Size does not matter for infrared water status assessment

Newly-developed infrared scanners could offer comparable results against high-resolution thermal cameras

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The Vineyard of the Future initiative is a multinational project that aims to establish a fully instrumented vineyard using wireless connectivity and automated data gathering and analysis. It also aims to be a test-bed for new technology and a trial site for investigating the potential effects of climate change on viticulture in Australia, Chile, US and Spain. Researchers involved with the project have been developing an infrared scanner to assess plant water status at a fraction of the cost of infrared cameras and with the same comparable results.

INTRODUCTION

Climate change predictions, specifically from increased temperatures and water scarcity, will exert considerable pressure to obtain high quality grape production. This scenario requires continuous monitoring to optimise vine water use, the quality of produce and yield. Several studies have demonstrated that a certain degree of water stress improves wine quality. However, these narrow thresholds need to be continuously monitored to avoid over stressing vines, which can lead to associated detrimental effects on productivity and quality.

Most of the methods used to monitor plant water status are based on manual measurement points, which have low spatial resolution and are time-consuming. These issues introduce significant difficulties for the efficient assessment of spatial variability of water status from vineyards caused by differences in soil characteristics or canopy architecture. In this context, canopy temperature (Tc) has been recognised as a good indicator of plant water status. Thermal images allow the visualisation of differences in surface temperature from emitted infrared radiation over large areas. This technique relies on the fact that when water is lost through stomata from leaves (transpiration), temperature decreases. However, if there is partial or complete stomata closure due to water stress, transpiration decreases or no longer occurs, therefore the temperature of leaves increases.

It has been shown in the last two decades that infrared thermography is an accurate tool to assess plant water status of different crops including olives (Jones et al. 2002, Fuentes et al. 2012). However, infrared cameras are still of high cost, making it difficult to use this technology by growers and irrigation practitioners. Furthermore, specialised know-how is required to use the cameras, process the images and interpret the results. Most of the

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commercial companies producing infrared cameras also have proprietary rights over the software used to analyse images to readily access information such as radiometric and emissivity information. This issue introduces great difficulties in the automated analysis of thermal images to obtain reproducible data in a rapid and understandable manner.

New open-source hardware and software technology has allowed the creation of sensors and mini-robots at considerably reduced costs with specialised analysis software. This has enabled users to automate data gathering and analysis processes.

In this paper we describe the creation and testing of infrared scanners (single and multi-sensors) controlled by inexpensive electronics against results from infrared thermal cameras to assess olive trees and grapevine water status. This idea is the basis of a collaborative project from The Vineyard of the Future (www.vineyardofthefuture.wordpress.com) between The University of Talca, in Chile, and The University of Melbourne, in Australia, through a FONDEF–IDEAS funding from the Chilean Government.

Preliminary results have shown that a reduction of up to 79% in resolution from infrared thermal images renders accurate and similar results compared with high-resolution infrared thermal cameras for the estimation of plant water status. Testing of this inexpensive technology was conducted in olives and grapevines in Chile.

**THEORETICAL BACKGROUND**

The control of stomata aperture in leaves results from changes in turgor of guard cells, which are dependent on the interaction of different chemical and hydraulic signals within the plant. The increase in leaf and canopy temperatures was first suggested in the 1960s as a method of tracking water stress using thermal infrared thermometers (Fuchs and Tanner 1966), with low spatial resolution.

The use of infrared thermal images (IRTI) allows the visualisation of differences in surface temperature between stressed and non-stressed plants of large groups of leaves or plants, simultaneously (Fig 1a and 1b). Therefore, leaf or canopy temperatures can be considered as suitable indicators of stomatal conductance (g_s) and, hence, canopy stress (Jones et al. 2002). To calculate an absolute index of plant water status it is necessary to obtain reference temperature thresholds, such as wet surface temperature (T_wet), dry surface temperature (T_dry), air temperature (T_a) and canopy temperature (T_c). In order to use T_c as a water status indicator, it needs to be normalised to account for the varying environmental conditions (Jones et al. 2002):

\[
T_g = \frac{T_{\text{dry}} - T_c}{T_c - T_{\text{wet}}}
\]  
(Eq. 1)

where: T_c is the canopy temperature (°C), T_wet is the temperature of a leaf transpiring at the maximum potential rate (°C) and T_dry is the temperature of a non-transpiring leaf (°C).

