1349-017 LISBOA, Portugal.
3. DRAPC/ Centro de Estudos Vitivinícolas do Dão, Quinta da Cale, 3520-090 NELAS, Portugal.
4. CI&DETS – Instituto Politécnico de Viseu
5. CEER - Instituto Superior de Agronomia
6. CBAA - Instituto Superior de Agronomia
*Corresp. Author: João Paulo Gouveia, phone +351232480600, email: gouveia.viti@gmail.com

SUMMARY

The dependency of ψ_s on soil water availability and air vapour pressure deficit (VPD) the diurnal pattern of the ψ_s was assessed during the 2009 growing season in an irrigation experiment set up at the Dão Wine Research Station (CEVDão), Nelas, Portugal. Diurnal ψ_s patterns were carried out every two hours on vines non-irrigated (NI) and those subjected to deficit irrigation (DI – 50% ETc) in two environmental contrasting days. In the first day of measurements (doy 202) the diurnal pattern of ψ_s showed, in both treatments, a slight decline in the early morning, achieving at midday values between -0.6 and -0.8 MPa, and a recovery in the late afternoon for both treatments that showed no differences. In the second day of measurements (doy 240) the ψ_s declined rapidly from morning to early afternoon, achieving the lowest values at 4:00 PM (-1.3 MPa in NI and -1.2 MPa in DI), and also a recovery in the late afternoon. As opposed to day 202, on doy 240, NI vines had a ψ_s lower than DI for all measurements. In both treatments the ψ_s had a negative correlation with the VPD measured at the time of the measurements. Results indicated that the rate of decrease of ψ_s with the increase of VPD was independent of the FASW. Data also showed that when the soil had a higher FASW in deep layers, in days with low VPD the ψ_s was not different between irrigation treatments.

RÉSUMÉ

Afin d'étudier la dépendance du potentiel de tige (ψ_s) selon de la disponibilité en eau du sol et du déficit de la pression de la vapeur de l'air (*DPV*), l'évolution journalière du ψ_s a été évaluée en deux jours au cours du cycle végétatif de 2009 dans un essai installé dans une vignoble du cépage 'Touriga Nacional' au Centre d' Etudes Vitivinicoles de la région du Dão (CEVDão), Nelas, Portugal. Les mesures ont été effectuées toutes les deux heures sur des plantes non irriguées (NI) et des plantes avec irrigation déficitaire (DI – 50% *ETc*) pendant deux jours avec différentes conditions environnementales. Pendant le premier jour (doy 202) l'évolution du ψ_s a montrée dans les deux modalités une légère diminution au début du matin, atteint des valeurs au midi entre -0.6 et 0.8 MPa, et une récupération à la finale de l'après midi et non pas présentée différences. Au deuxième jour (doy 240) le ψ_s à présentée une rapide diminution dès le début du jour jusqu'au début de l'après midi, atteint la valeur minimale à 16:00 (1.3 MPa pour la NI et 1.2 MPa pour la DI) et de nouveau une récupération à la finale de l'après midi. Par opposition au jour 202, pendant le jour 240, la modalité non irriguée à présentée des valeurs nettement inferieurs auxquelles de la modalité avec irrigation. Les valeurs du ψ_s des deux modalités présentent une corrélation négative avec le *DPV* enregistré au moment des mesures mais la régression linéaire montre une réponse diffèrent dans les deux jours de mesure. Les résultats montrent aussi que le taux de la diminution du ψ_s avec l'augmentation du *DPV* est indépendant de l'eau disponible dans le sol.

Keywords: irrigation, Touriga-Nacional, stem water potential, VPD, Dão.
Mots Clés: irrigation, 'Touriga Nacional', potentiel de la tige, déficit de la pression de vapeur de l'air DPV, Dão.

INTRODUCTION

Plant based physiological indicators are the most adequate to monitor plant water status as they allow to integrate the effect of the environmental conditions and cultural practices, namely irrigation (Choné *et al*., 2001a). Plant water status is usually evaluated by the measurement of leaf water potential, which gives an indication of the plant water energetic status which is the result of several components with different origin: pressure, osmotic, matric and gravitational (Castell, 1998). Plant water potential is determined in each instant by the balance between water uptake by the roots and the losses by transpiration. Water uptake by the roots depends on the characteristics of the root system and soil water content, while transpiration depends, among other factors, on climatic conditions, stomatal conductance and internal resistances to water fluxes (Rodrigues, 2011).

Given the ease of the measurement in field conditions, plant water status is frequently evaluated by the leaf and/or stem water potential.

