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Abstract
Predawn leaf water potential is widely considered an effective measurement of vine water status, but it is also a laborious and destructive method, therefore not allowing for temporal measurement on the same leaf. As a non-destructive method, hyperspectral field spectrometry and airborne/satellite remote sensing have recently received a lot of attention for the estimation of plant stress mainly through the monitoring of plant pigments such as chlorophyll, but also for the estimation of plant water status. This paper discusses preliminary findings in the first of a series of studies aimed at investigating the potential of hyperspectral remote sensing to assess vine water status. High resolution multispectral aerial photography was used to determine plot layout according to relative vine vigour within four vineyards, after which predawn leaf water potential was determined along with field spectrometer readings using a contact probe. The results comparing the predawn leaf water potential values with the spectral reflectance response between 350 and 2500 nm was in general disappointing, but nevertheless improved when the dataset was broken up into different vigour levels (low, medium and high) and with the four sites of different cultivars assessed separately. Notable was the differences in response between the different sites, and also between the low and high vigour plots of all sites, which suggested that lower vigour vines responded on a pigment level, while the higher vigour vines responded primarily on a leaf water content level. Further work is planned to investigate these results through refining the experimental layout, but also through the inclusion of midday leaf water potential, carbon isotope analysis and leaf temperature measurements to also facilitate scaling up to the canopy level.

INTRODUCTION
Even though predawn leaf water potential $\Psi_{PD}$ (Scholander et al., 1965) is often used in scientific studies as a measurement of the onset of water stress in grapevines, it has the downside of being a laborious and destructive method. Another complication of $\Psi_{PD}$ measurements, is the significant variation it can exhibit with changes in soil type (Chone et al., 2001). Considering the high degree of soil variability over relatively short distances found in soils utilised for viticulture in South Africa (Burger, 1977; Saayman, 1977; Conradie et al., 2002), $\Psi_{PD}$ may not give a good representation of vineyard water status. The main reason for the $\Psi_{PD}$ dependence on soil type, is that it measures plant water status at zero plant water flux, where it is considered to be in equilibrium with soil water status (Chone et al., 2001). Typical $\Psi_{PD}$ values of between -500 and -600 KPa are mostly considered an indication of vine water stress, but the onset of stress have also been reported to be as low as -315 KPa (Van Zyl, 1987).
With the recent advances in remote sensing technology, especially high spatial and spectral resolution airborne and satellite remote sensing, the estimation of vineyard water status may be a reality in the not too distant future. It is necessary however to investigate the effects of vine water deficit on the spectral properties of vine leaves and canopies in order to select the optimal configuration of airborne or spaceborne sensors. Leaf reflectance is sensitive to water content in leaves in broad spectral bands centered at approximately 970, 1200, 1450, 1950 and 2250 nm (Palmer and Williams, 1974; Carter, 1991; Ustin, 1997; Sims and Gamon, 2003). A review of the several narrow-band spectral indices and curve-fitting models used in water content estimation of leaves and plant canopies can be found in Sims and Gamon (2003). Apart from the primary effects of leaf water content on reflectance in these wavebands, secondary effects due to changes in pigment content or concentration, leaf physiological functioning, or cell structure may also play a role. It is therefore also expected that the effects of plant water status as measured by \( \Psi_{pd} \) would have complex effects on leaf reflectance.

**MATERIALS AND METHODS**

Four commercial vineyard blocks were selected that were also part of a study on natural terroir units in the Stellenbosch winegrowing area, South Africa. This included one Cabernet Sauvignon block (CS1) and three Sauvignon blanc blocks (Sb1, 2 and 3). High resolution (0.35m) digital multispectral images were collected in January 2005, which were classified into ratio vegetation index (RVI = Infrared / Red) images (Fig 1). The RVI index was considered by Dobrowski et al. (2002) to be optimal in vineyards that are vertically shoot-positioned. The classification process deviated from the widely used unsupervised classification method in that images was classified into two colour classes using a manual classification method. Firstly, most of the inter-row (cover crop/weed) signal was removed, after which the remainder of the image (mostly the vine canopies) was classified according to knowledge of the vigour situation in the vineyards confirmed through field visits before and after imaging.

