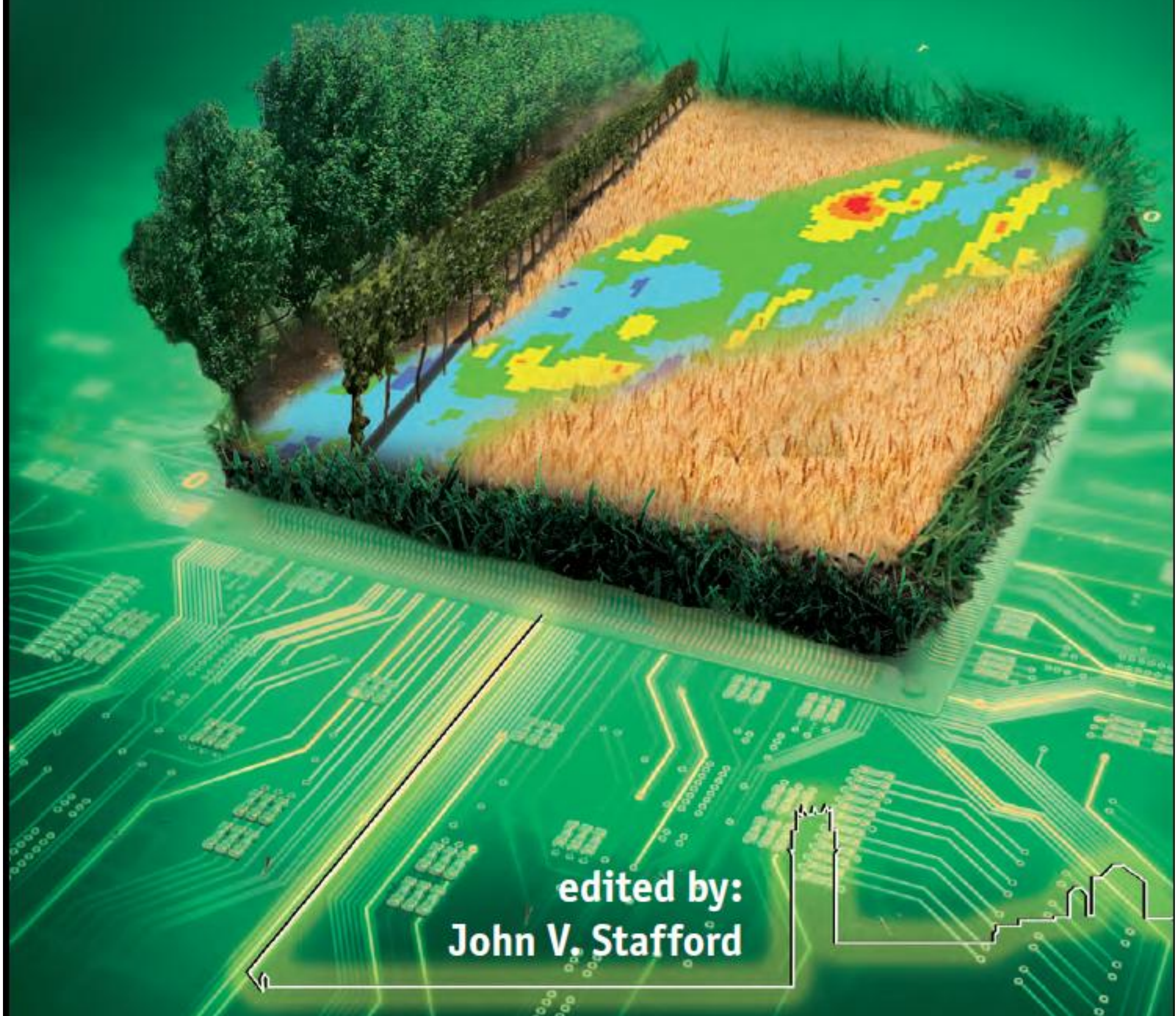
# Precision agriculture '13



edited by:
John V. Stafford

# Precision agriculture '13

edited by:

