New and emerging tools developed for the vineyard: Presentations at the VIII Int. Symposium on Irrigation of Horticultural crops (Lleida-Spain)



FINAL REPORT to
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Research Organisation: **The University of Melbourne**

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Abstract

Latest work lead by Dr Fuentes with collaborations with colleagues in Australia and Chile was presented at the VIII International Symposium on Irrigation of Horticultural Crops (Lleida-Spain). Specifically, one oral presentation and two posters were delivered:

- Low cost infrared scanner for estimating grapevine water status (oral)
- Almond crop coefficients calculation including day and night-time tree water uptake and transpiration (poster)
- Orchard water status variability assessed using proximal and aerial infrared thermography (poster)

Background

Projected climate change and its variability predict increased temperatures, higher evaporative demand and water scarcity over a large portion of Australia. These projections have increased the pressure to obtain high quality fruit production with more efficient water use. Several studies have demonstrated that carefully imposed water stress improves stone fruit quality parameters. However, most of the conventional methods to monitor plant water status are based on manual point measurements, which have low spatial coverage, and are resource expensive and time-consuming. This seriously constraints the efficient assessment of spatial variability of water status from orchards caused by heterogeneous soil characteristics, poor irrigation distribution uniformity and/or variability in canopy structure/architecture. This work has demonstrated the capability of unmanned aerial vehicles (UAVs) in detection of water stress for a stone fruit orchard (peach and nectarine). Furthermore, it was thought until recently that night-time water uptake for C3 and C4 plants corresponded to stem and organ rehydration. Any water loss at night-time was considered minimal, corresponding to cuticle conductance of leaves with no significant conductance through the stomata. Recent studies have shown that this knowledge was incomplete. In a climate change scenario, where night-time temperatures have been forecasted to increase at a higher rate compared to diurnal temperatures, night-time water losses for non-stress and mild stress water conditions may be exacerbated (Fuentes *et al*. 2013; 2014). Furthermore, counter-intuitively, elevated CO_2 may increase nocturnal water loss (Zeppel *et al*. 2012). Current methodologies and modelling algorithms to estimate ET_{real}, assume stomata conductance at night-time to be zero. Therefore, accurate crop coefficient calculations need to incorporate these important night-time water losses, which are not coupled to photosynthesis, hence reducing water use efficiency.

Project Aims and Performance Targets

The aims of the presentations were mainly to gather feedback from the international scientific community in relation to the applicability of the different techniques and tools presented. The performance targets will be measured in relation to the number of scientific publications. For this project, the publication that were set as targets and submitted are:

Development of an adaptive thermal & multispectral remote sensing system for an unmanned aerial vehicle (UAV): an orchard case study

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Highlights:

• We develop an intelligent multi-sensor UAV photogrammetry payload for precision agriculture

• Automatically adjusts image acquisition in flight to accommodate for ground speed and altitude variations

• Three cameras (visible, multispectral and infrared) and two UAV platforms (fixed-wing & multirotor) were evaluated

• Demonstrated crop water stress detection in an orchard using a multi-sensor UAV payload

