Australian Government

Grape and Wine Research and Development Corporation

Performance of vines under reduced irrigation: development of cost-effective irrigation scheduling tools



FINAL REPORT to

GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION

Project Number: GWT 0702

Principal Investigator: **Dr Brian Loveys**

Research Organisation: **CSIRO Plant Industry**

Date: **June 2008**

Summary

This report describes experiments carried out during a visit by Professor Hamlyn Jones during the period January 1st 2008 to January 12th 2008. The objective of the visit was to refine methods for the calculation of stomatal conductance from infrared measurements of canopy temperature. Stomatal conductance can provide a rapid non-destructive estimate of vine performance under a range of irrigation regimes. The limitations imposed by the need for multiple porometer measurements made over large areas of vineyard can be overcome by estimating canopy conductance from rapidly accumulated measures of canopy temperature using ground-based infrared thermometry or aerial thermal imaging together with appropriate meteorological data. This approach very successfully corrected for differing conditions on different days, such that the infra-red data could be used to detect changes in stomatal conductance associated with suboptimal irrigation across a wide range of environmental conditions. Further development of these methods for irrigation scheduling will require benchmarking the major winegrape varieties for seasonal and diurnal changes and reduction of error in the calculations of canopy conductance through refinement of the instrumentation.

Introduction

In September 2005 a final report was submitted to GWRDC describing experiments carried out in project CSP02/02, ***When to water? Assessment of plant-based measurements to indicate irrigation requirements***. The project sought to test a number of plant-based measures of vine performance and assessed their utility as irrigation scheduling aids. Most plant-based measurements require some sort of contact with target vines. For example, measurement of leaf or stem water potential requires removal of leaves and insertion into a pressure chamber; dendrometry (measurement of trunk or cane diameter) requires the attachment of strain-gauge or LVDT instruments to the target vines; measurement of sap flow similarly requires the insertion of instruments into the vine trunk, and measurement of stomatal conductance with gas exchange equipment requires contact with individual vines. Although all these techniques can yield valuable information about vine response to irrigation management they tend to be quite expensive and require considerable expertise in data gathering, management and interpretation. Furthermore, CSP02/02 also showed that there can be enormous vine to vine variability in all these measurements which requires that a large number of measurements need to be made to gain a reasonable estimate of the performance of a representative area of vines. This problem is particularly intractable when fixed pieces of equipment such as dendrometers or sap flow sensors are attached to vines on a semi-permanent basis. On the other hand, measurements such as leaf water potential and stomatal conductance can be made on a larger number target vines at strategic locations within the vineyard and project CSP02/02 identified pre-dawn leaf water potential and stomatal conductance as two measures worthy of development as irrigation scheduling tools. Stomatal conductance is particularly attractive because it is a non-invasive technique and it is the measure most closely linked to vine water use since virtually all water transpired by the vine passes through the stomata. The traditional way to measure stomatal conductance uses an instrument such as a diffusion porometer to assess water loss from individual leaves but in project CSP02/02 we also tested techniques described by Leinonen et al. (2006) to calculate a so-called Canopy Conductance Index (Ig) using measurements of canopy temperature made with an infrared thermometer or with a thermal imaging system. Fuentes et al. (2005) have shown that this approach, using thermal imaging techniques, can readily differentiate between vines subject to different irrigation strategies. One of the major advantages of using an estimate of canopy temperature to calculate conductance is that it eliminates the need for multiple porometer measurements and can be applied to large areas of vineyard by mounting the instrumentation on a vehicle such as a quad-bike (ATV). The instrumentation is relatively low cost and with suitable software to process the data, does not require a great deal of user expertise.

A world leader in the development of methods to assess stomatal opening from measurements of canopy temperature is Professor Hamlyn Jones from University of Dundee in Scotland.

