USING REMOTE SENSING TO QUANTIFY THE TEMPORAL AND SPATIAL EFFECTS OF EXTREME WEATHER EVENTS IN VINEYARDS

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Abstract:

Introduction - The increasing frequency of extreme weather events (EWE) represents a severe threat to viticulture. The accurate and early assessment of plant stress condition offers substantial advantages to minimize the effects of EWE. Vegetation indices obtained by remote sensing could provide useful information for early detection and quantification of abiotic stresses.

Methods - The analysis assessed several vineyards in Italy and Australia recently affected by EWE (2016-18). The spatio-temporal pattern of EWE (heatwaves, late frost) and their effects on vineyards were assessed by analysing the evolution of specific vegetation indices calculated using satellite imagery. The magnitude of indices variations was used to quantify the extent of canopy damage. Temporal variations were used to calculate the time necessary for complete recovery of the plants.

Results - Different spectral bands (NIR, red edge, SWIR, green and red) and several vegetation indices provided information to quantify the extension of the areas damaged by EWE. The comparison of the indices values and single bands in affected and unaffected areas allowed the estimation of the temporal pattern in different climate conditions of the studied areas. Specifically, it was possible to quantify the recovery time, needed by plants to return to an acceptable vigour after damages induced by frost. The results provided a basis for better understanding and management of EWE effects.

Discussion - The implementation of remote sensing techniques is widely used to monitor water status and spatial variability of the vineyards. By contrast, there is less application of these tools for monitoring effects and damages due to EWE. The results of this study demonstrate that the analysis of vegetation indices computed from remote sensing imagery can provide factual information of the spatio-temporal pattern of vineyards affected by EWE. The methodology established could be used to support decision-making towards calamity alleviation, insurance services and recovery management.

Keywords: Grapevine,Extreme weather events, Climate change, Remote sensing, Spatio-temporal pattern.

1. Introduction

The increasing frequency of extreme weather events (EWE) related to climate change (CC) represents a severe threat to agriculture. The long-lasting socio-economic costs of heatwaves, late frost, floods, hailstorms and other EWE pose serious challenges for the farmers and the communities (Motha 2011). The vulnerability of grapevine to the EWE varies with the variety and the phenological stages. For example, the occurrence of heatwaves during flowering and ripening might affect fruit-set and yield (Carvalho et al. 2018; Hayman et al. 2014; Moriondo, Giannakopoulos, and Bindi 2011; Webb et al.

2010). Late frost occurring right after budburst represents a severe risk because the high water content of new shoots makes them more susceptible (Trought et al., 1999).

The early assessment of plant stress condition offers substantial advantages to minimise the effects of EWE. The need to address the impact of EWE on wine production can take advantage of remote sensing techniques. The evaluation of stress condition is usually carried out through vegetation indices able to describe plant physiology derived from high spatial resolution images. The use of free, medium-spatial resolution satellite data could enable the implementation of an affordable method to evaluate the effects of the heatwaves on vineyards. The potentiality of Sentinel-2 to map evapotranspiration on vineyards was analysed by Ciraolo et al. (2012). Furthermore, medium and low-resolution images were used to derive maps of the frost occurrence (Pouteau et al., 2011), to predict wine yield (Cunha et al., 2010; Sun et al. 2017) and to compute leaf area index (Anderson et al. 2004; Richter et al., 2008).

2. Material and methods

Experimental sites - Experiments on the heatwaves were conducted at Yalumba Oxford Landing Estate (OLE) in South Australia (34°06'06.29" S and 139°50'39.21" E) over the 2016-17 and 2017-18 growing seasons. Experiments on late frost were carried out in Lonigo (VI) in north-east of Italy, after the frost event of 19th April 2017.

Meteorological data - The meteorological parameters were detected from the weather stations located within the trial areas. The evaluation was carried on examining the parameters recorded the same day of the satellite image, the day before and the amount of the three days before the image date.

Data acquisition and processing- The images acquired from Sentinel-2 Mission were pre-processed using SEN2COR tool available in the SNAP (Sentinel Application Platform) toolbox, to perform atmospheric correction. Pixels with NDVI below a designated threshold were considered no-productive areas or headlands and, therefore, removed.

Images validation - To reduce the bias, one WorldView-2 high-resolution image was acquired to calculate the NDVI values of one the experimental site after removing the inter-rows. The NDVI values of WorldView-2 image were compared with the Sentinel-2 image performing the Pearson correlation test.

Spectral bands and vegetation indices- Spectral bands and several vegetation indices were computed using R statistical software.

