Use of a new, miniaturized, low-cost spectral sensor to estimate and map the vineyard water status from a mobile platform

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Abstract

Optimizing the use of water and improving irrigation strategies has become increasingly important in most winegrowing countries due to the consequences of climate change, which are leading to more frequent droughts, heat waves, or alteration of precipitation patterns. In this context, this work aims at the development of a novel methodology, using a contactless, miniaturized, low-cost NIR spectral tool to monitor (on-the-go) the vineyard water status variability. On-the-go spectral measurements were acquired in the vineyard using a NIR micro spectrometer, operating in the 900–1900 nm spectral range, from a ground vehicle moving at 3 km/h. Spectral measurements were collected on the northeast side of the canopy across four different dates (July 8th, 14th, 21st and August 12th) during 2021 season in a Graciano (*Vitis vinifera* L.) commercial vineyard (3 ha). Calibration and prediction models were performed using Partial Least Squares (PLS) regression. The best prediction models for grapevine water status yielded a determination coefficient of cross-validation (r^2_{cv}) of 0.67 and a root mean square error of cross-validation ($RMSE_{cv}$) of 0.131 MPa. The outcomes presented in this work show the great potential of this low-cost methodology to assess the vineyard stem water potential and its spatial variability in a commercial vineyard.

Introduction

In the framework of climate change water use is becoming a critical issue in sustainable viticulture since periods of strong variability and uncertainty in water resources availability are forecast (IPCC 2014). Therefore, precise irrigation emerges as a key solution to optimize vineyard water with the aim to protect grapevines from severe water deficit stress. Irrigation scheduling is mainly addressed by different approaches, from soil water measurements or balance estimates to environmental modelling and plant water stress indicators (Rienth and Scholasch 2019). However, many of these methods monitor only a small, limited number of plants; therefore, they are unsuited to detecting spatial variation in water status within a vineyard (Acevedo-Opazo et al., 2008).

Thermal cameras of different resolution and prices used as portable devices (Carrasco-Benavides et al., 2020; Petrie et al., 2019) or-mounted on unmanned aerial vehicles have been used to monitor canopy temperature in some crops, such as grapevines (Baluja et al., 2012). However, sometimes aerial observation provides thermal imagery with a reduced spatial resolution in the measurements that shrinks several meters of the canopy into a few numbers of pixels, losing information. Moreover, in some cases, pixels are mixed of canopy and soil information, which need to be separated. Recently ground lateral and proximal sensing technologies (thermography, and NIR spectroscopy) have been successfully applied for on-the-go assessment of vineyard water status (Diago et al., 2018; Fernández-Novales et al., 2018; Gutierrez et al., 2018: Gutierrez et al., 2021), but the general use of reference temperatures in thermography applications somehow hinders its usage in commercial operations.

NIR spectroscopy is a well-known technique that enables rapid and non-destructive data acquisition which has been used to estimate in real time the plant water status under field conditions (De Bei et al. 2011; Santos and Kaye, 2009; Tardaguila et al. 2017). On-the-go spectral devices, which have been used under field conditions are expensive, heavy and require a lot of space when assembled in the ground vehicle, so it would be necessary to move towards more compact, miniaturized spectral devices, of lower cost, that enable the acquisition of spectral information, in an easier and affordable way.

The goal of this study was to develop a novel methodology, using a contactless, miniaturized, low-cost NIR spectral tool to monitor (on-the-go) the vineyard water status variability.

Materials and methods:

Experimental Layout

The field experiment was carried out in a commercial vineyard of Graciano (red) variety (*Vitis vinifera* L.) located in Tudelilla, La Rioja, Spain (Lat. 42°,18' 30.52'', Long. -2°,7' 05.17'', Alt. 497 m), along four different dates (July 8th, 14th, 21st and August 12th) during 2021 season in a commercial vineyard (3 ha). The vineyard was planted in 2016 (northeast-southwest orientation), grafted on rootstock R-110 with vine spacing of 2.60 m between rows and 1.20 m between vines, and trained to a vertically shoot-positioned trellis system on a double-cordon Royat.

In order to ensure an adequate variability of grapevine water status, three different water regimes were deployed in a completely randomized block design (Hinkelmann and Kempthorne, 2007) with three blocks. A total number of nine treatment replicates were established, and each one comprised 15 plants.

On the go spectral measurements

On-the-go spectral measurements were acquired at solar noon (between 14:00 – 15:00 GMT+1) on the northeast side of the canopy across four different dates, between July and August. A NIR micro spectrometer (1.7 NT/H, Insion Gmbh, Obersulm, Germany) operating in the 900–1900 nm spectral range, at 8.2 nm resolution and 2.5 Hz of acquisition rate was used. The system includes a sensor head for light emission with an integrated 20W tungsten lamp (Figure 1).