Professor Jones collaborated in project CSP02/02 and in that project we were able to show that canopy conductance index reliably differentiated between vines receiving different amounts of irrigation. Since the termination of project CSP02/02 we have used CSIRO and SARDI resources to continue development of methods to assess vine performance using infrared thermometry in collaboration with Yalumba Wines, Measurement Engineering Australia and Professor Jones and we have now developed the algorithms for data manipulation to the point where infrared thermometry data can be used to calculate canopy conductance. We have established a large experiment in the South Australian Riverland to impose a range of irrigation treatments to Cabernet Sauvignon vines. This experiment has been the focus of work in 2007/2008 and one of the key activities has been to refine the instrumentation for data acquisition and to improve the automation of stress estimation. We have used porometry and gas exchange analysis to confirm our measurements. This work required the close collaboration of Professor Hamlyn Jones. This report documents the progress of experiments involving Professor Jones whose visit during January 2008 was supported by GWRDC. Professor Jones arrived January 1st 2008 and departed January 12th 2008 but there has been an on-going dialogue to further develop the methodology.

Methods

An experiment was established at the Yalumba Oxford Landing Estate vineyard at Waikerie in the South Australia Riverland where 5 levels of irrigation were applied to Cabernet Sauvignon vines on Ramsey rootstock. Each treatment was applied to 5 adjacent rows of 68 vines. Measurements were made on the centre row of each treatment. Irrigation water was supplied at seasonal rates equivalent to 6.7, 3.3, 2.3, 1.7 and 0.6 ML/ha (treatments designated T0, T1, T2, T3, T4 respectively) and 82mm and 83.8mm of rain fell during the period September 1st 2006 to February 28th 2007 and 2008 respectively. Irrigation amounts were achieved by providing an additional drip line with appropriate rate drip emitters at the same spacing as the original. All vines received the same irrigation, as determined by the vineyard manager, until fruit set. At that time the second irrigation lines were turned on and the existing lines turned off. T4 vines did not receive any further irrigation until after harvest with the exception of that associated with fertigation events when the original irrigation configuration was temporarily restored to all treatments. This was done to ensure that all vines received the same nutrition. Irrigation frequency, disease and canopy management were determined by the vineyard manager.

Stomatal conductance was measured with a porometer (Delta-T Devices model AP4). 20 or 25 measurements were made on sun-exposed leaves of each treatment. Infrared measurements were made with an Everest 1100 or Raytek Raynger MX infrared thermometer. The analogue

output from the infrared thermometer was captured in a Unidata Prologger at 4Hz. The logger was housed in a steel box and additional instruments were attached to the box lid .

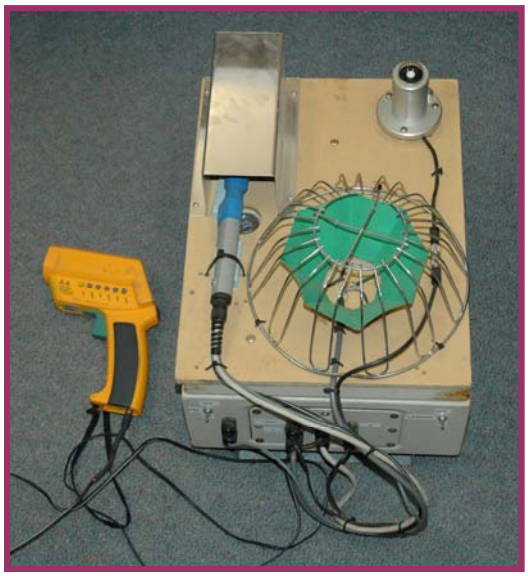


Figure 1. Instruments and data logger used for the capture of IR and meteorological data

These included thermistors to measure ambient temperature and the temperature of four segments of a green reference surface constructed of 180gsm paper. Solar radiation and ambient humidity were also logged. (Figure 1). The humidity and ambient temperature sensors were housed in a shielded and aspirated enclosure. The data logger was mounted on the front of a quad bike and measurements were made by driving the vehicle at about 8km/h and aiming the thermometer on the illuminated face of the canopy. The whole experimental block, representing approximately 300 vines, could be measured in less than 10 minutes (Figure 2).