One of the commonly used normalisation methods is a temperature-based crop water stress index (CWSI) developed by Idso et al. (1981). The CWSI is a measure of relative transpiration and it is defined as (Idso et al. 1981, Jackson et al. 1981):

\[
\text{CWSI} = \frac{T_c - T_{\text{wet}}}{T_{\text{dry}} - T_{\text{wet}}}
\]  
(Eq. 2)

According to this definition, when a canopy is transpiring at its potential rate, T_c = T_wet and CWSI = 0. When the canopy is not transpiring, T_c = T_dry and CWSI = 1. This normalisation is simple and reasonable, provided that T_dry and T_wet are known.

The upper threshold (T_dry) is set as a non-transpiring leaf temperature and computed assuming no transpiration flux. The lower threshold (T_wet) is set as a leaf transpiring at the potential rate. Originally these thresholds were obtained by physically painting one of the leaves with petroleum jelly and another leaf with water (Jones et al. 2012). Petroleum jelly will clog all stomata in the leaf reducing transpiration to zero, hence increasing the temperature of a leaf to a maximum (T_dry). Contrastingly, the leaf painted with water will increase transpiration to a maximum, hence reducing temperature to a

Figure 1a and 1b. Thermal images (a) thermal image of olive tree canopy (adapted from Poblete-Echeverria et al. 2013); (b) thermal image of a vineyard (Adapted from Turner and Lucieer 2011).
constant (kPa °K) aerodynamic resistance to latent heat transport (s) combined resistance to sensible heat R wind speed.

wind speed.

temperature, relative humidity and solar radiation or net radiation, air requires measurements of incoming

obtain thresholds. This method to discriminate non-leaf material makes it difficult to automate the computation of l, and CWSI (Fuentes et al 2012).

An alternative, which allows automated computation of water stress indices, is estimating T, and T, using the leaf energy balance approach (Fuentes et al 2012):

\[ T_{\text{dry}} = T_a + \frac{R_{nR}}{\rho C_p} \]  

(Eq. 3)

\[ T_{\text{wet}} = T_a - \frac{R_{nR}(T_{\text{max}} - T_{\text{min}}) R_{nR} + \Delta}{\rho C_p} \]  

(Eq. 4)

Where: T, is the air temperature (K); R, is net radiation (W m⁻²); rHR is the combined resistance to sensible heat transport (s⁻¹); r, is dry air density (kg m⁻³); C, is the specific heat of dry air at constant pressure (J K⁻¹ kg⁻¹); r, is aerodynamic resistance to latent heat transport (s⁻¹); the psychrometric constant (kPa °K⁻¹); Δ is the slope of saturated water vapour pressure versus temperature curve (kPa °K⁻¹) and VPD is vapour pressure deficit (kPa) (Ben-Gal et al. 2009, Agam et al. 2013).

The use of this analytical approach requires measurements of incoming solar radiation or net radiation, air temperature, relative humidity and wind speed.

PLANT MATERIAL AND INSTRUMENTS USED

Vineyard and Olive experiment
Random infrared thermal images were obtained from a commercial vineyard planted with cv. Carmenere located in the Talca Valley, Maule region, Chile. The vineyard was planted in 2008 in north-south orientated rows with a distance between rows of 2.5 metres and 2m distance between plants. Vines are trained on a vertical shoot positioned system (VSP). Infrared thermal images were obtained from the bottom of canopies in an upward-looking direction.

Infrared thermal images were also obtained randomly from a commercial drip-irrigated olive orchard cv. Arbequina located in Pencahupe valley, Maule Region, Chile. Olive trees were planted in 2009 in super intensive hedgerow (north-south orientated rows) with a distance between rows of 5m and 1.3m distance between plants. Olive trees are drip irrigated using two drippers (2 L h⁻¹) per tree. Infrared thermal images were obtained laterally from the canopy. The objective was to select thermal images for both crops with a range of canopy water stress indices given by different water supplies.

Thermal camera
The thermal infrared camera (model EasIR-9, Wuhan Guide Infrared Co., Ltd., Chinal) provides 120 x 120 pixel images. The built-in sensor is a thermal detector (microbolometer), thus it does not require an external cooling system. This sensor is sensitive to thermal radiation in the 8-14μm range of the electromagnetic spectrum. Information from the Thermal camera (IRTI) was primarily used as observed high-resolution data to obtain Ig (Eq. 1) and CWSI (Eq. 2) indices to be compared with simulated low-resolution data to emulate performance of a DIY thermal camera and an infrared scanner.

DIY thermal camera
A Thermacam® scanner (Figure 2) was used in parallel to the IRTIs, using only one infrared temperature sensor (TS305; -10 to 50°C – infrared temperature sensor) moved by two servo motors and controlled by an Arduino® Uno board (http://www.cheap-thermocam.net/). The resolution of a pseudo-image obtained with this instrument is 48 x 64 pixels (Figure 3). This corresponds to a reduction of 79% of the data compared with the IRTIs.