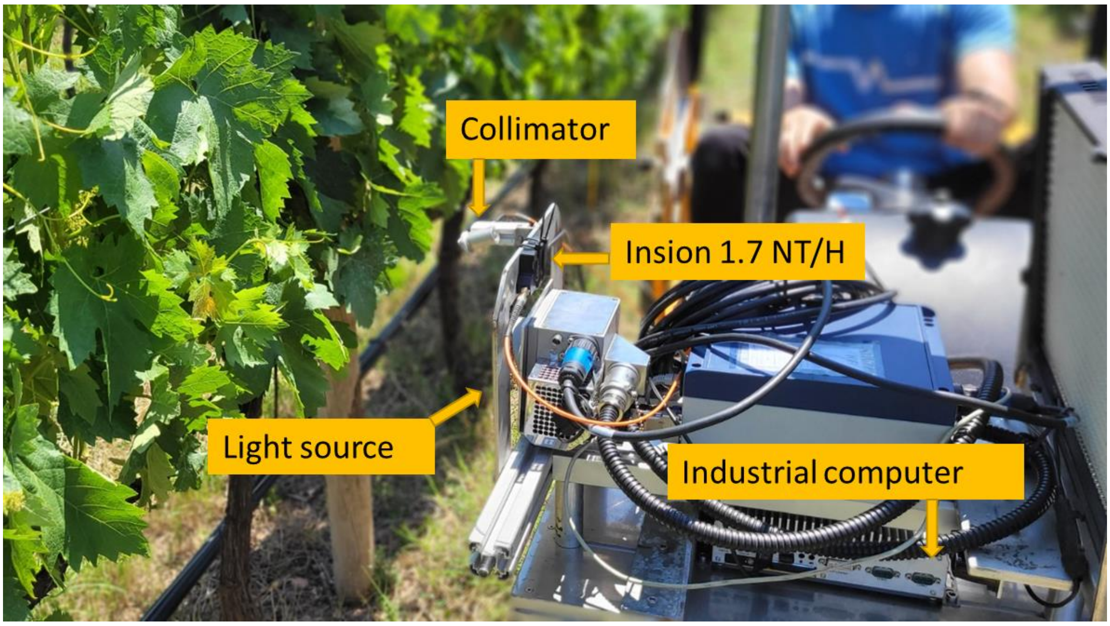

Figure 1. NIR spectral acquisition system installed on a ground vehicle to assess the vineyard water status.

The instrumentation was assembled in a ground vehicle. This ground vehicle was a modified brushcutter (940 Sherpa 4WD XL, AS-motor, Bühlertann, Germany) capable to make spectral acquisitions controlled by a tablet connected via WIFI to the industrial computer while the ground vehicle was in motion at a constant speed of 3 Km h $^{-1}$. Spectral measurements were georeferenced using a GPS receiver Ag Leader 6500 (Ag Leader Technology, Inc., Ames, IA, USA) with RTK correction installed on the ground vehicle.

Measurements of the Stem Water Potential (Ψ_s)

The reference method used for the measurement of the plant water status was the stem water potential (Ψ_s). The 15 plants in each treatment replicate were sorted into three groups (5 vines per group).In each group a random vine was marked, and one leaf from the mid-upper part of the canopy was selected and its stem water potential measured using a Schölander pressure bomb (Model 600, PMS Instruments Co., Albany, USA). Therefore, for each replicate, three measurements of Ψ_s were conducted at each monitoring day. Prior to the Ψ_s measurement, the selected leaves were covered with aluminium foil to drive them into dark adaptation for one hour. Over the season a total of 108 recordings of Ψ_s were taken.

Data Analysis

The spectral processing procedure presented in Diago et al., (2018) and Fernández-Novales et al., (2018) was required to analyze on-the-go spectral measurements of grapevine leaves. This allowed us to link the average spectrum of each treatment replicate with its corresponding reference of Ψ_s. Spectral data manipulation and calibration models were performed with algorithms programmed in MATLAB (version 8.5.0, The Mathworks Inc., Natick, MA, USA). The partial least squares (PLS) Toolbox (version 8.1, Eigenvector Research, Inc., Manson, WA, USA) was used for principal component analysis (PCA) and partial least square regression (PLS). To evaluate the quality of the models, the determination coefficient of calibration (R^2_c) and cross-validation (R^2_{cv}), the root mean square error of calibration (RMSEC) and cross-validation (RMSECV), and the number of latent variables (LVs) were calculated.

Results and discussion

Table 1 shows the values of range, standard deviation and mean for Ψ_s across four different dates during 2021 season in the commercial vineyard. The individual measurements of grapevine Ψ_s ranged from −0.10 MPa (no water stress) to −1.20 MPa (moderate water stress). The average value of Ψ_s remained constant in the first two dates, and later decreased until a value of -0.86 MPa in the last week.

Table 1. Descriptive statistics of the stem water potential (Ψ_s) data measured in a commercial Graciano vineyard during season 2021.