Figure 2. Instruments mounted on quad bike

Results and Discussion

Measurements of stomatal conductance, canopy temperature and associated variables were made on 12 occasions throughout the year. There was a general decline in conductance as the leaves aged but at each measurement time there was a steady decline associated with the reduction in irrigation amount (Figure 3).

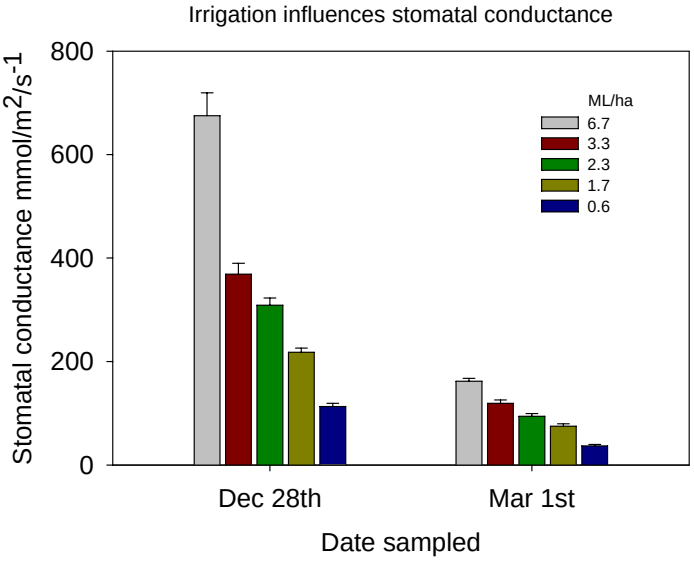


Figure 3. Stomatal conductance is strongly influenced by irrigation treatment and time of year

On any one sampling day there was a unique, linear relationship between stomatal conductance and canopy temperature, as measured by infrared thermometry (Figure 4).

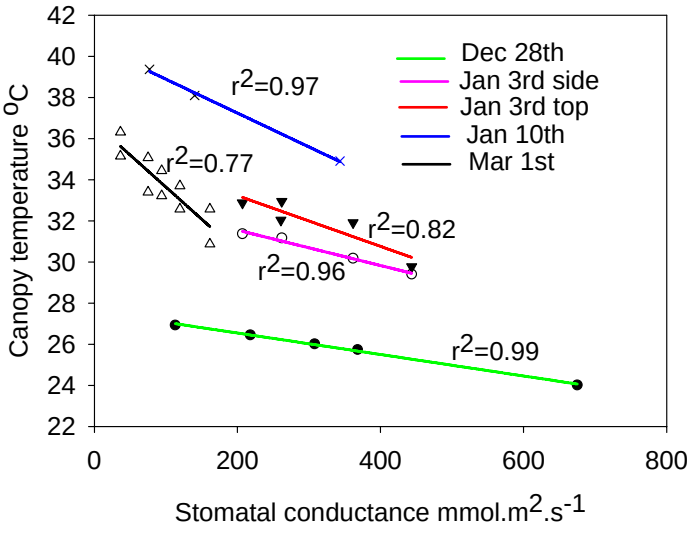


Figure 4. Stomatal conductance is linearly related to canopy temperature on any one day

On most sample days, canopy temperature was measured by aiming the infrared thermometer horizontally at the vertical northern face of the canopy, at an angle of about 30^{o} to the vine row. On one occasion (Jan 3rd) the top face of the canopy was also measured by aiming the thermometer vertically down from about 1m above the canopy. This aspect of the canopy

provided slightly higher temperatures, but also greater variability, probably due to gaps in the canopy allowing sighting of soil on the vineyard floor. In order to normalize these data, and allow meaningful comparisons between days, we estimated canopy conductance (gs) from temperature data by combining these with coincident meteorological data and by making use of the temperature of a dry reference surface as outlined by Leinonen *et al*. (2006). As shown in Figure 5 this normalization procedure very successfully corrected for differing conditions on different days, such that the infra-red data could be used to detect changes in stomatal conductane associated with suboptimal irrigation across a wide range of environmental conditions.