John V. Stafford

Papers presented at the 9th European Conference on Precision Agriculture
Lleida, Catalonia (Spain)
7-11 July 2013

Wageningen Academic Publishers

# Scheduling vineyard irrigation based on mapping leaf water potential from airborne thermal imagery

J. Bellvert[1], P.J. Zarco-Tejada[2], V. Gonzalez-Dugo[2], J. Girona[1] and E. Fereres[2,3]
[1]*Water Use Efficiency Programme, Institut de Recerca i Tecnologia Agroalimentàries (IRTA), Centre UdL-IRTA, 25198 Lleida, Spain; joaquim.bellvert@irta.es*
[2]*Instituto de Agricultura Sostenible (IAS), Consejo Superior de Investigaciones Científicas (CSIC), Córdoba, Spain*
[3]*Departamento de Agronomía, Universidad de Córdoba (UCO), Córdoba, Spain*

### Abstract

Crop water stress index (CWSI) has been used as a tool for mapping spatial variability in water requirements of vineyards. During 2009-2011, CWSI seasonal equations were obtained for varieties 'Pinot-noir', 'Chardonnay', 'Tempranillo' and 'Syrah' by using infrared temperature sensors and high resolution airborne thermal imagery. Leaf water potential ($\Psi_L$) measurements were used to validate the proposed methodology. Coefficients of determination ($r^2$) ranged from 0.54 to 0.93 indicating a contrasted CWSI sensitivity to water stress between phenological stages. In 2012, irrigation scheduling of a 16 ha 'Chardonnay' plot was carried out solely on the basis of remotely sensed $\Psi_L$ obtained throughout the season.

**Keywords:** crop water stress index, leaf water potential, grapevine, thermal imagery

### Introduction

Irrigation scheduling in vineyards is usually performed by using a water balance model. However, this approach does not take into account vineyard heterogeneity. This may result in water being wasted in some parts of the vineyard, while excessive water stress might occur in other parts. Managing irrigation water in viticulture is especially important because they occupy the highest area of any fruit crop in the world. From a more technical point of view, water availability also has implications regarding berry composition.

Individual plant measurements may be used to obtain information about plant water status and adopt irrigation strategies based on their representativeness. Crop water stress index (CWSI), based on measuring canopy temperature is a good indicator of plant water status. The basic assumption was that water stress induces stomatal closure, transpiration is reduced and therefore, the temperature of leaves increase. The empirical approach for calculating CWSI was based on the non-water-stressed baseline, that relates canopy-air temperature difference ($T_c$-$T_a$) and air vapour pressure deficit (VPD) for a well-watered grapevine transpiring at the potential rate (Idso *et al.*, 1981). In recent years, the possibility of measuring canopy temperature by high-resolution remote sensing has increased the interest to adopt irrigation strategies at field scale (Sepulcre-Canto *et al.*, 2006). Recent studies successfully related CWSI with leaf water potential in vineyards. Then, remotely sensed CWSI could be used as a tool for mapping spatial variability in water requirements of vineyards. However, stomatal control over conductance of water leaf is highly sensitive to VPD (Soar *et al.*, 2006, Rogiers *et al.*, 2012) and there are clear differences in this response between varieties (Schultz and Stoll, 2010). Moreover, stomatal responses to $\Psi_L$ values indicated different sensitivity between phenological stages (Olivo *et al.*, 2009) and the relationships between $\Psi_L$ and VPD appear to change throughout crop development. If CWSI has to be a successful tool for detecting plant water status through the season and taking irrigation decisions on this assumption, information about differences between varieties and seasonal sensitivity in the relationship between CWSI and $\Psi_L$ is necessary.

