ASSESSING CANOPY TEMPERATURE PATTERNS IN TWO GRAPEVINE VARIETIES SUBJECTED TO DEFICIT IRRIGATION : A TOOL TO OPTIMIZE WATER MANAGEMENT ?

SUIVI DE L'ÉVOLUTION DE LA TEMPÉRATURE DU COUVERT VÉGÉTAL DE DEUX VARIÉTÉS SOUMISES A UNE IRRIGATION DÉFICITAIRE : UN OUTIL POUR OPTIMISER LA GESTION DE L'EAU ?

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Abstract
A better understanding of grapevine responses to drought and high air temperatures can help to optimize vineyard management to improve water use efficiency, yield and berry quality. Faster and robust field phenotyping tools are needed in modern precision viticulture, in particular in dry and hot regions such as the Mediterranean. Canopy temperature (Tc) is commonly used to monitor water stress in plants/crops and to characterize stomatal physiology in different woody species including Vitis vinifera. Thermography permits remote determination of leaf surface or canopy temperature in the field and also to assess the range and spatial distribution of temperature from different parts of the canopies. Our hypothesis is that grapevine genotypes may show different Tc patterns along the day due to different stomatal behaviour and heat dissipation strategies. We have monitored the diurnal and seasonal course of Tc in two grapevine genotypes, Aragonez (syn. Tempranillo) and Touriga Nacional subjected to deficit irrigation under typical Mediterranean climate conditions. Temperature measurements were complemented by determination of the diurnal course of leaf water potential (ψleaf) and leaf gas exchange. Measurements were done in two seasons (2013 and 2014) at different phenological stages: i) mid-June (green berry stage), ii) mid-July (veraison), iii) early August (early ripening) and iv) before harvest (late ripening). Correlations between Tc and minimal stomatal conductance will be presented for the two genotypes along the day. Results are discussed over the use of thermal imagery to derive information on genotype physiology in response to changing environmental conditions and to mild water stress induced by deficit irrigation. Strategies to optimize the use of thermal imaging in field conditions are also proposed.

***Keywords** : thermal imaging, genotypes, diurnal and seasonal water stress responses, phenotyping*

Résumé
Une meilleure compréhension des réponses de la vigne à la sécheresse et aux températures élevées de l'air peut aider à optimiser la gestion du vignoble pour améliorer l'efficience d'utilisation de l'eau, le rendement et la qualité des baies. Des outils de phénotypage de terrain rapides et robustes sont nécessaires pour la viticulture moderne de précision, notamment dans les régions chaudes et sèches du bassin méditerranéen. La température du couvert végétal (Tc) est actuellement utilisée pour suivre le stress hydrique dans les plantes/cultures et pour caractériser la physiologie des stomates chez différentes espèces ligneuses dont *Vitis vinifera*. La thermographie infrarouge permet d'estimer à distance la température de surface de feuilles individuelles et du couvert sur le terrain et également d'évaluer la gamme et la distribution spatiale des températures de différentes parties du couvert végétal. Notre hypothèse est que différents génotypes de vigne peuvent montrer différentes variations de Tc au long de la journée en raison de différentes stratégies de comportement stomatique et/ou dissipation de chaleur. Nous avons suivi l'évolution journalière et saisonnière de Tc chez deux variétés, Aragonez (syn . Tempranillo) et Touriga Nacional soumises à une irrigation déficitaire dans des conditions climatiques typiques de la Méditerranée. Les mesures de température ont été complétées par des cinétiques journalières du potentiel hydrique (ψleaf) et les échange gazeux foliaires. Les mesures ont été effectuées en 2013 et 2014 à différents stades phénologiques: i) mi- juin (stade de baies vertes), ii) mi- Juillet (véraison), iii) début Août (début de maturation) et iv) avant la récolte (maturité). Les corrélations entre la conductance stomatique minimale et Tc seront présentées pour les deux génotypes au long de la journée. Les apports de l'imagerie thermique pour obtenir des informations sur la physiologie des génotypes en réponse au changement des conditions environnementales et au stress hydrique modéré induit par irrigation déficitaire sont discutés. Des stratégies pour optimiser l'utilisation de l'imagerie thermique au terrain sont également proposées.

