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High-resolution UAV-based thermal imaging to estimate the instantaneous and seasonal variability of plant water status within a vineyard

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ABSTRACT

Thermal imaging can become a readily usable tool for crop agricultural water management, since it allows a quick determination of canopy surface temperature that, as linked to transpiration, can give an idea of crop water status. In the last years, the resolution of thermal imaging systems has increased and its weight decreased, fostering their implementation on Unmanned Aerial Vehicles (UAV) for civil and agricultural engineering purposes. This approach would overcome most of the limitations of *on site* thermal imaging, allowing mapping plant water status at either field or farm scale, taking thus into account the naturally existing or artificially induced variability at those scales. The aim of this work was to evaluate to which extent high-resolution thermal imaging allows evaluating the instantaneous and seasonal variability of water status within a vineyard. The novelty and significance of our approach is that the specifically designed and build unmanned aerial vehicle (UAV) provided very high-resolution imaging (pixel <9 cm), and that it was used at a commercially relevant acreage (7.5 ha). This set-up was used to obtain Crop Water Stress Index (CWSI) from thermal images in a clear-sky day. CWSI values were and compared to stem water potential (Ψs) and stomatal conductance (g_s) measured at 14 sampling sites across the vineyard at the moment when images where acquired. In order to evaluate the potential of CWSI acquired in a single day to estimate within-vineyard patterns of variation in water status, a spatial modeling approach was used. CWSI correlated well with Ψs and g_s at the moment of image acquisition, showing to have a great potential to monitor instantaneous variations in water status within a vineyard. The information provided by thermal images proved to be relevant at a seasonal scale as well, although it did not match seasonal trends in water status but mimicked other physiological processes occurring during ripening. Therefore, if a picture of variations in water status is required, it would be necessary to acquire thermal images at several dates along the summer.

1. Introduction

In the last two-decades, Precision Agriculture techniques have been progressively implemented in viticulture, giving birth to what is called Precision Viticulture (PV). Along those years, PV has focused on delineating management zones, i.e.: on defining within-vineyard areas that are relatively homogeneous, and different to other areas in the same vineyard (Arno et al., 2011; Arnó et al., 2009; Urretavizcaya et al., 2014). This approach is very appropriate for high-value crops such as grapevine and, when transferred to grape-growing companies, it usually implies adopting site-specific cultural practices for each zone defined (Bramley et al., 2011b; Santesteban et al., 2013; Serrano et al., 2015). In those companies, where new generation grape harvesters are available, the zones delineated can also be used to automatically segregate grapes from the same field into two batches to improve global wine quality (Bramley et al., 2011a; Santos et al., 2012).

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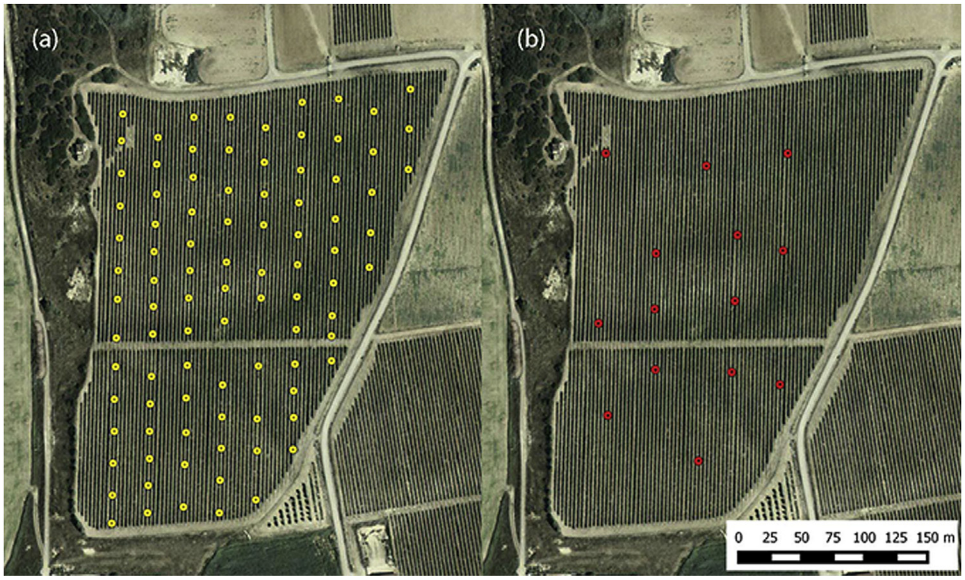

Fig. 1. Aerial view of the vineyard indicating the location of (a) Sampling Points (SP) and (b) Water status Sampling Points (WSP).