The goals of this study were: (1) to develop the 'non-water-stressed baselines' for calculating CWSI in grapevines varieties `Pinot-noir´, `Chardonnay´, `Syrah´ and `Tempranillo´ at different phenological stages; (2) to define the relationships between CWSI and leaf water potential by using remote sensing thermal images; and (3) scheduling vineyard irrigation on the basis of remotely sensed $\Psi_L$ maps throughout the season.

## Materials and methods

The development of crop water stress index (CWSI) empirical equations and validations were carried out during 2009-2011 growing seasons in commercial vineyards of 'Pinot-noir' (PN), 'Chardonnay' (CH), 'Tempranillo' (TMP), and 'Syrah' (SYR) located in Raimat (Lleida, Spain). In 2012, irrigation scheduling of a 16 ha 'Chardonnay' plot was carried out solely on the basis of $\Psi_L$ maps.

### *Crop water stress index*

In a small area within each vineyard, two irrigation treatments were set up to measure canopy temperature under different levels of water status. Each irrigation treatment contained 12 grapevines. Irrigation treatments were: (1) well-watered, where irrigation replaced 100% of $ET_o$; and (2) stressed, where water was applied only after midday leaf water potential ($\Psi_L$) dropped below -1.6 MPa. Two infrared temperature sensors (IRTS) (model PC151LT-0, Pyrocouple series, Calex electronics Limited, Bedfordshire, UK) were installed one meter above two grapevines of each variety, in each irrigation treatment. IRTS were installed aiming vertically downward (nadir view) in such a way that visual inspection ensured that 100% of the temperature signal came from leaves. Recorded data of canopy temperature ($T_c$) of well-watered grapevines was used to calculate the empirical CWSI as (Idso *et al.*, 1981):

$$CWSI = \frac{(T_c - T_a) - (T_c - T_a)_{LL}}{(T_c - T_a)_{UL} - (T_c - T_a)_{LL}} \quad (1)$$

where ($T_c$-$T_a$) is canopy - air temperature difference; LL is the ($T_c$-$T_a$) values for lower limit or non-water-stressed baseline (NWSB), UL is the upper limit of the same and is defined as the $T_c$-$T_a$ of the same canopy where transpiration is completely halted. For the CWSI calculation, the NWSB were established for four varieties from relationship of canopy-air temperature difference of a well-watered grapevines, and vapour pressure deficit (VPD). The same methodology described by Testi *et al.* (2006) was used on this analysis. Each point was obtained from half hourly averages of $T_c$, $T_a$ and VPD from 11:00 to 16:00 hours. Only clear days and with windspeed at 10 m height below 6 m/s were used in the assessment of the NWSB. UL was calculated according to the methodology described by Idso *et al.* (1981). $T_a$ and VPD were obtained from a portable weather station (Watchdog 2000, model 2475 Plant growth, Spectrum Technologies, Inc. Plainfield, Illinois, USA) located on one side of the vineyard.

### *Airborne campaigns*

The airborne campaigns were conducted with a thermal camera (FLIR SC655, FLIR Systems, USA) installed on an aircraft (CESSNA C172S EC-JYN). The software to acquire thermal images was developed at the Laboratory for Research Methods in Quantitative Remote Sensing (Quantalab, IAS-CSIC, Spain), as described in Zarco-Tejada *et al.* (2012). The camera had a resolution of 640×480 pixels, equipped with a 24.5 mm f1.0 lens, connected to a computer via USB 2.0 protocol. The spectral response was in the range of 7.5-13 μm. In 2011, six flights were conducted at 12:00 solar time (14:00 local time) on 9 and 24 June, 7 July, 4 and 28 August and 12 September at 150 m altitude above the ground level. These flights were used to validate the CWSI calculation with leaf water potential measurements. In 2012, weekly airborne thermal images were collected from May to September over a 16 ha 'Chardonnay' vineyard to obtain $\Psi_L$ maps. Images obtained had 30 cm spatial resolution enabling the capture of only grapevine crowns and excluding soil, background targets, and shadows.