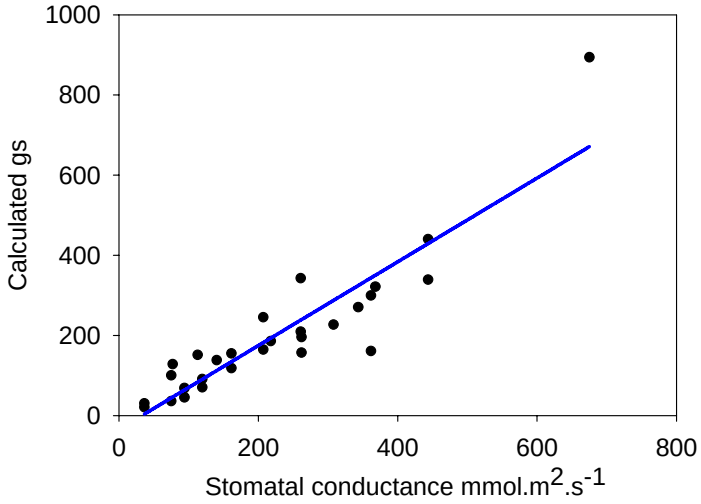


Figure 5. Relationship between calculated conductance and conductance measured with a porometer (data from Figure 4 have been normalised to take account of differing ambient conditions)

On one day during Professor Jones' visit arrangements were made to have Mr Ashley Wheaton from University of Melbourne visit the site and obtain some aerial images of the vines using his balloon and attached thermal imaging camera. (Figure 6 and 7).



Figure 6. Helium balloon and trailer



Figure 7. Balloon and instrument module

The balloon instrument module provided both high resolution digital images and images captured by the thermal camera. Figure 8 shows a high resolution image of part of the experimental site.

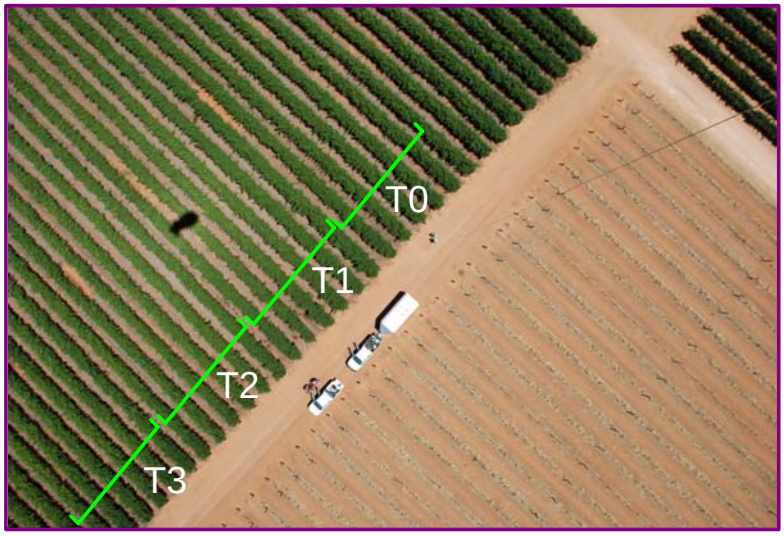


Figure 8. High resolution image of part of the experimental site

A representative image from the thermal camera is shown in figure 9.

