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Using field spectrometry and a plant probe accessory to determine leaf water content in commercial vineyards

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ABSTRACT

Vine water status is widely considered to be fundamental to grape yield and quality. Typical Mediterranean vineyards experience seasonal droughts so water deficits need to be controlled. We evaluated the usefulness and effectiveness of a field spectroradiometer used to estimate vine water content at the leaf and canopy levels. The experiment was conducted in four commercial vineyards located in the Bierzo region (northwestern Spain) on four different grape varieties (Mencía, Cabernet Sauvignon, Tempranillo and Merlot). Data on spectral measurements and leaf variables (total specific leaf fresh weight, equivalent water thickness and specific leaf weight) were compiled during the growth phase up to berry set and veraison in 2009 and 2012 and the relationship between leaf variables, vegetation indices and continuum removal variables was studied. The results varied depending on the variety; also, at canopy level they were not suitable for determining water content. Equivalent water thickness and total specific leaf fresh weight for Tempranillo and Mencía were related to the normalized difference infrared and shortwave infrared water stress indices. Using the continuum removal variables, the best correlations for equivalent water thickness were achieved for band area and maximum band depth calculated for the 1200 nm, 1450 nm and 1950 nm intervals. To estimate vine water status, we recommend calculating the band area for 1450 nm because of its link to equivalent water thickness (R^2 = 0.681 for Tempranillo). We demonstrate that yield spectroradiometry is a rapid and non-destructive method for estimating leaf water content in commercial vineyard at leaf level.

1. Introduction

Controlling vine humidity levels is crucial to producing quality wines. An indirect method for measuring vine water content is to measure leaf water content (Kennedy et al., 2002). Mediterranean vineyards typically do not use irrigation systems but depend on climatic conditions and this explains why vines may experience water stress. Since water stress modifies the pigment composition of vine leaves (Flexas et al., 2010), reduces content in biochemical elements, turgor and total water potential and, in general, negatively affects plant growth; measuring leaf water content provides information on vine water content. Severe water stress reduces leaf area and, consequently, reduces photosynthesis and affects metabolism, resulting in stunted growth (Lisar et al., 2012) or even vine death (Shao et al., 2008). Leaf water content variations affect grape composition, must quality (Serrano et al., 2010) and yield (Leeuwen et al., 2009). Although a certain amount of water stress after veraison increases must quality (Chaves et al., 2010), water needs must particularly be met during and after bloom. In the period between bloom and veraison, water stress reduces must sugar content, with the resulting low alcohol content reflected in poor quality wines (Leeuwen et al., 2009). Mild water deficits have an impact on berry size, development and composition by increasing content in the tannins and anthocyanins that determine wine quality. In fact, deficit irrigation is a strategy to improve

Abbreviations: A, area of the three leaf disc; BA, band area; CR, continuum removal; DM, leaf dry weight (g); EWT, equivalent water thickness (kg/m^2); FM, leaf fresh weight (g); fWBI, floating position water band; FWHM, full width at half maximum; MBD, maximum band depth; NDII, normalized difference infrared index; NDVI, normalized difference vegetation index; NDWI, normalized difference water index; SIWSI, shortwave infrared water stress index; SLW, specific leaf weight (kg/m^2); SRWI, simple ratio water index; TSLW, total specific leaf fresh weight (kg/m^2); VI, vegetation index; WI, water index.

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grape quality while allowing for a small drop in yield (Chaves et al., 2010).

Crops are influenced by climatic, phenological and biological changes that can be detected in variations in plant reflectance, especially in leaves (Moshou et al., 2014). Although the usual method for estimating water status is to measure leaf water potential in a pressure chamber, implementation is slow and results may be influenced by temperature, light, size and leaf position (Serrano et al., 2010). Water content is typically estimated nowadays by remote sensing at different scales, using vegetation indices, physical models, continuum removal (CR) analysis, etc. Santos and Kaye (2009) demonstrated the greater speed and validity of near infrared (NIR) spectroscopy in comparison to the pressure-chamber method. Suárez et al. (2010) demonstrated the usefulness of reflectance in evaluating water stress in fruit trees using a yield spectroradiometer and fluorescence and thermal airborne imagery. Gaulton et al. (2013) obtained estimates of plant water content using a yield spectroradiometer and dual-wavelength laser scanner.

Many studies have associated leaf water content with vegetation indices (VI)—calculated using spectral values—mainly the water index (WI: ratio of reflectance at 900 nm and 970 nm) and normalized difference vegetation index (NDVI: ratio of the difference between infrared and red reflectance and the sum of infrared and red reflectance). Serrano et al. (2010) demonstrated that the WI can be used to monitor drought, control irrigation and assist in decisions regarding grape harvesting times; Dzikiti et al. (2010) reported similar results for citrus trees. Serrano et al. (2012) studied relationships between the WI and the NDVI and must quality, yield and vigour, concluding that the WI affects must quality but not yield or vigour and that the NDVI affects vigour but not must quality. Although Suárez et al. (2010) analyzed the relationship between the NDVI and vigour variables, it is necessary to study further VIs to determine leaf composition variables.