*Field measurements*

Leaf water potential ($\Psi_L$) was measured weekly at 12:00 solar time from two vines where IRTS were installed, covering the two irrigation treatments. Two fully expanded leaves exposed to direct sunlight were taken from each vine. A Scholander pressure chamber (Soil Moisture plant water status console 3005 Corp. Sta. Barbara, CA, USA) was used following the recommendations of Turner and Long (1980).

Concomitant to each flight in 2011, $\Psi_L$ was measured in twenty grapevines for each variety with the aim of comparing the temperature obtained from aerial thermal imagery with a ground-based stress indicator. To carry out these measurements, two teams, each equipped with a pressure chamber on a truck carried out all the measurements so that they could be performed within one hour around the time of flight.

*Irrigation scheduling on the basis of remotely sensed leaf water potential maps*

In 2012, irrigation scheduling of a 16 ha 'Chardonnay' plot was carried out solely on the basis of weekly $\Psi_L$ maps obtained remotely throughout the season. These maps were estimated from seasonal relationships with CWSI. The irrigation system of the plot was divided into twelve regular sectors between 1 to 1.6 ha, and irrigation decisions were taken individually for each irrigation sector based on the estimated averaged $\Psi_L$. Irrigation water was daily supplied to all irrigation sectors through a drip irrigation system. Irrigation was scheduled on a weekly basis immediately two days after the thermal flight. Irrigation was applied at different percentages of calculated $ET_c$ when averaged $\Psi_L$ was more negative than the established threshold defined at different phenological stages. The established $\Psi_L$ thresholds were: -0.8 MPa from anthesis to full fruit set (Stage I), -1.2 MPa from full fruit set to 50% of veraison (Stage II), and -0.8 MPa from the end of stage II to harvest (stage III). Applied irrigation water was determined by reading the water meters in each irrigation sector on a weekly basis. Harvest was carried out on August 9$^{th}$. Experimental vines were hand harvested, clusters for each vine were counted, and total vine yield was weighed.

## Results and discussion

*Crop water stress index*

Crop water stress index was empirically calculated at different phenological stages by using different non-water-stressed baselines. The NWSB indicated a clear distinction of VPD influence on $T_c$-$T_a$ between varieties at different phenological stages. These relationships decreased linearly with increased VPD. For instance, in stages I and II, relationships between varieties were similar, except for CH in stage I, and CH and SYR in stage II, which had slopes significantly flatter than other varieties. It implies that in others, for a given incremental increase in the air VPD, more transpirational cooling occurs than in CH and SYR in their respective stages. In stage III, there existed also significant differences between varieties ($P$<0.0001). Only the regression values for CH and SYR were similar ($P$=0.081). TMP had the lowest $T_c$-$T_a$ values in response to VPD in stages II and III, and therefore increased evaporative cooling. In contrast, PN and SYR presented the highest $T_c$-$T_a$ values.

Table 1 shows the baselines (LL and UL) used in the Equation 1 for calculating the CWSI for different varieties and phenological stages. The UL at the stages I and II-III were similar in all varieties, except TMP which the intercept increased at stage II-III. Maximum intercept of UL at VPD=0 was found in CH during stage I by reaching at 6.61 °C. At this stage, the UL of other varieties were similar. The UL during stages II-III presented differences between varieties. While CH presented the maximum intercept at VPD=0 ($T_c$-$T_a$ = 6.45 °C), SYR had the lowest ($T_c$-$T_a$ = 4.67 °C). TMP and PN had a

Table 1. Equations of lower and upper limits for each phenological stage of four grapevine varieties. y represents the difference of crop and air temperature ($T_c$-$T_a$), and x represents vapour pressure deficit (VPD). *PN* Pinot-noir, *CH* Chardonnay, *SYR* Syrah, and *TMP* Tempranillo.