Abstract: Mapping the spatial and temporal variability of crops is a prerequisite for precision agriculture (PA) including precision irrigation. Remote sensing using Unmanned Aerial Vehicles (UAV) enables the collection of high resolution imagery to aid in the PA decision management process. The generation of agricultural orthomosaics and three-dimensional models using photogrammetric techniques requires accurate management of image forward overlap to ensure stereoscopic coverage of the target area. In this study, we present an intelligent multi-sensor UAV photogrammetry payload system that adapts image acquisition in real-time based on mission requirements and changing flight conditions was developed. The adaptive intervalometer dynamically adjusted image acquisition in flight to accommodate for variation in ground speed and altitude. Reliably maintaining adequate image forward overlap ensures stereoscopic coverage of the target area for post processing and multi-sensor image co-registration. The adaptive intervalometer was evaluated on a multirotor and fixed-wing platform achieved a RMSE of 0.84% and 2.26% respectively, significant improvement in the accuracy of image forward overlap compared to the commonly used time intervalometer. To illustrate the effectiveness of the UAV payload proposed, the adaptive intervalometer was used to simultaneously collect high-resolution thermal (8 cm/px) and multispectral (5 cm/px) imagery to detect crop water stress status in an orchard. Thermal and multispectral orthomosaics were constructed using structure from motion (SfM) techniques and their geometric accuracy evaluated against DGPS surveyed validation markers. High spatial resolution thermal imagery confirmed that plants under water stress have a higher average canopy temperature (+2.65°C) than air temperature, enabling the successful detection of water-deficit plants. In this study, we also compared two multispectral radiometric calibrations using i) on-ground reflectance measurements and ii) known reflectance of artificial targets, to convert digital numbers (DN) to reflectance. Results from this study confirmed that on-ground measurements provide greater accuracy than artificial targets. However, when calculating some ratio-based vegetation indices, on-ground measurements can be substituted for artificial reflectance targets without significantly reducing reflectance accuracy. This presented orchard case study confirmed that the effectiveness of the multi-sensor (thermal & multispectral) UAV payload proposed for the estimation of biophysical parameters and the estimation of crop water stress and vegetation condition in an orchard.

Keywords: UAV, thermal, multispectral, remote sensing, photogrammetry, canopy temperature, radiometric calibration, NDVI

Automated detection and segmentation of vine rows using high resolution UAS imagery in a commercial vineyard

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Abstract: Climate models predict increased average temperatures and water scarcity in major agricultural regions of Australia over the coming decades. These changes will increase the pressure on vineyards to manage water and other resources more efficiently, without compromising their high quality grape production. Several studies have demonstrated that high-resolution visual/near-infrared (VNIR) vineyard maps acquired from unmanned aerial systems (UAS) can be used to monitor crop spatial variability and plant biophysical parameters in vineyards. However, manual segmentation of aerial images is time consuming and costly, therefore in order to efficiently assess vineyards from remote sensing data, automated tools are required to extract relevant information from vineyard maps. Generating vineyard maps requires separating vine pixels from non-vine pixels in order to accurately determine vine spectral and spatial information. Previously several image texture and frequency analysis methods have been applied to vineyard map generation, however these approaches require manual preliminary delineation of the vine fields. In this paper, an automated algorithm that uses skeletonisation techniques to reduce the complexity of agricultural scenes into a collection of skeletal descriptors is described. By applying a series of geometric and spatial constraints to each skeleton, the algorithm accurately identifies and segments each vine row. The algorithm presented here has been applied to a high resolution aerial orthomosaic and has proven its efficiency in unsupervised detection and delineation of vine rows in a commercial vineyard.

Keywords: *Photogrammetry, image processing, precision viticulture*

Submitted as a full paper to: *21st International Congress on Modelling and Simulation (MODSIM2015)*

Results / Discussions

Following is a summary of the presentations delivered:

Low cost infrared scanner for estimating grapevine water status.

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Introduction: Global warming forecasts predict a general water scarcity and a progressive increase of temperatures in most of the agricultural zones. This has encouraged the study of more efficient and cost effective techniques to assess irrigation requirements and water status of crops to maximise quality. Is well known that infrared thermography is a useful tool to assess grapevine water status. However infrared thermal cameras are still an expensive and complicated technology for vine growers. Recently, new hardware and software development has allowed the creation of cheaper sensors and mini-robots, allowing users to obtain and analyse infrared data easily and efficiently. The aim of this study was to compare the results from infrared scanners (inexpensive technology) against results from infrared thermal cameras to assess grapevine water status for irrigation scheduling purposes.

Material and Methods: The experiment was carried out during the 2014 season with the cultivar Grenache, and two irrigation regimes, moderate water stress and rainfed. The experimental site was located at the UIB. Leaf temperature, solar radiation, stomata conductance and leaf gas exchange measurements at different canopy positions were carried out to validate the results of crop water stress indices (CWSI) obtained by the low-cost infrared scanner and infrared thermal cameras.

