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PROSPECTS OF THERMAL IMAGING AS A NON-INVASIVE TOOL TO ASSESS WATER STATUS FOR IRRIGATION SCHEDULING IN COMMERCIAL VINEYARDS

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Abstract

Aim: Irrigated viticulture is expanding worldwide mainly as a short-term adaptation strategy to climate change. Plant-based methods are increasingly being used for irrigation scheduling in commercial vineyards. Canopy temperature (TC) has long been recognized as an indicator of plant water status. TC, but also the thermal stress indices, e.g. crop water stress index (CWSI) and stomatal conductance index (I_G) have been used to support and manage irrigation in several crops including grapevine. The goal of this work was to review thermal imaging as non-invasive tool to assess water status in commercial vineyards in Rioja (Spain) and in the wine regions of Douro and Alentejo (Portugal).

Methods and Results: Thermal cameras were used as ground based portable sensors to manually assess water status. Significant correlations between T_C and/or thermal indices and stomatal conductance or stem water potential (Ψ_{stem}) were observed in the vineyards of these top wine regions. Recently, a thermal camera was also mounted in an all-terrain-vehicle for the on-the-go acquisition of thermal images. T_C, CWSI and I_G were significantly correlated to Ψ_{stem} at both canopy sides. Water status of a commercial Tempranillo vineyard was also evaluated using on-the-go thermal imagery retrieved from a moving quad at 5 km/h in Rioja. Moreover, an infrared radiometer was installed in an autonomous terrestrial robot to assess and map water status of commercial Touriga Nacional vineyard in the Douro Valley.

Conclusions: Several trials carried out in Spain and Portugal showed the effectiveness of thermal imaging to monitor water status in commercial vineyards.

Significance and Impact of the Study: Our results are promising and show the potential of thermal imaging as a non-invasive technology in precision viticulture to evaluate vineyard water status, helping grape growers to optimize irrigation management.

Keywords: Sensing technologies, non-invasive sensor, CWSI, I_G, precision irrigation

Introduction

Irrigated viticulture is expanding worldwide mainly as a short-term adaptation strategy to climate change, but it also puts pressure on local and regional resources, which demands more precise irrigation strategies in order to save water. Rioja, Douro and Alentejo wine regions experienced an increase in the irrigated areas in the recent decades in order to minimize the impact of more dry and warm conditions and more frequent heat waves (Fraga *et al.,* 2020; Costa *et al.,* 2020).

Plant-based methods are increasingly being used for irrigation scheduling in commercial vineyards. Canopy temperature (TC) is recognized to be an indicator of plant water status (Jones 2004ab; Costa *et al.*, 2013). In addition, thermal stress indices, e.g. crop water stress index (CWSI) and stomatal conductance index (I_G) were used to support/manage irrigation in several crops including grapevine (Jones 2004; Bellvert *et al.,* 2016).

In precision viticulture the usefulness and convenience of spatial variation of vineyard water status was proposed by several authors (Baluja *et al.,* 2013; Cohen *et al.,* 2016; Gago *et al.,* 2015). Most published data from applications of thermal imaging to grapevine relates to images taken facing or perpendicular to the rows by portable and hanheld cameras (Grant *et al.,* 2016; Pou *et al.,* 2014; Garcia-Tejero *et al.,* 2016) or also along rows (Jones 2002; Costa *et al.,* 2019). Recently, thermal cameras have been also mounted on an ATV (Gutiérrez *et al.,* 2017, 2018), a robot (Lopes *et al.*, Unpublished data), on unmanned aerial vehicles (Baluja *et al.,* 2013) and on aircrafts (Bellvert *et al.,* 2016) for vineyard water status monitoring.

The goal of this work was to do a short review of thermal imaging as non-invasive tool to assess water status in commercial vineyards in Rioja (Spain), Douro and Alentejo (Portugal) wine regions and discuss the potential/limitations of the technique for the sector.

Material and Methods

Several trials carried out in Spain and Portugal showed the effectiveness of thermal imaging to monitor water status in commercial vineyards.

Experiments in Rioja

Water status of a commercial Tempranillo VSP vineyard (with North-South row orientation at 2.60 ×1.20 meters inter and intra row distances) located in La Rioja (Spain) was evaluated using on-the-go thermal imaging. A thermal camera (FLIR A35. FLIR® Systems, USA) was mounted in an all-terrain-vehicle for the on-the-go acquisition of thermal images. On-the-go thermography was acquired with a thermal camera operating at 1.2 m distance from the canopy, mounted on a quad moving at 5 Km/h in July 2016 (Gutiérrez *et al.,* 2017). All thermal images were georeferenced using a GPS installed on the quad. On-the-go thermal assessments were performed on both sides on the canopy. Stem water potential (ψ_{stem}) was also measured and used as reference method. T_{dry} and T_{wet} values were measured for the calculation of different thermal indices. All measurements were carried out in leaves of the mid-upper part of canopy at solar noon. Crop water stress index (CWSI) and stomatal conductance index (I_g) as indicators of plant water status were computed from the canopy temperature (TC) extracted from the thermal images.