| | Lower limits | | Upper limits | |
|---|---|---|---|---|
| | Stage I | Stage II-III | Stage I | Stage II-III |
| PN | $y = 0.31x^2-2.92x+2.61$ | $y = -1.33x+1.33$ | $y = 0.43x+5.04$ | $y = 0.28x+5.42$ |
| CH | $y = 0.42x^2-3.47x+4.04$ | $y = -1.39x+2.16$ | $y = 0.63x+6.61$ | $y = 0.64x+6.45$ |
| SYR | $y = -2.21x+3.18$ | $y = -1.46x+2.73$ | $y = 0.37x+4.65$ | $y = 0.23x+4.67$ |
| TMP | $y = -1.44x+1.09$ | $y = -1.78x+1.25$ | $y = 0.26x+3.98$ | $y = 0.47x+5.32$ |

similar intercept. Lower limits (LL) showed that during stages II-III, TMP was the variety which presented more transpirational cooling for a given increase in the air VPD.

*Relationships between crop water stress index and leaf water potential*

Midday $\Psi_L$ measurements correlated significantly with CWSI for four varieties ($P<0.0001$). Figure 1 showed the relationship between CWSI and $\Psi_L$ for four varieties by applying their respective baselines at each phenological stage. As drought intensified, vine leaves were more affected and reacted by closing the stomata and therefore reducing their transpiration rate. Thus, more stressed grapevines were related with both maximum leaf temperatures and CWSI values. The relationship shown in Figure 1 followed a curvilinear model, which indicated that transpiration decreased progressively from a certain $\Psi_L$ threshold until arriving at complete stomatal closure (CWSI=1).

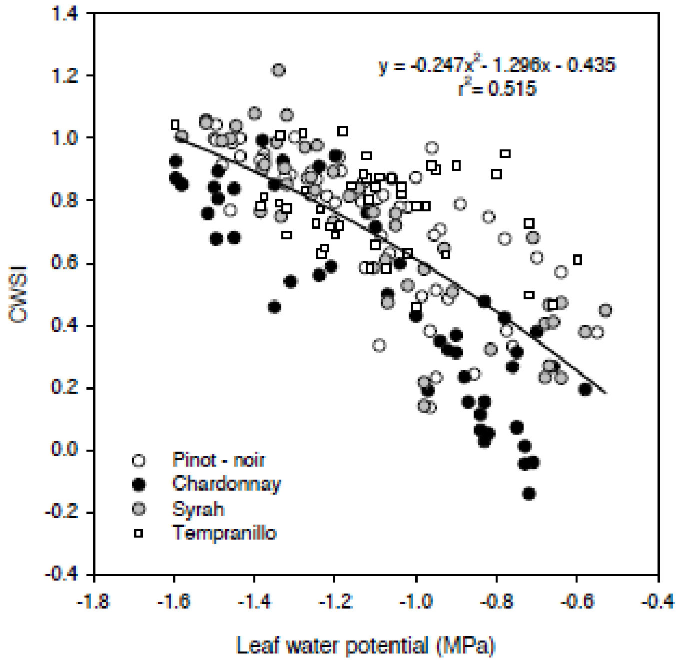



Figure 1. Relationships between crop water stress index (CWSI) and midday leaf water potential ($\Psi_L$) measured in vines of Pinot-noir (PN), Chardonnay (CH), Syrah (SYR), and Tempranillo (TMP). CWSI was obtained from thermal camera imagery on board an aircraft. The bold line indicated the relationship for all varieties.

However, there existed a phenological sensitivity of CWSI to water stress. According to the averaged value of $\Psi_L$ for the three phenological periods considered, vine water stress increased as crop developed (data not shown). Higher sensitivity to water stress was found at early stages with a reduction of transpiration rate which was affected by increasing leaf temperature and therefore resulted in higher CWSI values. For instance, stage I in PN was the most sensitive due to CWSI values corresponding to higher $\Psi_L$. The relationship in stage II was not as sensitive as stage I, but more than stage III. During stage III, most leaf measurements attained maximum CWSI.