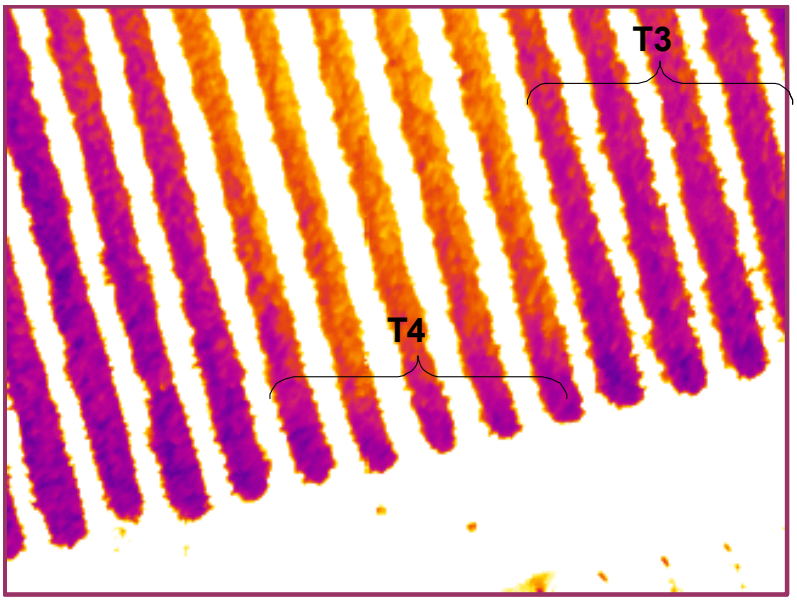


Figure 9. Thermal image of part of treatments T3 and T4.

This false colour image clearly shows temperature differences between the treatments and these are summarised for all treatments in Figure 10 and compared with concurrent canopy measurements obtained with the ground-based infrared thermometer.

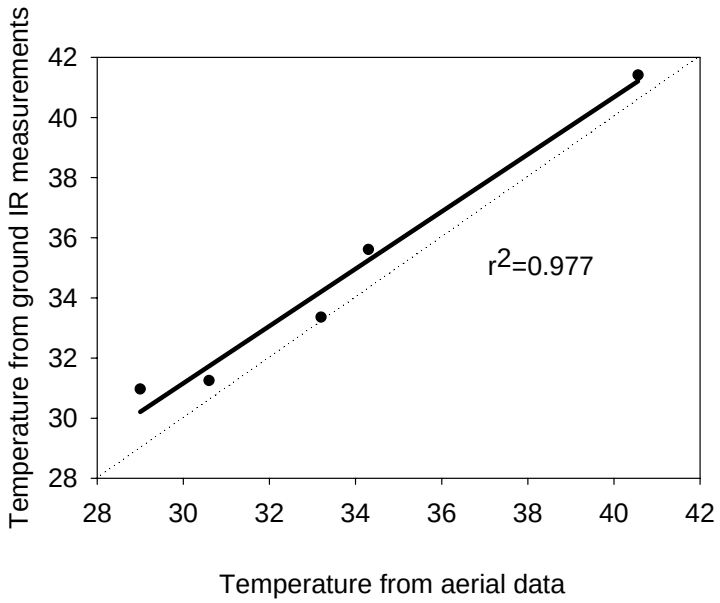


Figure 10. relationship between canopy temperature determined from ground-based infrared measurements and aerial thermal imaging. Each data point represents one treatment (T0-T4)

There was a very high correlation between these measurements but the ground-based IR measurements tended to be about 2^{o}C higher than the thermal imaging estimate, possibly due to the former measurements being confined to the illuminated side of the canopy whereas the aerial image integrated a greater proportion of shaded leaves. Nevertheless, either set of data could be used to calculate canopy conductance to obtain a relative estimate of the effect of response to irrigation (Figure 11).

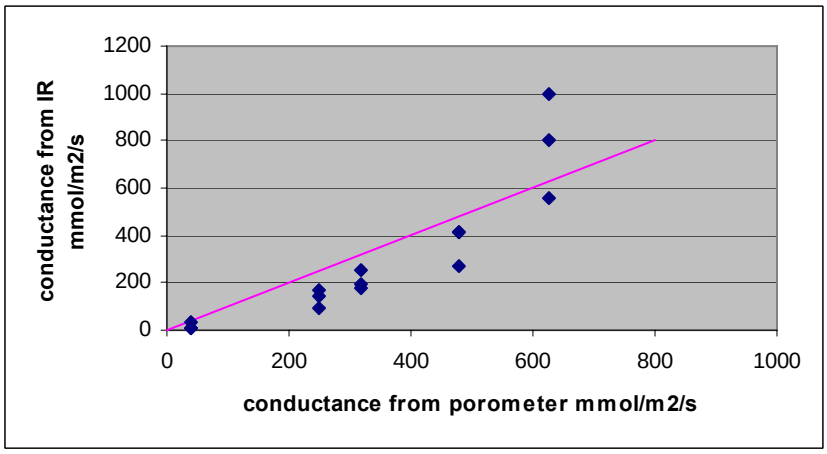


Figure 11. canopy conductance calculated from infrared data compared with concurrent measurements made with a porometer. These data were collected concurrently with the aerial data.