Analysis - The analysis relating the heatwaves investigated the correlations between the trends of weather parameters and the trends of spectral bands/vegetation indices. The examination was carried out considering all the Sentinel-2 images available over the two growing seasons. A second analysis focused on the heatwaves, computing the correlation matrix between the meteorological parameters and the spectral bands/vegetation indices. Exclusively the images before and after the heatwaves were considered. This last investigation was applied to the frost area as well. Furthermore, the multispectral information was used to evaluate the recovery time of the vineyards affected by frost event, comparing the evolution of the vegetation indices in the area affected by frost and in the control area after the frost event.

3. Results and discussion

3.1. *Images validation*

The Pearson correlation test at a confidence level of 95% lead to a significative correlation coefficient of 0.665 (Fig. 1). This result indicates that the information about the vigour of vegetation provided by medium-resolution images used in this study is reliable.

3.2. Heatwaves:Trends of vegetation indices and spectral bands compared to weather conditions

*T*he results of the correlation analysis between the yearly weather conditions and the performance of the spectral bands and the vegetation indices allowed to identify the multispectral information more sensitive to the heatwaves. The analysis highlighted the positive correlation between growing degree days and some vegetation indices (NDVI, SAVI). A positive correlation was also found between relative humidity and spectral bands and vegetation indices (red edge, EVI, Fig. 2). These results suggest that vegetation indices calculated from medium- spatial resolution images may be successfully used to describe the evolution of the weather conditions during the heatwaves.

3.3. *Late frost: evaluation of the recovery time*

The comparison of the evolution of the vegetation indices allowed to assess the recovery time of the grapevines after the damages (Fig. 3). Based on the available Sentinel-2 images, the estimated recovery time was around 40 days. It is worthwhile to stress the fact that after full recovery there is evidence of higher activity of the plants affected by frost. The reason for this behaviour must be sought in the younger age of the new shoots.

4. Conclusions

The analysis highlighted that multispectral imagery provides information useful to assess the spatio-temporal pattern of vineyards affected by extreme weather events and that medium- spatial resolution data can be used for this kind of analysis.

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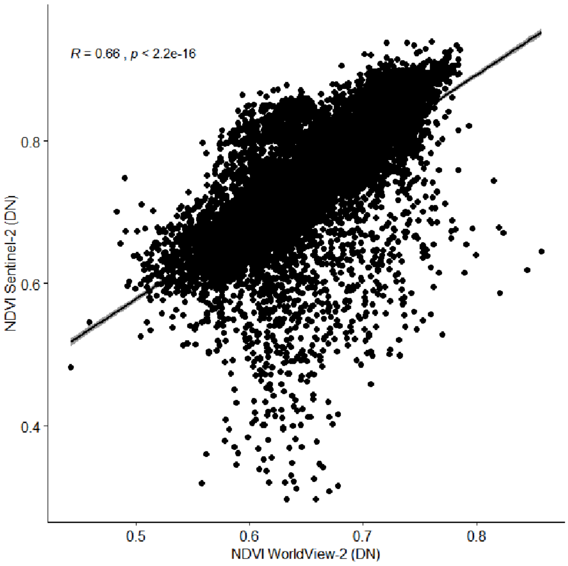

Fig. 1. Correlation between NDVI values in the Sentinel-2 and the WorldView-2 images

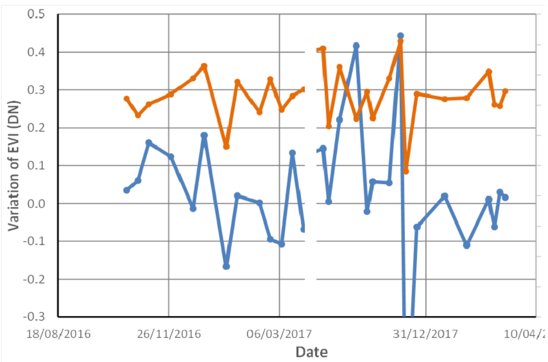

Fig. 2. Correlation between the trend of enhanced vegetation index (EVI-blue line) and relative humidity (RH-orange line) over the two growing seasons

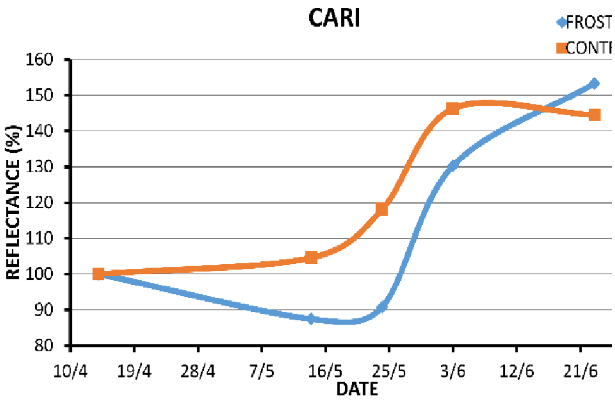

Fig. 3. Comparison of the trend of Chlorophyll Absorption Ratio Index (CARI) in frost affected area (blue line) and not affected area (orange line)