CR normalizes reflectance values to a common baseline, thereby allowing comparison of individual absorption features (Kokaly and Clark, 1999). Curran et al. (2001), in studies to measure water content in pines from fertilized and unfertilized plots located in Florida, compared the results with those for reflectance data obtained using a spectrometer, testing two CR methods: band depth at the centre of the absorption feature and the area of the absorption feature. Stimson et al. (2005) related percentage dry mass and plant water potential for two co-occurring New Mexican conifer species, obtaining the best relationships for CR for both species. Huber et al. (2008) used CR hyperspectral data for leaves from mixed forests located in Switzerland to estimate concentrations of nitrogen, carbon and water. Wang et al. (2009) studied different types of pine leaves in China, collecting data on fresh leaves, calculating specific leaf weight (SLW) and equivalent water thickness (EWT) and relating these to the VI (WI, NDVI, etc.) and to the variables obtained after applying CR at 970 nm and at 1200 nm (calculated from field spectroradiometer data).

Although CR is used in mostly in forests, its usefulness has also been demonstrated for agricultural crops. Rodriguez-Pérez et al. (2007), in a study of the relationship between CR and water content in vineyards, concluded that using hyperspectral data could improve current methods for estimating water status in individual vines. Liu et al. (2010) used CR to obtain twelve spectral indices to determine, with reasonable accuracy, subtle variations in leaf chlorophyll content in rice under heavy metal stress in China. Jiang et al. (2012) used CR to process original spectral data measured in a single soybean leaf to identify severity of rust disease and common mosaic disease infections. Fu et al. (2013) used hyperspectral data with two different types of spectral transformations (CR and first derivative) to make models to predict winter wheat biomass, obtaining the highest estimate accuracy for CR.

Spectroscopy analysis is an efficient, non-destructive, rapid and accurate measurement technique that is widely applied to plant category discrimination, disease and nutritional status inspections and fruit quality assessments. One drawback to measuring reflectance at canopy level is that the measurement depends strongly on the sun inclination angle, the roughness of the canopy and the position of the fibre optic cable of the spectroradiometer. One way to overcome these drawbacks is by using an integrating sphere, which can correct reflectance measurements at leaf level (Zarco-Tejada et al., 2005); however, this accessory is too fragile for use in the field. An alternative solution is to use the more robust plant probe accessory, which has the added advantage that it is non-destructive (measurements can be made directly from the vine without removing leaves). When the light reaches the leaf with the same inclination angle, the spectral measurements are very repeatable (Milton et al., 2009).

The main objective of this research was to evaluate the usefulness and effectiveness of a field spectroradiometer for estimating vine water content at canopy level and leaf level, using a pistol grip and a plant probe, respectively.

2. Materials and methods

2.1. Study site and experimental design

The research was conducted in four commercial vineyards, located in Cacabelos in the province of León, Spain, cultivating the following grape varieties: (a) Cabernet Sauvignon, (b) Mencía, (c) Merlot and (d) Tempranillo. The vineyards, owned by Ribas del Cúa Winery, lie within the Bierzo Protected Designation of Origin, between the longitude and latitude coordinates 6.713009° W and 42.613049° N (northwest corner) and 6.698804° W and 42.605011° N (southeast corner) (ETRS89 Reference System). Mean altitude is 585 m with a mean slope of 5%. Soil is composed of 11% gravel and has a loamy texture (36% sand, 45% silt and 19% clay). The 1103 Paulsen rootstock vines were planted in 1997 on bilateral cordons with two pairs of shoot-positioning wires, with row spacing of 1.1 m × 2.8 m. The same fertilization, tillage, pest and weed management methods were used in the years 2009–2012 (encapsulating the period of the study).

Selected within each of the four vineyards were one line out of 10 and one vine out of 20 within each line. A regular grid pattern of 20 m × 29 m was thus defined, corresponding to approximately 14 vines/ha and resulting in 47 Cabernet Sauvignon, 45 Mencía, 27 Merlot and 43 Tempranillo vines. Each data vine was geo-referenced using a Topcon Hiper+ GPS receiver (Topcon Corporation, Tokyo, Japan) with real-time kinematic correction (centimetre precision).

The study was conducted in two years (2009 and 2012), specifically chosen for their annual rainfall, temperature data and sky conditions for the spectral measurements. In 2009 and 2012, annual rainfall in the area was 551.2 mm and 449.3 mm, respectively, and average temperatures were 11.76 °C and 12.20 °C, respectively; the skies were also cloudless near the veraison. The years 2010 and 2011 were excluded because the weather conditions were not suitable for spectral measurements in the period between fruit set and veraison, impeding canopy spectroradiometer data capture under clear skies.

Data was collected in the field on three days (18–20 August) in 2009 and two days (16–17 July) in 2012. These dates corresponded physiologically to the growth phase between fruit set and veraison—recommended as the best time for measurement (Santos and Kaye, 2009).