Results: Results showed that results from scanners were highly comparable to those obtained from the use of infrared cameras with a resolution reduction of around 80%. The scanner seemed to be an interesting and inexpensive tool to determine water status of grapevines at different irrigation levels.

Keywords: *Thermal images, irrigation scheduling, crop water stress indices, infrared temperature, Matlab programming.*

Almond crop coefficients calculations including day and night-time tree water uptake and transpiration

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Introduction: It was thought until recently that night-time water uptake for C3 and C4 plants corresponded to stem and organ rehydration. Any water loss at night-time was considered minimal, corresponding to cuticle conductance of leaves with no significant conductance through the stomata. Recent studies have shown that this knowledge was incomplete. In a climate change scenario, where night-time temperatures have been forecasted to increase at a higher rate compared to diurnal temperatures, night-time water losses for non-stress and mild stress water conditions may be exacerbated. Furthermore, counter-intuitively, elevated CO_2 may increase nocturnal water loss. Current methodologies and modeling algorithms to estimate ETreal, assume stomata conductance at night-time to be zero. Therefore, accurate crop coefficient calculations need to incorporate these important night-time water losses, which are not coupled to photosynthesis, hence reducing water use efficiency.
Material and Methods: The experiment was carried out during the 2009-2010 season in field-grown almond trees located in Berri South-Australia under two irrigation regimes (T100 and T60 which are percentages of ETc). Soil moisture probes and sap flow sensors (heat-pulse compensated method) were installed in both treatments to calculate the partition between soil evaporation (E) and transpiration (T) respectively. Reference ET was calculated from a meteorological station close to the site (ETo). Crop coefficients were calculated considering diurnal and nocturnal water use.
Results: Results showed that night-time water use was around 15-20% compared to diurnal transpiration throughout the season. Crop coefficients were calculated for almond trees incorporating diurnal and nocturnal water uptake and transpiration.
Keywords: *night-time transpiration, canopy conductance, sap flow sensors, capacitance soil moisture, evapotranspiration.*

Orchard water status variability assessed using proximal and aerial infrared thermography

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Introduction: Projected climate change and its variability indicate increased temperatures, higher evaporative demand and water scarcity over large portion of Australia. It has increased the pressure to obtain high quality grape and fruit production with more efficient water use. Several studies have demonstrated that carefully designed water stress improves wine and peach fruit quality. However, most of the conventional methods to monitor plant water status are based on manual point measurements, which have low spatial coverage, and are resource expensive and time-consuming. This seriously constraints efficient assessment of spatial variability of water status from vineyards and orchards caused by heterogeneous soil characteristics, poor irrigation distribution uniformity and/or variability in canopy structure/architecture. This work has demonstrated the capability of unmanned aerial vehicles (UAVs) in detection of water stress for a commercial vineyard and stone fruit trees (peach and nectarine).

Material and Methods: The experiment was carried out during the 2014-15 growing season in field-grown grapevines and peach trees from a commercial vineyard (Curly Flat) located in the Macendon Ranges, Victoria and a stone fruit experimental orchard in Tatura, Vitoria respectively. Water stress treatments were imposed by restricting irrigation in selected sections for both peach and nectarine orchards. The UAV was equipped with visible-near/thermal-infrared camera systems. Water stress indices maps produced using the UAV-borne images were evaluated with ground-based measurements of leaf conductance, stem water potential and proximal infrared thermography.
Results: Results showed highly comparable and significant agreements between indices obtained using the UAV and remote sensing with the ground-truth data.
Keywords: *Crop water stress index, stem water potential, leaf conductance, unmanned aerial vehicles, spatial variability.*

Outcome / Conclusions

This conference was a great opportunity to gather information of similar research done by different international institutions. It also confirmed that the work done on new and emerging technologies from The University of Melbourne is very advanced compared to similar research internationally. Following are the full posters presented in Lleida – Spain.