*Irrigation scheduling on the basis of remotely sensed leaf water potential maps*

Irrigation scheduling on the basis of $\Psi_L$ maps was successfully achieved. Figure 2 shows an example of $\Psi_L$ map obtained on 4 July (stage II) from high resolution thermal images. Spatial variability of vine water status ranged from $\Psi_L$ between -0.5 to -1.6 MPa. For instance, averaged $\Psi_L$ for irrigation sectors 3 ($\Psi_L$ = -1.4 MPa) and 4 ($\Psi_L$ = -1.6 MPa) were more negative than in others. Thus, irrigation scheduling during that week consisted in applying more irrigation water in these irrigation sectors. On the other hand, irrigation sectors with higher $\Psi_L$ values (i.e. 5, 8 and 10) were not irrigated during that week.

Irrigation water applied through the season was different between irrigation sectors, ranging from 150 to 300 mm. Non significant differences were found in yield, number of clusters and berry fresh weight between irrigation sectors. Yield ranged from 7.5 to 8.7 kg/vine, number of clusters per vine and berry fresh weight at harvest was around 38 and 1.6/g vine, respectively. Therefore, this method allowed adoption of regulated deficit irrigation strategies, leading to water savings of 50% in some irrigation sectors without affecting yield.

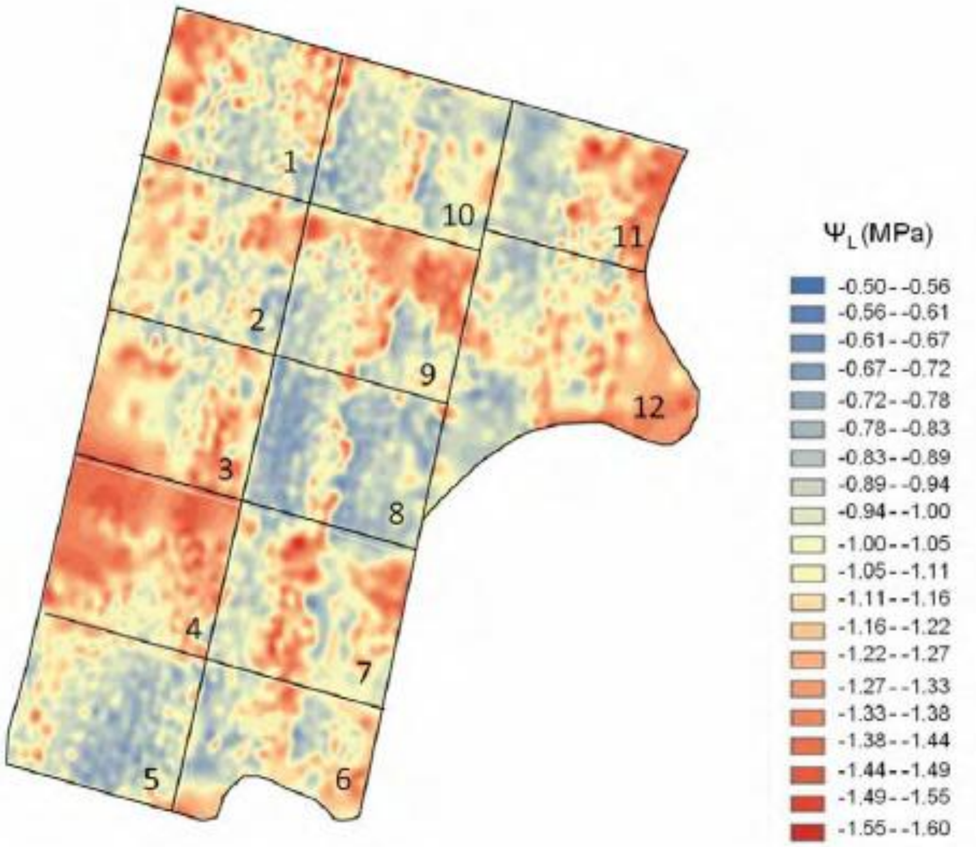



Figure 2. Leaf water potential ($\Psi_L$) map of a 16 ha 'Chardonnay' vineyard, obtained from high resolution thermal images. Estimated $\Psi_L$ values were obtained from relationship between CWSI and $\Psi_L$ in stage II.