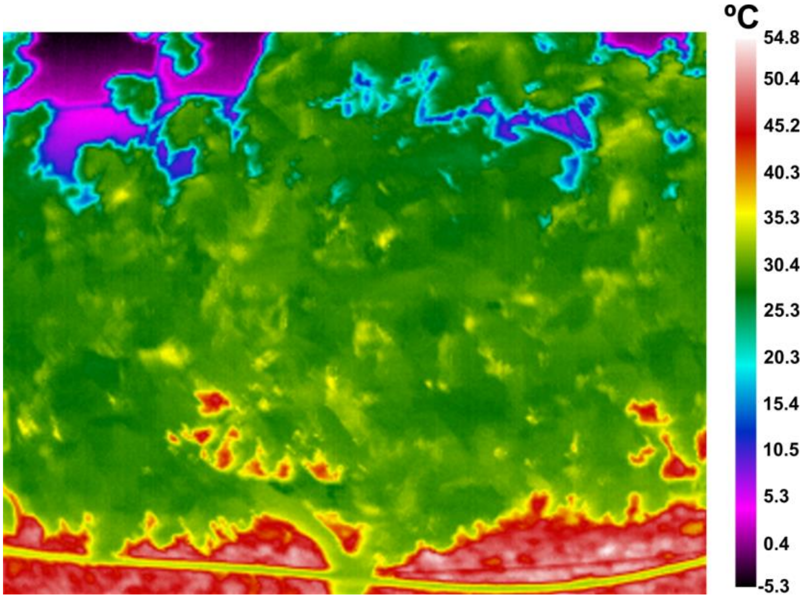

Figure 1: Thermal image acquired on-the-go using an ATV in a commercial Tempranillo vineyard located in Rioja, Spain.

Experiments in Douro

The experimental parcel was located at Quinta do Bomfim (Douro Valley) and used plants of the cv Touriga Nacional grafted on 196-17 in narrow terraces with E-O row orientation and a plant density of 3000 vines/ha. Vines were under the Vertical Shoot Positioning system, bilateral Royat Cordon pruning system. The soil is silty-loam soil and low organic matter. Vines were subjected to two irrigation treatments (Control Rainfed and a sustained deficit irrigation strategy used by the farm consisting of an equal proportion of crop evapotranspiration (30% Etc) applied from when pre-dawn water potential reached -0,3 MPa until one week before harvest. Weekly pre-dawn water potential was accessed and diurnal courses (8-20h, every 3h) of leaf water potential (ΨPD, Ψleaf), were performed. This trial uses a randomized complete block design (2 irrigation treatments and 3 blocks).

Experiments in Alentejo

The trial was carried out in South Portugal (38º22’ N 7º33’ W) and used plants of the cvs Touriga Nacional and Aragonez (syn. Tempranillo) planted in N-S row orientation at a plant density of 2200 vines/ha and grafted on 1103-P rootstock. Vines were under the vertical shoot positioning system, bilateral Royat cordon pruning system. The soil was a sandy to silty-clay-loam soil, with pH=7-7.6 and low organic matter. Vines were subjected to two irrigation treatments: DI1 - sustained deficit irrigation strategy used by the farm consisting of an equal proportion of crop evapotranspiration (ETc) (0.28 in 2014 and 0.36 in 2015) applied along irrigation period and DI2 - similar to DI1 but with reduced volume applied (0.18 ETc in 2014 and 0.24 in 2015). Diurnal courses (8-20h, every 3h) of leaf water potential (ΨPD, Ψleaf), individual leaf gas exchange (Licor 6400, Licor BioSciences), canopy temperature (TC, Flir B20, 7-13 µm, ε=0.96) were determined. We used a randomized complete block design (2 irrigation treat., 4 blocks). The use of low-cost cameras (e.g. Flir One, Flir, USA) coupled to a mobile phone has bee also tested recently (in 2020) in order to assess the robustness of the derived thermal data.

Results and Discussion

Results from the three regions and experimental approaches showed significant correlations between T_C and/or thermal indices (CWSI and I_g) and ecophysiological traits such as leaf gas exchange (stomatal conductance to water vapour) or water potential.

In Rioja, canopy temperature was significantly correlated to Ψstem at both canopy sides. CWSI was strongly and significantly correlated with Ψstem at midday (R^2=0.76**). Moreover, I_g was also significantly correlated with Ψstem in both canopy sides (R^2=0.89** and R^2=0.77** for east and west sides respectively). Similar results were shown in other works (Gutiérrez *et al.,* 2017, 2018).