Infrared scanner
An infrared scanner is currently under development by the VoF FONDIF-IDEAS project. The general schematics of this scanner can be seen in Figure 4. A minimal resolution of 10 x 10 pixels was used to simulate the performance of this scanner. This corresponds to a reduction of 99.9% of resolution compared with the IRTIs.

DATA ANALYSIS

Data analysis was performed using a variation of a customised code developed by Fuentes et al. (2012) using MATLAB®, version 2014a [Mathworks Inc. Matick, MA, USA]. Regression analyses were used to compare data obtained from IRTI images against data simulated by reducing resolution of infrared images down to the DIY thermal camera’s resolution (79%) and minimum resolution from the infrared scanner (99%). The parameters used to evaluate these regressions were the determination coefficient (R²) and the slope of the curves (b). Threshold parameters (T, and T,) were obtained using the statistical approximation approach outlined in Figure 7 (Fuentes et al. unpublished).

RESULTS AND DISCUSSIONS

Comparison between IRTIs and thermal camera resolution
Results showed good and
Comparison between IRTIs and an infrared scanner at minimal resolution

A minimal simulated resolution of 10 x 10 pixels corresponds to a simulation of the infrared scanner with 10 sensors and measurements every 20cm for each plant. Results showed lower comparability with IRTIs for olive trees and grapes. In the case of olives, this comparison was better for the \( I_g \) \( (R^2 = 0.68; b = 0.93) \) and CWSI \( (R^2 = 0.68; b = 0.87) \) compared with grapevines' \( I_g \) \( (R^2 = 0.25; b = 0.78) \) and CWSI \( (R^2 = 0.37; b = 0.77) \). This reduction in accuracy in the case of olives can be explained by the method used to obtain the IRTIs [upward-looking]. This method was selected since the shaded side of the canopy offers the most stable conditions to obtain IRTIs according to Fuentes et al. (2012) and Jones et al. (2002). Therefore, upward-looking IRTIs from olive canopies could offer a more stable infrared index, however, it reduces the area of leaf material analysed as shown in Figure 7. In theory, lateral IRTIs from olive canopy walls would offer comparative results with olive trees.

The infrared scanner is designed to scan the canopy wall of crops laterally,
By Brad Hickey, Brash Higgins Wine Co., McLaren Vale, South Australia

In October 2009, we dedicated a half-hectare research block on our Omensetter mountain farm to Nero d’Avola, a variety of Sicilian inspiration for novel Italian inspiration for novel wine making. We had heard of this variety before, but had not been convinced it would work in our McLaren Vale climate, so it seemed like a good fit for our environment.

We had some better suited grapes to bring onboard. Even for our Shiraz and Cabernet Sauvignon varieties we could plant on our vineyard that even for our Shiraz and Cabernet Sauvignon varieties we could plant on our vineyard that Nero d’Avola making

Italian inspiration for novel Nero d’Avola making

The blend for the Pepik is usually a mixture of own roots and rootstocks. (October-April). The mean January temperature is dosed to contain a final sugar content of 20-30%. The mean January temperature is dosed to contain a final sugar content of 20-30%.

The first fruit bearing year, we pruned the vines and has an elevation of 85-170m at Relbia, 15km south of Launceston, where we have a permanent sward of clover and a mixture of own roots and rootstocks.

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CONCLUSIONS

Preliminary results using simulation analysis have demonstrated that a reduction of 79% of data resolution from IRTIs renders comparable results for different horticultural crops, such as olive trees and grapevines, to obtain plant water status indices. The simulation methodology proposed in this paper will help in finding the optimal number of sensors for the infrared scanner proposed in the FONDEF-IDEAS project according to canopy vigour, training systems and irrigation treatments. Until recently, the use of thermal infrared technology has been limited due to a lack of timeliness in data acquisition, data delivery, spatial resolution and automated analysis constraints. Today, new technologies offer the opportunity to integrate these techniques in terrestrial and aerial

Figure 6. Regressions between \( I_{g} \) (filled markers) and CWSI (open markers) data obtained from the high-resolution infrared camera (IRTI) and simulated reduction of resolution by the low-resolution infrared scanner for olive trees (circles) and grapevines (triangles).
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vehicles (UTV and UAV) to collect remotely-sensed imagery at low cost over large areas to determine plant water status routinely and its spatial variability.

REFERENCES


Figure 7. Upward-looking infrared image from olive canopies (a); binary image separating canopy and non-canopy material (b) and histogram showing the temperature distribution in the whole image with temperature below zero corresponding to sky (c).