The classified images were also used in the terroir study to facilitate experimental plot selection best representing the natural terroir units studied. The objectives of image classification for this study was to ensure that plots of an intermediate vigour was studied, but also to select two additional plots that investigate the effects of higher and lower vigour on the wine style of the terroir unit. Predawn leaf water potential (\( \Psi_{pd} \)) was measured for three representative vines from each medium vigour plot and four representative vines of each of the low and high vigour plots. Each measured leaf was removed from approximately the fifth node from the base of a main shoot on the same side of the canopy for each site. The experimental procedure involved abscission of the leaves, immediate measurement of the leaf water potential using a pressure bomb, and spectral measurements on the same leaves within five minutes of abscission.

Spectral reflectance measurements were conducted with the FieldSpec Pro spectroradiometer (www.asdi.com) and the ASD Contact Probe from the same company with a leaf clip attachment. This combination made measurements possible in the predawn conditions. Apart from the light source, the leaf clip also has a built-in Spectralon (Labsphere, North Sutton, NH, U.S.A.) 100% reflectance standard, which facilitated regular calibration of measurements (after each reflectance measurement).
RESULTS AND DISCUSSION

Pre-dawn leaf water potential ($\Psi_{PD}$) did not differ significantly between the different sites, but significantly ($p \leq 0.05$) higher $\Psi_{PD}$ values were measured for the lower vigour plots compared to the medium and high vigour plots of all sites. When the different experimental plots were considered separately, the low vigour site of CS1 and high vigour site of Sb3 featured the highest water stress levels, while the high vigour site of Sb1 appeared the least stressed of all sites. These results confirm the importance of representative sampling in a vineyard block when the water status of vines is determined.

Correlograms were created to investigate the correlation between leaf reflectance and the measured $\Psi_{PD}$ values. The overall correlation values for all sites and vigour levels were disappointing, which was probably a result of confounding effects between the high and low vigour levels, as well as a general weak response from the medium vigour levels. The latter were also characterised by intermediate $\Psi_{PD}$ values, characteristic of moderate water stress (Fig 2). The combined correlation showed some response in the green peak (550 nm), red edge (approximately 730 nm) and the two primary water absorption bands (A1 centered at 1450 nm and A2 centered at 1900 nm), but it was not significant even at the $p \leq 0.10$ level.

Effects of $\Psi_{PD}$ on reflectance was not consistent between plots, and included less significant effects in the 350 to 700 nm range, with more significant correlations existing in the 1300 to 2500 nm range for the Sb1 and Sb3 sites. The CS1 site was the only site that showed significance in the 700 to 1300 nm region. An interesting observation is the inverse effects that can be seen between the Sb1 and Sb3 sites in the 1300 to 2500 nm region. The Sb1 site’s response was similar to the response of all high vigour plots combined (Fig 4). It is noticeable that the low vigour (and presumably more stressed) vines generally showed good response in the green peak (550 nm) region, with very good response at 737 nm (red edge). The results depicted in Fig 4 therefore may suggest that in the lower vigour vines, factors other than merely leaf water content, such as pigment concentration and functioning, respond better to varying levels of $\Psi_{PD}$. This was further investigated by grouping all measured $\Psi_{PD}$ values into two groups of $\Psi_{PD} \leq -490$ KPa (“L” or low water stress) and $\Psi_{PD} \geq -560$ KPa (“H” or high water stress). These two groups (mean spectra shown in Fig 5) were then subjected to a Students T-Test and the p-values were plotted against wavelength to determine areas of the spectrum where the groups can be best differentiated (Fig 6). The only areas of significance were the green peak and red edge, similar to the observations in the lower vigour vines. Some effect could also be seen in around 1050 nm and in the vicinity of the primary water absorption bands, with the interesting effect of weakening of the signal in the secondary water absorption bands (B1 centered at 970 nm and B2 centered at 1200 nm).