Almond crop coefficient calculations including day and night-time tree water uptake and transpiration

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INTRODUCTION

It was thought until recently that night-time water uptake for C3 and C4 plants corresponded to stem and organ rehydration. Any water loss at night-time was considered minimal, corresponding to cuticle conductance of leaves with no significant conductance through the stomata. Recent studies have shown that this knowledge was incomplete. In a climate change scenario, where night-time temperatures have been forecasted to increase at a higher rate compared to diurnal temperatures, night-time water losses for non-stress and mild stress water conditions may be exacerbated (Fuentes *et al*. 2013; 2014). Furthermore, counter-intuitively, elevated CO_2 may increase nocturnal water loss (Zeppel *et al*. 2012). Current methodologies and modelling algorithms to estimate ET_{real}, assume stomata conductance at night-time to be zero. Therefore, accurate crop coefficient calculations need to incorporate these important night-time water losses, which are not coupled to photosynthesis, hence reducing water use efficiency.

MATERIALS AND METHODS

The experiment was carried out during the 2009-2010 season in field-grown almond trees located in Berri South-Australia under two irrigation regimes (T_{100} and T_{60} which are percentages of ET_c). Soil moisture probe arrays and sap flow sensors (heat-pulse compensated method) were installed in both treatments to calculate the partition between soil evaporation (E) and transpiration (T) respectively (Fig. 1). Reference ET was calculated from a meteorological station close to the site (ET_o). Crop coefficients were calculated considering diurnal and nocturnal water use.

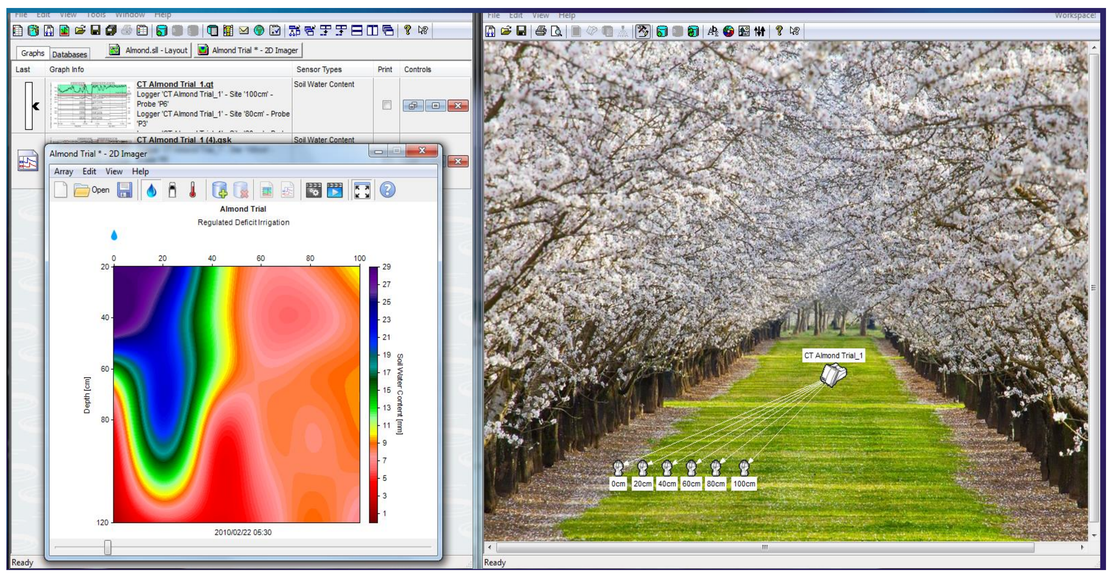


Fig. 1. Diagram showing array of soil moisture probes and wetting patterns analysis using The Wetting Patterns Analyser WPA© (Sentek Pty. Ltd. Putney, SA. Australia).

RESULTS

Results showed that night-time water use (S_n) measured using sap flow sensors, was around 15-20 % compared to diurnal transpiration throughout the season and parabolicaly correlated to stem water potential (Ψ_s) from the previous day (Fig. 2).