Because there was inevitably some time discrepancy between making the porometer measurements and collecting the IR data, it is unclear how much of the variation in calculated conductance was due to error and how much was due to real variation resulting from minor changes in ambient conditions or normal diurnal progression.

Nevertheless, these results demonstrate that it is possible to obtain reasonable estimates of canopy conductance using a hand-held, relatively inexpensive, infrared thermometer and that these conductance estimates can provide information about vine response to irrigation. The real advantage of this methodology over the use of gas exchange equipment such as a porometer is that it can very rapidly integrate data from large areas of vines. For example, if every 5^{th} row were measured it would take about 15 minutes to measure 1ha of vines. As currently set up some post-run data processing is required to obtain the conductance estimate. This consists of down-loading the data logger and importing the data into an Excel spreadsheet. An evolution of this methodology may be to incorporate the data processing into the logger program so that real-time estimates of conductance could be obtained. The work carried out during Professor Jones' visit also identified some limitations of the technique. For example, sparse canopies with many gaps tended to yield less reliable estimates of canopy temperature because the infrared thermometer cannot differentiate between canopy and the vineyard floor, sky or other non-vine components. These sources may inject erroneous temperature figures into the data-set. These can be filtered out to some extent but the system obviously works best when there is an entire canopy with no gaps. Rapidly changing temperature and radiation, as may occur on cloudy days, can also introduce errors, especially if the various instruments have different time constants.

Outcomes/Conclusions

We have been able to validate the methods that were first described in project CSP02/02 and refine them to the point where it is possible to use infrared thermometry, along with other environmental data, to calculate canopy conductance. We recognize that there are some instances when there are errors in the estimations, probably due to slightly different time constants in the various logged instruments, especially under conditions of varying radiation such as occurs under variable cloud cover. Our next step will be to reduce these errors so that a robust and relatively inexpensive instrument can be constructed. This project has confirmed the dynamic nature of stomatal conductance changes and shown that it can be a ready indicator of vine response to irrigation.

Recommendations

Future research will continue to refine the methods described here and rectify the small errors in calculation. The present system requires that the data loggers are downloaded for data manipulation and calculation. It should be possible to make these data manipulations in real-time to allow an instant appraisal of vine performance. We will continue to liaise with

Measurement Engineering Australia to refine the measurement hardware with the aim of producing a working commercial model.

Communication

Much of the work described here has been presented at a number of industry fora including the 2nd National Rootstock Forum in Irymple, May 2008 and the ASVO seminar "Water Friend or Foe" November 2007. It will also form part of the Drought Response Module being prepared for submission to GWRDC in June 2008.

References

Fuentes, S., Conroy, J.P., Kelley, G., Rogers, G., and Collins, M. (2005): Use of Infrared Thermography to Assess Spatial and Temporal Variability of Stomatal Conductance of Grapevines Under Partial Rootzone Drying: an Irrigation Scheduling Application. *Acta Horticulturae,* 689:309-316.

Leinonen, I., Grant, O.M., Tagliavia, C.P.P., Chaves, M.M. and Jones, H.G. (2006) Estimating stomatal conductance with thermal imagery. *Plant, Cell & Environment* **29**, 1508-1518

Staff

Professor Hamlyn G Jones, University of Dundee

Dr Brian Loveys, CSIRO Plant Industry

Dr Michael McCarthy, SARDI

Ms Kerryn O'Brien, CSIRO Plant Industry

Acknowledgements

We wish to thank the Yalumba Wine Company for allowing access to their vineyards and providing substantial material support. Kerryn O'Brien provided technical assistance and we thank the GWRDC for previous financial support which assisted with project development. CSIRO Plant Industry is part of the Wine Innovation Cluster (WIC) at the University of Adelaide Waite campus.