Leaf water potential reflects the combined effects of the environmental conditions to which the leaf is subjected in a certain instant, namely air vapor pressure deficit (*VPD*), intercepted radiation, available soil water (*ASW*), internal hydraulic conductivity and stomatal resistance. Stem water potential (ψ_s) is determined in leaves that prior to measurements are bagged in a plastic bag and covered with an aluminium foil in order to stop transpiration and enable leaf water potential to equilibrate with the water potential of the corresponding stem. Therefore ψ_s depends on the whole plant transpiration and on the resistance to the water fluxes between soil and leaves, representing the ability of the vine to transfer water from the soil to the atmosphere (Choné *et al.*, 2001b). On a typical summer day, ψ_s shows a similar diurnal variation as leaf water potential, decreasing throughout the morning until a minimum value is obtained around midday (Patakas *et al.*, 2005). The value registered during midday (ψ_{sMD}) is used by several authors to characterize vine water status (e.g. Williams and Araújo, 2002; Silvestre, 2003; Patakas *et al.*, 2005).

In this work, the daily evolution of ψ_s in vines subjected to different soil water availability was studied on two days characterized by very contrasting environmental conditions.

MATERIAL AND METHODS

This work took place at the Dão Grape and Wine Research Station (CEVDão), Nelas, Portugal (Latitude 40° 31'N, Longitude 7° 51'W, Elevation 440 m) in a vineyard planted in 2000 with the red grape variety 'Touriga Nacional' grafted on 110 R rootstock. The vines were spaced 1.1 m within and 2.0 m between rows, trained on a vertical shoot positioning with a pair of movable wires and spur-pruned on a bilateral Royat Cordon system. The experimental design was a randomized complete block design with four replications of 12 experimental vines per elemental plot, and the following two treatments: NI - Non irrigated (rainfed, control) and DI - deficit irrigation of 50% ET_c.

The soil was from granitic origin, with a coarse texture and acid pH, with very good infiltration capacity. Meteorological variables were measured at an automatic weather station installed within the experimental plot.

Drip irrigation lines were positioned in the row of the plants and consisted of self-compensating and self-cleaning 1.7 L/h drippers spaced 0.75 m apart. Irrigation scheduling was based on the available soil water, expressed as a percentage of transpirable soil water down to the 0.6 m depth (fraction of available soil water; $FASW_{0\text{-}60}$). In the deficit irrigation treatment (DI50) the critical $FASW_{0\text{-}60}$ levels were 20 to 30%. Irrigation depth was calculated from the accumulated values of daily ET_c, as determined with the methodology of Allen *et al.* (1998), and the rainfall occurred since the last irrigation event.

Soil water content was measured with a portable capacitance probe (Diviner 2000®; Sentek Sensor Technologies, South Australia), calibrated for the soils of this experiment. In each elemental plot two access tubes were installed, one in the row, between two contiguous vines and close (0.05 m) to the dripper, and another one in the middle of the interrow. Readings were taken twice a week between budburst and harvest at increments of 0.1 m from the soil surface to a depth of 1.6 m. At a given date the available soil water (*ASW*) was calculated as the difference between soil water content on the day of measurements and the minimum soil water content, calculated with volumetric water content at wilting point (~ pF 4.2). The *FASW* was calculated as the ratio of *ASW* to total transpirable soil water as described in Rodrigues *et al*. (2012).

The ψ_s was measured on non-transpiring leaves that were enclosed in a plastic bag and wrapped in aluminium foil at least 2 hours before measurement and were carried out on adult leaves (3 leaves per elemental plot), using a pressure chamber (Model 600 PMS instrument Co., Corvallis, OR, USA) during two days (21th July and 29th August) between 8:00 AM and 06:00 PM, with an interval of 2 hours between each measurement.

Data were subjected to a two-way analysis of variance and to a linear regression analysis using the Statistical Package for the Social Sciences (SPSS for Windows, Standard Version Release 19.01). Treatment comparison was performed each day by Tukey's-b test at $P \leq 0.05$.

RESULTS AND DISCUSSION

To evaluate the influence of the environmental factors on the ψ_s values two days of the 2009 growing season were analyzed: DOY 202, the day after the first irrigation event, and DOY 240, corresponding to the third irrigation event in the DI treatment. These two days showed important differences regarding the meteorological conditions (Fig. 1) and soil water availability (Fig. 2): i) 21th July (DOY 202) was a mild Summer day with a lower air vapour pressure deficit (VPD < 1.9 kPa) and where DI treatment had a higher FASW in the upper layers but similar to NI in deeper ones (> 60 cm); ii) 29th August (DOY 240) was a warm Summer day, in which the VPD achieved values around 4.0 kPa at 4:00 PM and where the DI treatment presented a similar FASW as on DOY

202 but where NI showed lower FASW values either in upper and lower layers as compared to the values observed on DOY 202.