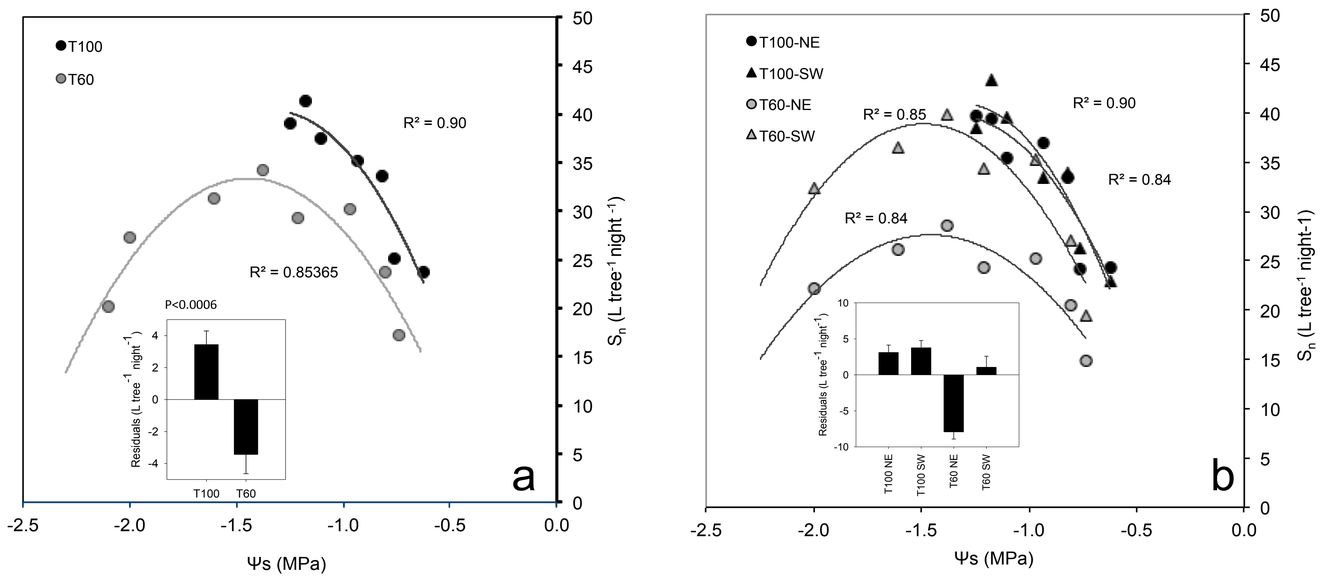


Figure 2. (a) Parabolic relationships between midday Ψs (MPa) and Sn (L tree^{-1} night^{-1}) for T100 (black-filled circles) and T60 (grey-filled circles) for measurement days throughout the early season. Residual analysis was performed to assess decoupling of treatments. (b) Parabolic relationships between midday Ψs (MPa) and Sn (L tree^{-1}night^{-1}) by positioning of the probes within T100 and T60. Residual analysis was performed to assess decoupling of treatments and location of probes. From (Fuentes *et al.* 2013).

Crop coefficients were calculated for almond trees incorporating diurnal and nocturnal water uptake and transpiration (Fig. 3 and 4).