The most common sources of information on field spatial variability for zone delineation are (i) vegetation indices obtained from airborne multispectral cameras, (ii) soil apparent conductivity or resistivity, and (iii) data gathered in situ following a sampling grid (Arnó et al., 2009). However, those approaches are not considering any variable directly related to plant water status, which, in semiarid areas, is usually regarded to be the major factor determining grape yield and berry composition (Medrano et al., 2014). Besides, in a context of climate change, water status is also expected to play an increasingly relevant role in cooler areas, as water deficit periods along the growing season are expected to occur more likely in the near future (Ashenfelter and Storchmann, 2016; Fraga et al., 2012; Viguié et al., 2014), so PV approaches should pay much greater attention to water availability.

Whole field imaging using thermal cameras is a source of useful information in this regard, as it allows estimating canopy temperature, known to be related to plant transpiration and, therefore, to plant water status (Jackson et al., 1988, 1981). High resolution thermal cameras have been successfully mounted on aircraft platforms (Sepulcre-Canto et al., 2006) and on unmanned aerial vehicles (UAV), increasingly using higher performance sensors in terms of lower size and weight, and of greater spectral and spatial resolutions. Last generation thermal cameras can reach centimeter ground resolution, providing enough accuracy for canopy extraction in discontinuous crops in rows such as grapevines and fruit trees, and are a promising tool for field and irrigation management applications (Berni et al., 2009; Zarco-Tejada et al., 2012).

In viticulture, proximal thermal sensing has been shown to be a good tool to estimate plant water status (Fuentes et al., 2012; Grant et al., 2007; Jones et al., 2002; Pou et al., 2014). In those approaches, a thermal camera is directly used to get a lateral view, or mounted on a shaft or a crane, to get a zenithal view; and relatively good agreement is observed between canopy-temperature derived indices and plant water potential or stomatal conductance. On the contrary, the implementation of UAV-based thermal imaging solutions has not been well explored yet in viticulture, since the resolution obtained must be sufficient to enable targeting pure canopy pixels, avoiding mixed soil/vegetation pixels (Gonzalez-Dugo et al., 2015), which is particularly complicated in most vineyards due to the structure of the crop, trellised in narrow rows. In one of those works, Baluja et al. (2012a) evaluated the water status variability of a commercial rainfed Tempranillo vineyard using a UAV platform, and observed that some vegetation indices, not derived from thermal images but from multispectral ones, were better correlated to stomatal conductance and leaf water potential, probably as they reflected a longer term response. Another research team also working in Spain, evaluated the correlation between Crop Water Stress Index (CWSI, a canopy-temperature derived index) and leaf water potential, reporting that correlation improved at noon (Bellvert et al., 2014), and exploring the potentiality of the technique for setting thresholds useful for irrigation scheduling (Bellvert et al., 2015a, 2015b).

Gonzalez-Dugo et al. (2013) recently suggested that the requirements to achieve the water stress monitoring using aerial platforms are: (a) establish a strong correlation between stress indices and actual water stress in the field; (ii) the spatial resolution must be sufficient to enable targeting pure canopy pixels, avoiding mixed soil/vegetation pixel; (iii) the ability to evaluate entire fields in individual flight; (iv) faster turn-around acquisition times and processing in order to provide quasi-real time water status maps helping the farmer decision-making process.

The aim of this study is to evaluate the interest of high-resolution UAV-based thermal imaging to estimate the instantaneous and seasonal variability of plant water status within a vineyard. The significance of our approach is that we worked at a commercially realistic scale (7.5 ha), the high resolution of the thermal images acquired (9 cm pixel^{-1}), and that we tested to which extent the information provided by one flight campaign can be used to evaluate spatial variability in water availability across the season.

2. Material and methods

2.1. Vineyard characterization

The experimental work was performed in a 7.5 ha vineyard located in Traibuenas, Navarra, Spain (42°22′20.1″N 1°37′34.2″W, WGS84, Altitude: 328 m), in a region characterized by a semiarid climate (Bs type in Koppen's classification; P < 350 mm; ETP_{Penman} >1150 mm). The vineyard is trained as a vertical shoot positioned bilateral cordon, bud number fixed at 12 buds per m of row line, plant spacing being 3 m between rows and 1 m within the row. The vineyard was 18 years-old at the beginning of the experiment, it was managed according to standard practices in the area, and vines were not affected in a significant way by pests or diseases,

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