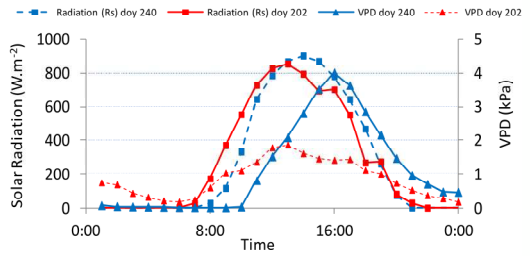

Figure 1. Daily evolution of solar radiation (*Rs*) and air vapour pressure deficit (*VPD*) on DOY 202 and 240 of year 2009.

Évolution journalière de la radiation solaire (Rs) et du déficit de la pression de vapeur de l'air (VPD) sur le jour 202 et 240 de l'année 2009.

On DOY 202 the diurnal pattern of ψ_s showed a similar trend with no differences between the two treatments. In the beginning of the day, the ψ_s decreased, reaching the lower values at 12:00 AM,

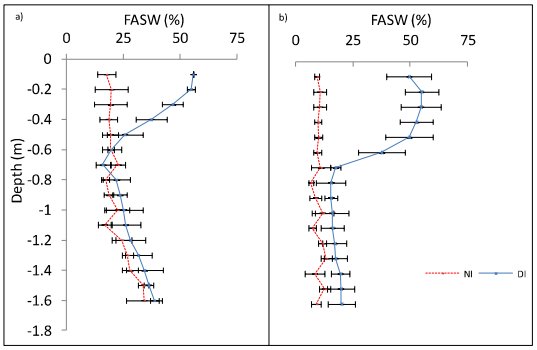

Figure 2. Profile of the available soil water on a) DOY 202 and b) 240 of year 2009 of deficit irrigation (DI) and non irrigated (NI) treatments. The points represent the average values (4 repetitions) and the horizontal lines the respective standard errors.

Profil de l'eau disponible dans le sol le jour 202 a) et au jour 240 b) de l'année 2009 dans les modalités (DI) et (NI). Les points représentent les valeurs moyennes (4 répétitions) et les lignes horizontales les respectives erreurs standards.

a plateau between 12:00 AM and 4:00 PM and then a recovery towards the end of the day (Fig. 3). This absence of differences between irrigation treatments indicate that, despite the differences in the $FASW_{0\text{-}160}$ and in the water distribution along the profile, the non-irrigated vines attained a similar water status as the irrigated ones (Fig. 3a).

On the second date (DOY 240), despite the similar trend presented by the two treatments, NI vines had a lower ψ_s than DI ones all day (Fig. 3b). These results are similar to those reported by Intrigliolo and Castel (2009) showing the effect of soil water availability on plant water status.

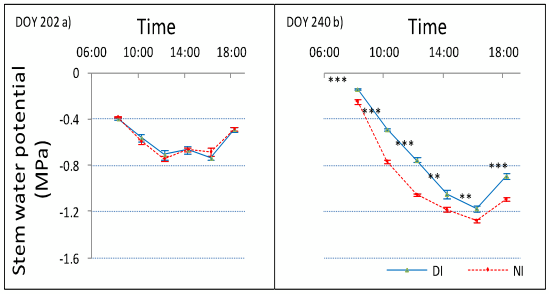

Figure 3. Diurnal pattern of stem water potential (ψ_s) in treatments DI and NI on DOY a) 202 and b) 240.

Évolution journalière du potentiel de la tige (ψ_s) dans les modalités DI et NI dans le jour de l'année 202 a) et dans le 240 b).

When comparing the diurnal pattern between dates we observed that while on DOY 202 the minimum ψ_s values were attained between 12:00 AM and 2:00 PM, corresponding to the period of maximum radiation, on DOY 240 the minimum ψ_s was attained only at 4:00 PM, corresponding to the period where the *VPD* reached the highest values.

Regarding the minimal values (Table I) on DOY 202 both treatments had similar ψ_{sMD} values, indicating a moderate to mild water stress situation (Ojeda, 2008). This similar ψ_{sMD} values were obtained irrespective to the differences observed in $FASW_{0\text{-}160}$, indicating an apparent absence of dependency of the ψ_{sMD} from soil water availability. This seems to indicate that ψ_{sMD} was not influenced by the available soil water measured in all soil profile, but rather by the available soil water measured at the more wetted deeper soil layers (where both treatments presented similar values), as also observed by Améglio *et al*. (1999) and Rodrigues (2011) relatively to predawn leaf water potential. This results show that when the soil has a higher FASW in deep layers, in days with low VPD the ψ_s was not able to distinguish between irrigation treatments.

Regarding the irrigated treatment, despite the similar total available soil water and distribution observed on the two dates (Table I and Fig. 2b), the ψ_{sMD} presented a much lower value on DOY 240 than on DOY 202, indicating that the atmospheric conditions at the time of measurement were the main factor responsible for the observed ψ_{sMD} differences. These results suggest that, for high *VPD*, the ψ_s may not adequately reflect soil water availability, as observed by Williams and Baeza (2007) and Rodrigues *et al*. (2012) relatively to the predawn leaf water potential. Indeed Salón *et al*. (2005) stated that the ψ_s measured during the morning period is the best indicator of plant water status and the one with the best correlation with yield and wine quality parameters.