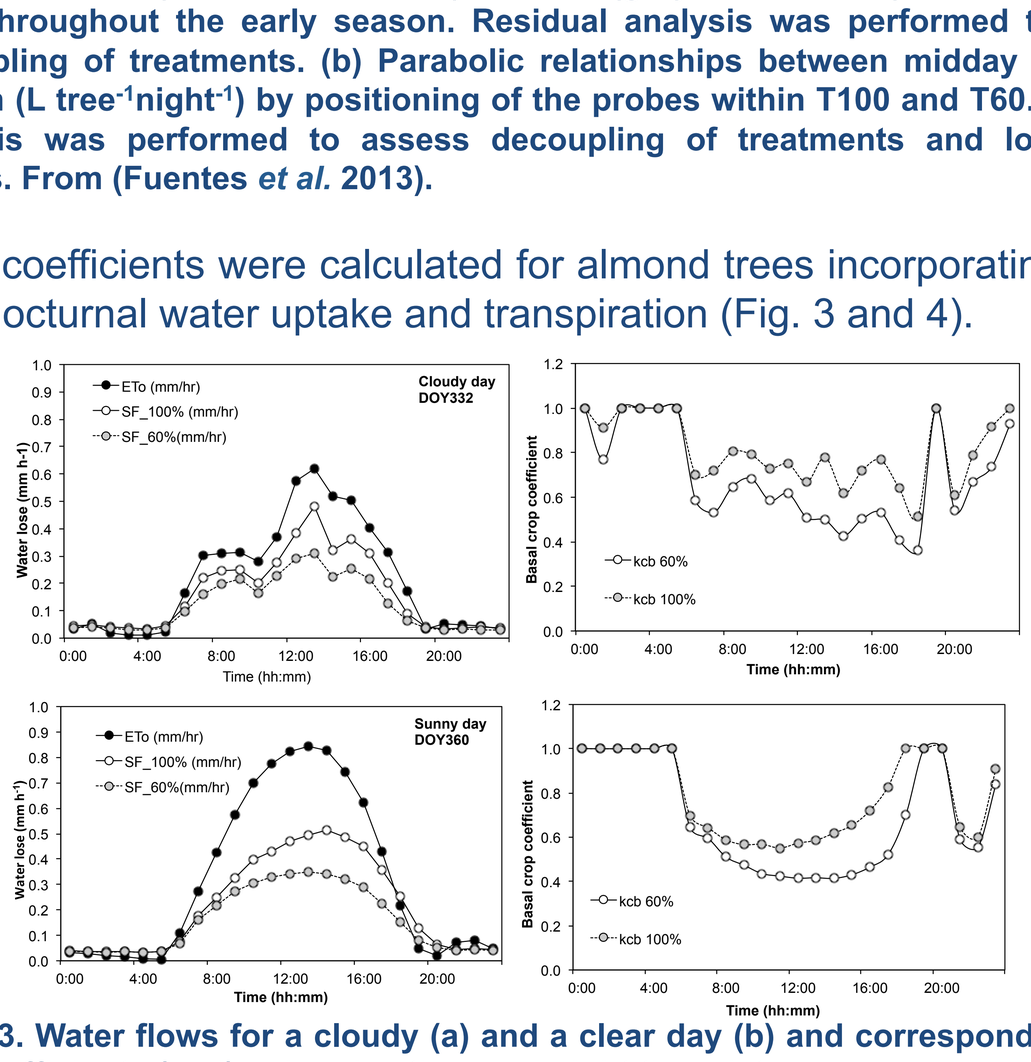


Figure 3. Water flows for a cloudy (a) and a clear day (b) and corresponding basal crop coefficients (c; d) using day time and night time data.