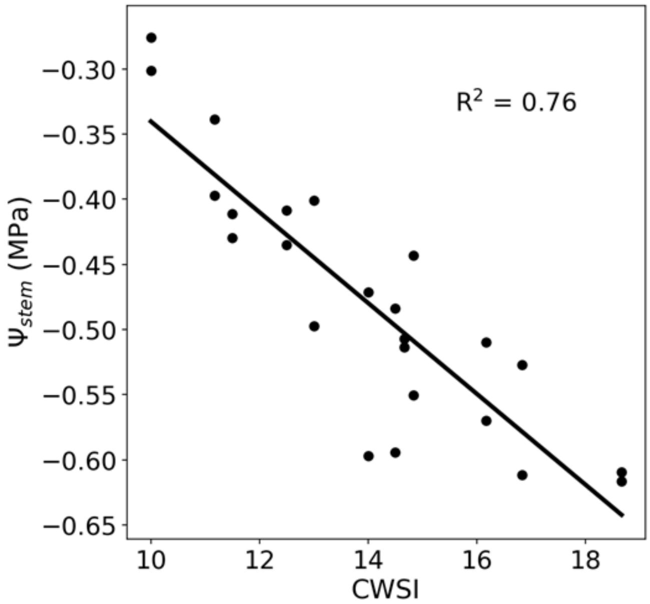

Figure 2: Correlation between crop water stress index (CWSI) computed from thermal imaging acquired on-the-go in both canopy sides and midday stem water potential (Ψstem) in Rioja commercial Tempranillo vineyard (Gutiérrez *et al.,* 2017).

These results suggested that lateral and proximal thermal imaging could be taken on-the-go for monitoring vineyard water status and characterizing the spatial variability in commercial vineyards. These results are promising and highlight the potential of non-invasive, on-the-go thermal imaging to become a tool to evaluate and map vineyard water status, and to be used as a practical tool to drive irrigation scheduling decisions in precision viticulture.

In Alentejo, we found strong correlations between TC and vine leaf gas exchange traits (stomatal conductance to water vapour) and water status during the three-year trial which supports the use of TC as predictor of vine water status. Moreover, values obtained for soil surface temperature (TS) showed that TS can positively influence TC especially at the cluster zone and under the warmest conditions of the day (Costa et al., 2019). Our results support the use of TS as predictor of vine water status. Further work is being implemented to study the robustness of thermal data derived from low resolution (60x80 pixels) and low-cost thermal devices to monitor water stress in irrigated vineyards (Costa & Neves, Unpublished).

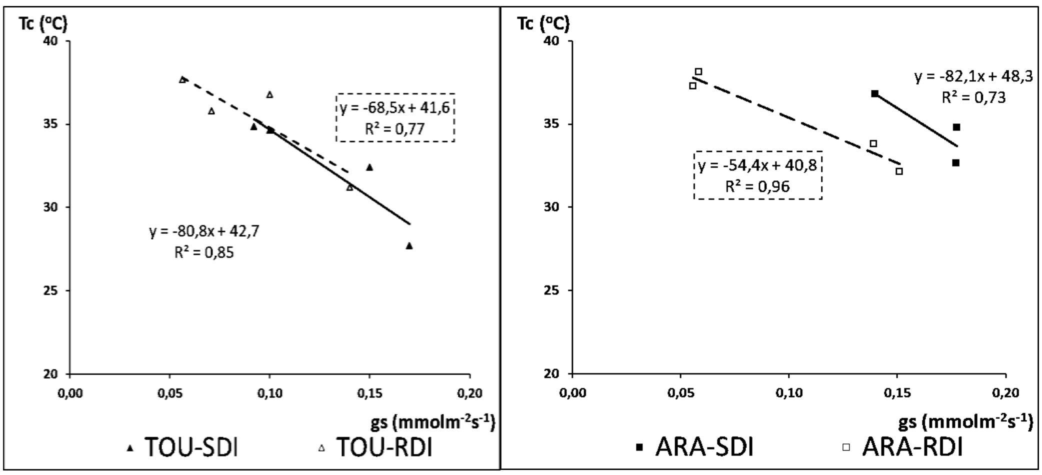

Figure 3: Relationship between sunlit canopy temperature (TC) and stomatal conductance to water vapour (gs) measured for the two *V. vinifera* varieties (Aragonez- syn. Tempranillo (ARA) and Touriga Nacional (TOU) measured on 2015, with plants subjected to deficit irrigation treatments (D1-SDI and D2-RDI). Measurements were done at the period of larger stress, between 14 and 17h.

Conclusions

Our results are promising and show the potential of thermal imaging as a non-invasive technology in precision viticulture to evaluate vineyard water status, helping grape growers to optimize irrigation management. Nevertheless, the use and technological solutions must still be optimized at a fair and reasonable cost for both uses in plant phenotyping and crop monitoring purposes. In parallel with aerial and robotics the use of lower cost devices can be a positive aspect to promote the use of thermography in agriculture and viticulture

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