Ψ_s (MPa)	08/07/21	14/07/21	21/07/21	12/08/21
# samples	27	27	27	27
Maximum	-0.10	-0.05	-0.45	-0.65
Minimum	-0.55	-0.60	-0.70	-1.20
Standard deviation	0.10	0.16	0.07	0.14
Mean	-0.37	-0.36	-0.59	-0.86

The best model obtained for Ψ_s was selected by statistical criteria, choosing the one which presented the lowest value of RMSECV and highest values for R^2_{cv} with a lower number of latent variables to avoid overfitting. The best regression model for cross validation returned a R^2_{cv} value of 0.67, a RMSECV of 0.131 MPa and seven latent variables were used to build the Ψ_s prediction model (Figure 2).

The micro NIR sensor presented in this study weights 130 g, the dimensions are 108 x 77 x 21 mm, and its cost did not exceed 4.500 € in comparison with other more expensive and heavier NIR sensors used in preceding works (Fernández-Novales et al. 2018; Diago et al. 2018). These results are in good agreement with a previous work that used on-the-go thermal imaging to assess vineyard water status (R^2_{cv} = 0.65 and RMSE = 0.184MPa, Gutierrez et al. 2018) and another study applying aerial thermal imaging with a R^2_c value of 0.50 (Baluja et al., 2012).

The outcomes obtained in this study in terms of R^2_{cv} are slightly lower than the works presented by Diago et al., (2018) (R^2_{cv} = 0.71) and Fernández-Novales et al., (2018) (R^2_{cv} = 0.90), mainly due to the limited water stress data range gathered along the season. Nevertheless, this R^2_{cv} value (Shenk & WesterHaus, 1996) could be sufficiently reliable to estimate the Ψ_s in three plant water stress levels and facilitate the decision-making process about the water use efficiency and the irrigation scheduling in precision viticulture.

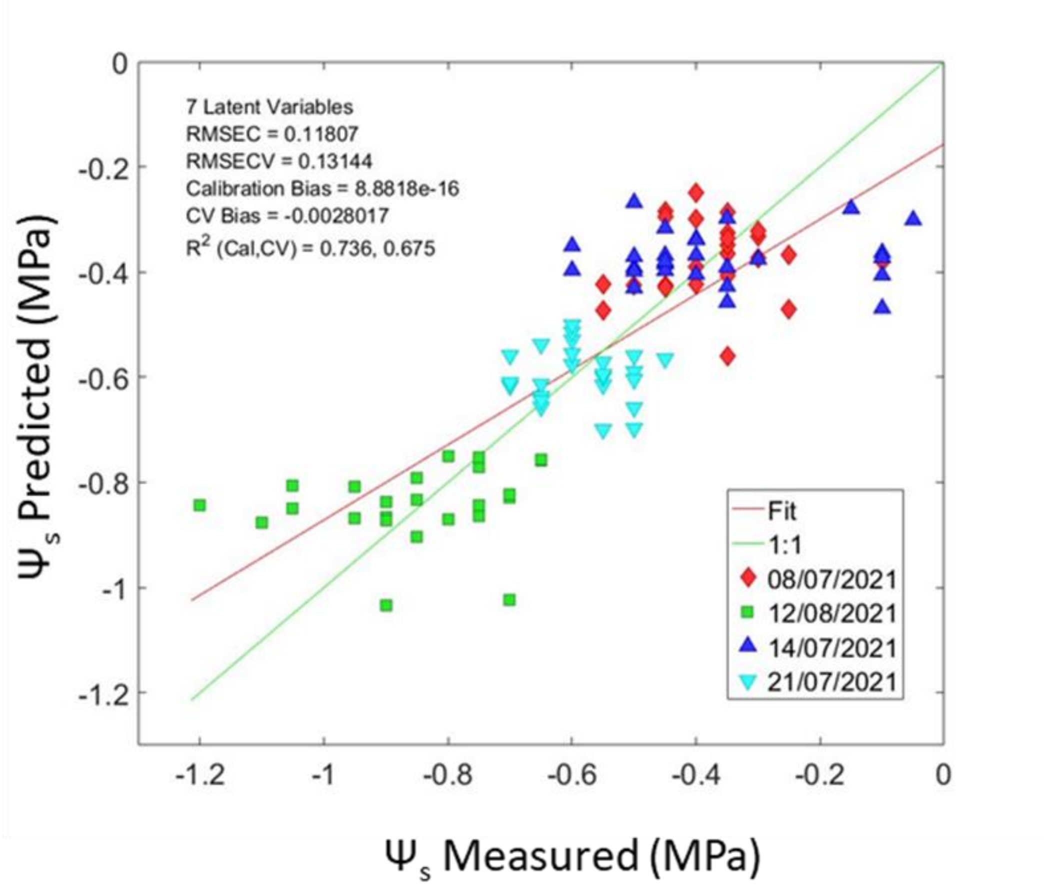

Figure 2. Regression plot for stem water potential with cross validation using the best PLS model from spectral measurements acquired on-the-go in a commercial Graciano vineyard during season 2021.

Conclusion

The results presented in this work show the great potential of this low-cost methodology to assess the vineyard stem water potential and its spatial variability in a commercial vineyard. The capability to monitor the spatiotemporal evolution of the vineyard water status will promote the implementation of appropriate irrigation strategies in precision viticulture.

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