## Conclusions

This study demonstrated the possibility of using high resolution thermal imagery in creating $\Psi_L$ maps. These maps have the potential for effective irrigation management incorporating the water status variability within a vineyard.
CWSI has been successfully related to $\Psi_L$ in all varieties, with this relationship being different at different phenological stages. Differences were explained by the same CWSI induced to lower values of $\Psi_L$ as vine cycle growth developed. This implied that the determination of vine water status would depend on variety and phenological stage and the appropriate CWSI equation should be applied in each case.

## Acknowledgements

This work received partial financial support from SUDOE for the European project Telerieg SOE1/P2/E082 and the Spanish Ministry of Science and Innovation (MCI) for the projects CONSOLIDER CSD2006-00067, AGL2009-13105 and INNPACTO IPT-2011-1786-060000. We are grateful for the opportunity to carry out this study under the research agreement between CODORNIU and IRTA. The authors thank the team of Quantalab, IAS-CSIC of Córdoba for the technical support in field airborne flights and image processing, and also the team of Water Use Efficiency of IRTA for their support in the field campaign.

## References

Idso, S.B., Jackson, R.D., Pinter, P.J., Reginato, R.J., Hatfield, J.L. 1981. Normalizing the stress-degree day parameter for environmental variability. Agricultural Meteorology 24 45-55.

Olivo, N., Girona, J., Marsal, J. 2009. Seasonal sensitivity of stem water potential to vapour pressure deficit in grapevine. Irrigation Science 27 175-182.

Rogiers, S.Y., Greer, D.H., Hatfield, J.M., Hutton, R.J., Clarke, S.J., Hutchinson, P.A., Somers, A. 2012. Stomatal response of an anisohydric grapevine cultivar to evaporative demand, available soil moisture and abscisic acid. Tree physiology 32 249-261.

Schultz, H.R., Stoll, M. 2010. Some critical issues in environmental physiology of grapevines: future challenges and current limitations. Australian Journal of Grape and Wine Research 16 4-24.

Sepulcre-Canto, G., Zarco-Tejada, P.J., Jimenez-Muñoz, J., Sobrino, J., de Miguel E., Villalobos, F.J. 2006. Detection of water stress in a olive orchard with thermal remote sensing imagery. Agricultural and Forest Meteorology 136 44.

Soar, C.J., Speirs, J., Maffei, S.M., Penrose, A.B., Mc Carthy, Loveys, B.R. 2006b. Grape vine varieties Shiraz and Grenache differ in their stomatal response to VPD: apparent links with ABA physiology and gene expression in leaf tissue. Australian Journal of Grape and Wine Research 12 2-12.

Testi, L., Goldhamer, D.A., Iniesta, F., Salinas, M., 2008. Crop water stress index is a sensitive water stress indicator in pistachio trees. Irrigation Science 26 395-405.

Turner, N.C., Long, M.J. 1980. Errors arising from rapid water loss in the measurement of leaf water potential by pressure chamber technique. Australian Journal of Plant Physiology 7 527-537.

Zarco-Tejada, P.J., González-Dugo, V., Berni, J.A.J. 2012. Fluorescence, temperature and narrow-band indices acquired from a UAV platform for water stress detection using a micro-hyperspectral imager and a thermal camera. Remote Sensing of Environment 117 322-337.