Mots-clés : imagerie thermique, génotype, cycle journalier et saisonnier de réponse au stress hydrique, phénotypage

1. Introduction

Climate change scenarios for South Mediterranean Europe predict longer and more severe soil water deficits and higher air and soil temperatures (Teskey et al., 2014; Hannan et al., 2014; Rogiers and Clarke, 2014). Heat waves are also striking more frequently and for longer periods the South European Mediterranean regions (Teskey et al., 2014). This represents a major limitation for Mediterranean viticulture because it limits grapevine longevity, yield and berry quality and can influence its socio-economical sustainability. In addition, water is considered the most important but vulnerable resource in the Mediterranean region (EU-ERANETMED, 2014).

Nevertheless irrigation expanded fast in the Mediterranean region (e.g. South Portugal) as means to mitigate climate stress effects, guarantee yield and stabilize quality. Genotype influences grapevine responses to drought and heat stress namely via different leaf gas exchange behaviour (Chaves et al., 2010; Costa et al., 2012; Tomás et al., 2014). Nevertheless, there are still knowledge gaps regarding the combined effect of drought and high temperatures on grapevine physiology. In addition, and as part of precision monitoring, the sector needs faster and robust field tools to tackle the increasing and most demanding challenges imposed by more efficient and sustainable viticultural systems.

Thermography is a remote, non-destructive option to monitor the effects of climate (air temperature, VPD), soil management and plant traits on water and heat fluxes in the vineyard, but needs optimization for robust canopy and soil monitoring (Costa et al., 2013). Canopy temperature (Tc) has been also used to characterize stomatal physiology in response to environment in economically relevant crops such as *V. vinifera* (Jones et al., 2002; Grant et al., 2006; Costa et al., 2012). This is relevant for breeding purposes but also to optimize irrigation scheduling in accordance to the genotype traits (Costa et al., 2012).

Our hypothesis is that grapevine genotypes may show different Tc patterns along the day due to different stomatal behaviour and different heat loss strategies. We have monitored the diurnal and seasonal course of Tc in two grapevine genotypes, Aragonez (syn. Tempranillo) and Touriga Nacional subjected to deficit irrigation under typical Mediterranean climate conditions.

2. Material and methods

Plant material and growing conditions

The experiment was located in a commercial vineyard in Alentejo, Reguengos de Monsaraz, South Portugal (38° 23' 55.0'' N, 7° 32' 46.00'' W, elevation 200 m). The climatology in the study area is attenuated meso-Mediterranean, with mild temperatures in winter, rarely below to 5 ºC, and high temperatures in summer, especially July and August, when average temperature reaches 25 ºC, with maximum values above 40 ºC punctually.

We used 11 years-old vines of two red varieties Touriga Nacional (TOU) and Aragonez (ARA), grafted onto 1103 Paulsen rootstock. The two varieties were planted side by side in two adjacent plots and were subjected to identical canopy and cultivation standard practices. Planting density was 2200 vines/ha, spaced 1.5 m within and 3.0 m between north -south oriented rows. Vines were trained on a vertical shoot positioning with one pair of movable wires and spur-pruned on a bilateral Royat Cordon system with 16 nodes per vine.

All vines were uniformly pruned to 15 to 16 nodes per vine. Soil texture was a sandy–loam to silty-clay-loam, with a pH of 7,0 to 7,6, a low content in organic matter (1.39% for ARA and 0.72% for TOU) and high P_2O_5 and K_2O values (113 and 192 respectively for ARA and 107 and 154 for TOU). Deficit irrigation was applied by drip irrigation (single pipe line,1.8 emitters/per vine, flow rate of 2.1 L/h). The irrigation treatments were sustainable deficit irrigation (SDI – control, done in accordance to the farm schedule; about 30% Etc), with water applied 1 to 2 times a week from pea size and regulated deficit irrigation (RDI, 50% to 65% of the control in 2013 and 2014 respectively).