It can be concluded that the difference in response between different sites and vines of differing vigour has to be investigated further with additional measurement techniques. Diurnal measurements of vine water status is proposed, also including the method of carbon isotope analyses (Gaudillere et al., 2002) as well as leaf chlorophyll and carotenoid analyses, along with the quantification of leaf water content and leaf structural parameters (size, specific mass).
Acknowledgements

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Literature Cited


Figures:

**Figure 1** High resolution multispectral images of vineyard blocks studied (CS = Cabernet Sauvignon and Sb = Sauvignon blanc). High (H), medium (M) and low (L) vigour plots are also indicated.
Figure 2  Pre-dawn leaf water potential of different sites (here denoted as “plots”) and vigour levels (top graph shows separate effects).
Figure 3 Correlogram showing the response ($R^2$ values) of predawn leaf water potential to leaf reflectance for the different vineyard plots, as well as for all vineyard plots and vigour levels combined.

Figure 4 Correlogram showing the response ($R^2$ values) of predawn leaf water potential to leaf reflectance for the different vigour levels of all vineyard plots, compared to the combined effects of all plots and vigour levels.
Figure 5  Leaf reflectance spectra of grouped water stress levels (L=lower stress and H=higher stress), also showing the dominant water absorption areas (see text).

Figure 6  Significance of difference between grouped lower and higher water stress levels according to Predawn LWP, based on results of a Student’s T-test.
Estimation du statut hydrique de Vitis vinifera L. par spectrométrie au champ : étude préliminaire incorporant la classification de la vigueur par analyse multispectrale.

Mots clés : Hyperspectral, potentiel hydrique des feuilles à l’aube, stress hydrique, télédétection.

Résumé

Le potentiel hydrique des feuilles mesuré avant l’aube est considéré comme une mesure efficace du statut hydrique des cepes de vigne, mais il s’agit d’une méthode laborieuse et destructive, ne permettant donc pas la mesure de la même feuille au cours du temps.

En tant que méthodes non destructives, la spectrométrie au champ et la télédétection/imagerie aérienne ont récemment retenu l’attention pour l’estimation du stress des plantes, principalement pour le suivi de certains pigments tels que la chlorophylle, mais aussi pour l’estimation du stress hydrique des plantes.

Cet article discute les résultats préliminaires d’une première série d’études portant sur les potentialités de la télédétection hyperspectrale pour estimer le statut hydrique de la vigne.

Des photographies aériennes multispectrales de haute résolution ont été utilisées pour classer les parcelles en fonction de la vigueur des cepes dans deux vignobles. Le potentiel hydrique des feuilles avant l’aube a été préalablement mesuré ; de même, des mesures au contact à l’aide d’un spectromètre portable ont été effectuées.

Les résultats comparant les valeurs du potentiel hydrique des feuilles mesuré avant l’aube et les mesures spectroscopiques en réflectance entre 350 et 2500nm ont été globalement décevants ; néanmoins, ils ont été améliorés quand la banque de données était scindée en fonction des niveaux de vigueur (faible, moyenne, forte), et en traitant séparément les deux parcelles comportant des cépages différents.

En particulier, pour les niveaux de vigueur faibles et moyens pour la parcelle de Sauvignon blanc, la réponse spectrale dans la bande d’absorption de l’eau était relativement forte, même si la banque de données ne comporte pas d’observations suffisantes pour conforter ces résultats.

Des travaux futurs sont planifiés afin de conforter ces résultats en raffinant les zones expérimentales, mais aussi en incluant d’autres paramètres que le potentiel hydrique des feuilles comme l’analyse isotopique du carbone et la mesure de la température des feuilles pour faciliter l’agrandissement à l’échelle de la canopée.