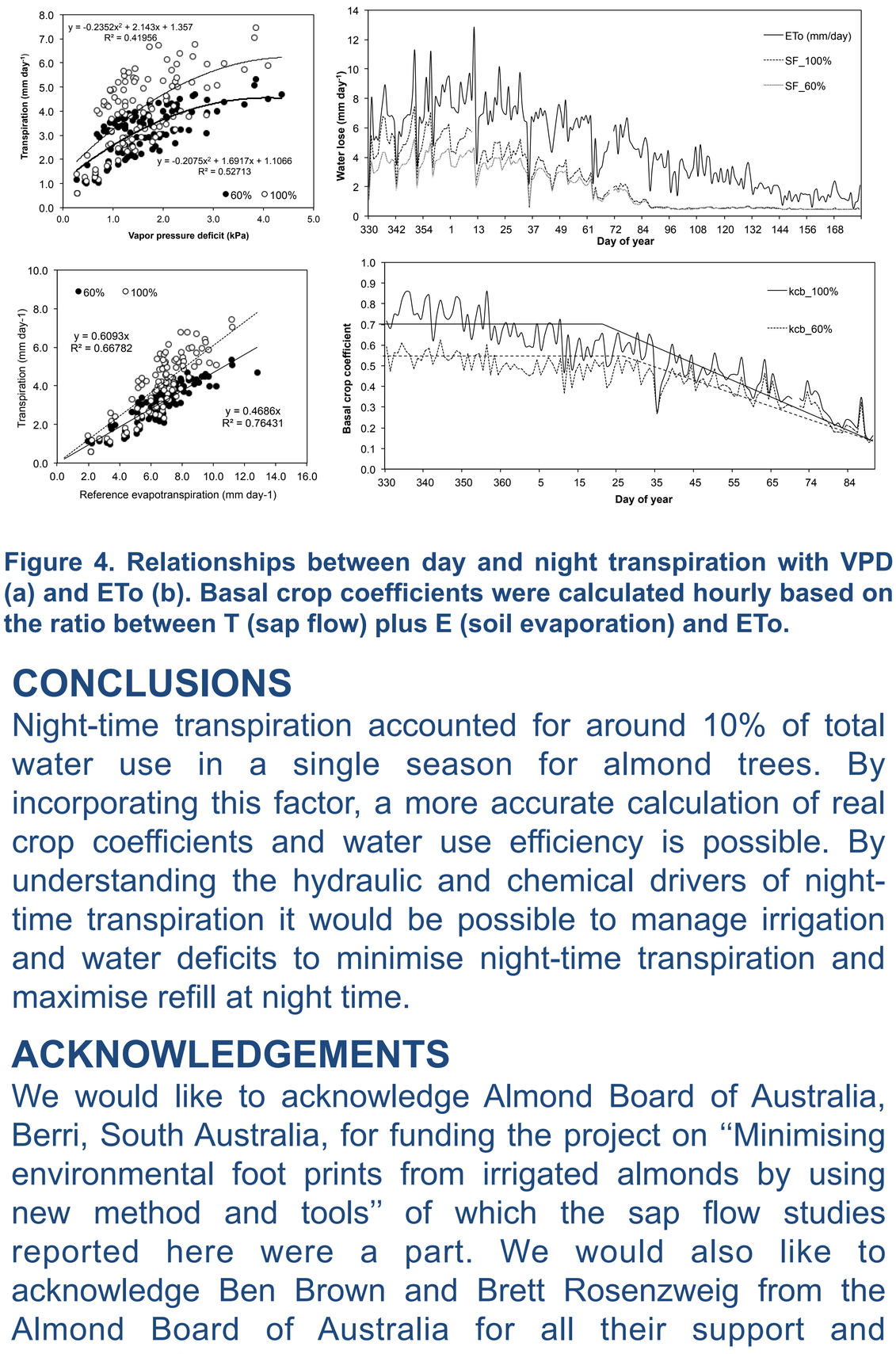


Figure 4. Relationships between day and night transpiration with VPD (a) and ETo (b). Basal crop coefficients were calculated hourly based on the ratio between T (sap flow) plus E (soil evaporation) and ETo.

CONCLUSIONS

Night-time transpiration accounted for around 10% of total water use in a single season for almond trees. By incorporating this factor, a more accurate calculation of real crop coefficients and water use efficiency is possible. By understanding the hydraulic and chemical drivers of night-time transpiration it would be possible to manage irrigation and water deficits to minimise night-time transpiration and maximise refill at night time.

ACKNOWLEDGEMENTS

We would like to acknowledge Almond Board of Australia, Berri, South Australia, for funding the project on ‘‘Minimising environmental foot prints from irrigated almonds by using new method and tools’’ of which the sap flow studies reported here were a part. We would also like to acknowledge Ben Brown and Brett Rosenzweig from the Almond Board of Australia for all their support and assistance for the experiment.

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Orchard water status variability assessed using proximal and aerial infrared thermography

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INTRODUCTION

Projected climate change and its variability predicts increased temperatures, higher evaporative demand and water scarcity over a large portion of Australia. These projections have increased the pressure to obtain high quality fruit production with more efficient water use. Several studies have demonstrated that carefully imposed water stress improves stone fruit quality parameters. However, most of the conventional methods to monitor plant water status are based on manual point measurements, which have low spatial coverage, and are resource expensive and time-consuming. This seriously constraints the efficient assessment of spatial variability of water status from orchards caused by heterogeneous soil characteristics, poor irrigation distribution uniformity and/or variability in canopy structure/architecture. This work has demonstrated the capability of unmanned aerial vehicles (UAVs) in detection of water stress for a stone fruit orchard (peach and nectarine).