Plant measurements

Diurnal curves of leaf water potential (ψleaf), canopy temperature (Tc) and leaf gas exchange were done along two consecutive years (2013 and 2014) for both varieties. In 2013, observations were done on 20 June (berry touching), 17 July (veraison), and 21 August (full maturation). In 2014 measurements were done at veraison (24 July) and at full maturation (19 August). Leaf water potential was measured with a Scholander pressure chamber and ground based measurements of Tc were done by thermal imaging (7-13 µm, ε=0.96). Thermal images were followed by visible imaging. Leaf gas exchange was determined with a portable infra-red gas exchange analyzer (Licor 6400, Licor Inc, USA), equipped with a 2x3cm transparent leaf chamber.

Experimental set up and statistical analysis

The experimental layout was a randomized complete block design with two drip irrigation treatments and four replications per treatment. The irrigation treatments were Sustainable deficit irrigation (SDI - control), with water applied 1 to 2 times a week from berry touch (berries beginning to touch - stage 77 of the BBCH-scale for grapes) and regulated deficit irrigation (RDI). In order to analyze the relationships between Tc and stomatal conductance (gs) a correlation analysis was performed for the two genotypes. Statistical analysis has been done by using Pearson correlations between variables (Tcanopy, gs, VPD), with the Statistix 9.0, analytical software.

Figure 1. *Visible (on the left) and false colored IR thermal image (on the right) from two rows and the inter row (3m) of vines of the variety Aragonez. Measurements were done at 14.30h on 24 July 2014, by using a Flir ThermaCAM B20, 240x320 pixels,7-14µm, ε=0.96) under the following average environmental conditions: Tair =28.3ºC, RH = 38%; VPD= 2.8KPa; Wind speed = 2.8 ms^{-1} ; Global radiation = 800Wm^{-2}. Tc sunlit side (selected area 01) = 27.4 ± 1.1ºC, Tc shadow (selected area_ 02)=26.8± 1.1 ºC, Tsoil (selected area_03) = 37.1± 2.5 ºC.*

Figure 1. Image visible (gauche) et thermique (droite) de deux lignes de la vigne de la variéte Aragonez. Les mesures ont été effectuées à 14h30 le 24 Juillet 2014, en utilisant un Flir ThermaCAM B20, 240x320 pixels,7-14µm, ε=0.96), dans conditions environnementales moyennes suivantes:Tair=28.3ºC, RH=38%; VPD=2.8KPa;Vitesse du vent=2.8 ms^{-1}; Global rayonnement = 800Wm^{-2};Tc du côté ensoleillé (zone sélectionnée 1, ARO1) = 27.4 ± 1.1°C, Tc ombre (zone sélectionné 2, ARO2) = 26.8 ± 1.1ºC, Tsoil (zone sélectionné 3, ARO3)= 37.1 ± 2.5ºC.

3. Results and discussion

Climate and soil water

The years 2013 and 2014 differed with regards to climate conditions. Solar radiation values were similar in both years but the year 2013 was hotter and dryer than 2014. The year 2014, had also lower spring precipitation, lower VPD and Tair and thus lower cumulative ETo than 2013 (Table 1). The irrigation volumes in 2014 were also significantly smaller as compared to 2013 (Table 1).

Table 1. *Cumulative data for rainfall, ETo and irrigation water used in 2013 and 2014*
Tableau 1. Données cumulatives pour les précipitation, ET0 et pour de l'eau d'irrigation utilisée, en 2013 et 2014.