Table I – Stem water potential measured at 2:00 PM (ψ_{sMD}), fraction of available soil water down to the 1.60 m depth ($FASW_{0-160}$) in NI (non-irrigated) and DI (deficit irrigated) treatments and maximum air temperature (T_a), minimum relative humidity (RH_{min}) and maximum vapour pressure deficit (VPD_{max}) on DOY 202 and 240 of year 2009. DOY: day of the year.

Potentiel de la tige à 14h (ψ_{sMD}), fraction de l'eau disponible dans le sol jusque à la profondeur de 1.60 m ($FASW_{0-160}$) dans les traitements NI et DI et la température maximale de l'air (T_a), le minimum d'humidité relative (RH) et le déficit de pression de vapeur (VPD) au jour de l'année 202 et le jour 240 de l'année 2009. DOY: jour de l'année.

DOY	Ψ_{sMD} (14:00)			$FASW_{0-160}$		T_{max} (ºC)	RH_{min} (%)	VPD_{max} (kPa)
	DI	NI	*sig*	DI	NI			
202	-0.66 ± 0.03	-0.66 ± 0.02	*ns*	32.5 ± 4.8	23.3± 3.9	27.5	47.2	1.86
240	-1.05 ± 0.04	-1.18 ± 0.02	***	29.5± 6.5	10.0 ± 2.5	35.6	28.1	4.01

ns: non significant; ***: significant, p<0.001

*ns: non significatif; ***: significatif, p<0.001*

In order to better understand the dependency of ψ_s on VPD a regression analysis was performed for each date, using VPD as independent variable. In both dates and treatments a high and significant coefficient of determination were obtained showing a strong dependency of ψ_s on VPD (Fig. 4). Similar results were reported by Williams and Baeza (2007). Also Rodrigues *et al.* (2012), using data from the same vineyard, found a high correlation between predawn leaf ψ and *VPD*, either in water stressed and well irrigated vines.

The similar slope of the relationship between ψ_s and VPD obtained on each day for both treatments show that the rate of ψ_s variation due to variations in *VPD* was independent of the irrigation treatment and thus of the soil water availability. The effect of soil water availability on this relationship was reflected only on the intercept, which was lower in NI on day 240.

CONCLUSIONS

The negative correlation found between ψ_s and VPD show that the daily pattern of ψ_s was strongly determined by the weather conditions at the time of measurement and that the rate of decrease of ψ_s with the increase of VPD is independent of the FASW. Data also showed that when the soil has a higher FASW in deep layers, in days with low VPD the ψ_s was not able to distinguish between irrigation treatments. The ψ_s seems to be a good tool to characterize the water status of vines, with the early morning period measurements being the best ones to discriminate the irrigation treatments.

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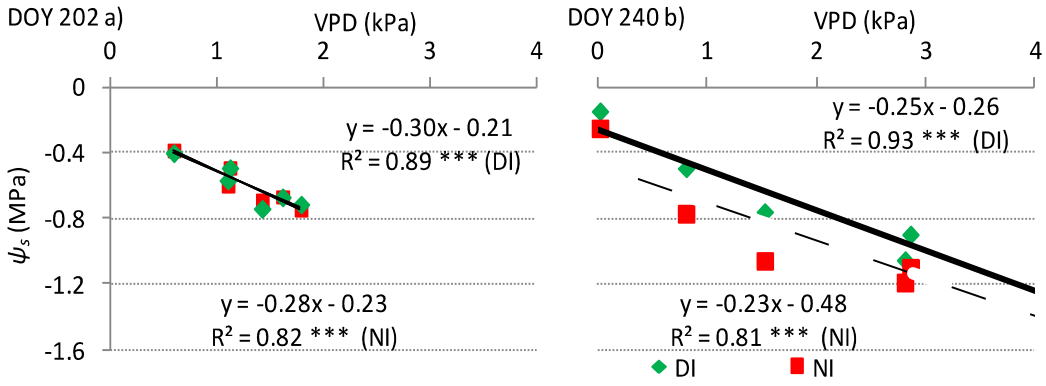

Figure 4. Relationship between the average values of stem water potential (ψ_s) and vapour pressure deficit (*VPD*) recorded during the measurement periods for the two irrigation treatments (NI and DI), on DOY a) 204 and b) 240.

Relation entre les valeurs moyennes du potentiel de la tige (ψ_s) et du déficit de la pression de la vapeur (DPV) enregistrées au cours des périodes de mesure pour les deux traitements d'irrigation (NI et DI), sur les jours de l'année 204 a) et 240 b).

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