YEAR	**Rainfall during dormancy Period (Oct - Feb)**	**Rainfall during growth Period (Mar - Aug)**	**Cumulative ET0 (Mar - Aug)**	**SDI Irrigation (mm) (Jun - Aug)**
2013	308	255	820	**112**
2014	321	157	776	**67**

Leaf water potential

In 2014, leaf water potential (ψpd) on 24 July was around -0.3 and -0.40 MPa for TOU and ARA respectively. In 19 August, under more stressful conditions, the values of ψpd ranged from -0.69 to -0.88 for ARA and -0.46 to -0.64 MPa for TOU. Just like in 2013, values of leaf water potential along the most stressful hours of the day were more negative for ARA than TOU. This can be related to a larger total leaf area, and consequently, larger transpirational water loss.

Canopy temperature and leaf gas exchange

Overall the Tc measured for both genotypes and irrigation treatments had similar diurnal behavior. In both years the diurnal variation of Tc was characterized by a progressive increase until 17:00 h. Contrary to 2013, in 2014 the values of Tc were only punctually above the optimal range for photosynthesis considered for grapevine (25-30ºC) (Mullins et al., 1992), which could be explained by lower Tair along the season. Regarding leaf gas exchange, gs decreased along the day, in parallel with an increase of Tc. In 2014, TOU shows the tendency for lower Tc as result of higher gs. We also found significant negative correlations between Tc and gs (Table 2) as well as between Tc and ψpd (not shown). Correlations were mainly significant in the afternoon in agreement with previous results (Costa et al., 2012). Higher air VPD seems to have a positive effect on Tc measured between 14 and 17 h on sunlit leaves in both varieties subjected to mild drought stress (ψpd = -0.29 for TOU and ψpd =-0.41 for ARA) on 24th July (Table 2). However, under more severe stress (19th August), Tc correlated negatively with VPD in both genotypes and in particular in the case of ARA (Table 2). In 2014,we observed no significant temperature differences between RDI and SDI treatments which could be attributed to minor differences in the amount of the applied irrigation water combined with minor differences in vine water stress. In addition moderate VPD and low evaporative demand conditions during summer 2014 has limited detection of differences based on Tc.

Table 2*. Correlations between leaf stomatal conductance to water vapour (gs) and canopy T (Tc), between gs and air VPD and between air VPD and Tc measured during the afternoon (14 – 17h), for the west sunlit side of the canopy on July and August 2014, for Aragonez (ARA) and Touriga Nacionall (TOU)*

Tableau 2. Correlations entre la conductance stomatique à la vapeur d'eau (gs) et la temperature du covert végétal (Tc), entre gs et le VPD de l'air, et aussi entre le VPD de l'air et la Tc mesurée pendant l'après-midi (14 - 17h), pour le côté ensoleillé à l'ouest de le couvert sur Juillet et Août 2014, et pour Aragonez (ARA) et Touriga Nacional (TOU).

2014		**r (gs, Tc)**		**r (gs,VPD)**			**r (VPD,Tc)**	
		ARA	**TOU**	**ARA**	**TOU**		**ARA**	**TOU**
24 July		-0.97	-0.06	-0.74	-0.07		0.83	1.00
19 Aug		-0.93	-0.92	0.85	0.24		-0.89	-0.6

4. Conclusion

Our results show different genotype response to mild water stress. ARA had in both seasons lower leaf water potential as compared to TOU which suggests that ARA is losing more water along the season. This can be related to earlier shoot development and/or larger total leaf area, which result in larger transpirational water loss. In agreement with previous literature, temperature measurements showed more clear correlations with physiological parameters such as gs, when done during the afternoon. However, mild water stress in combination with low or moderate VPDs can limit detection of temperature differences between genotypes in field conditions. Physiologically, there is still the need to establish leaf/canopy temperature thresholds (thresholds of relevant thermal indexes) (Costa et al., 2013) for different biotic or abiotic stress effects and for different grapevine genotypes. This will support the development of a more user-friendly, faster and still robust use of thermal imaging in field conditions.

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