MATERIALS AND METHODS

The experiment was carried out during the 2014-15 growing season in field-grown grapevines and peach trees from a stone fruit experimental orchard in Tatura, Victoria. Water stress treatments were imposed by restricting irrigation in selected sections for both peach and nectarine orchards. The UAV was equipped with a visible-near/thermal-infrared camera systems (Fig. 1). Water stress indices maps, produced using the UAV-borne images, were evaluated with ground-based measurements of leaf conductance, stem water potential and proximal infrared thermography. During aerial image acquisition all of the camera parameters remained constant while the flight parameters were dynamic. In order to maintain optimal forward overlap between consecutive images, the on-board intervalometer recalculated the forward distance with every new altitude estimate from the UAV's flight controller (Fig. 2).



Fig. 1. The multirotor UAV platform (S900, DJI, Shenzhen, China) carrying a thermal and multispectral payload, IMU, GPS receiver and autopilot.

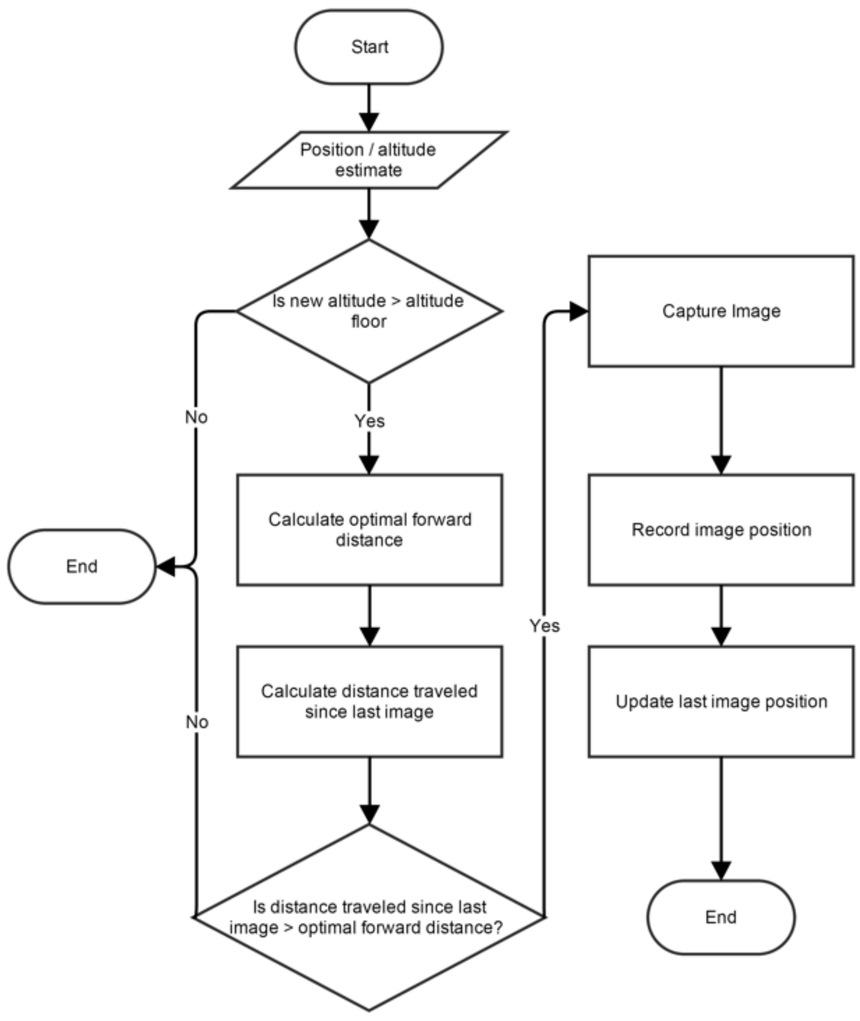


Figure 2. Adaptive intervalometer algorithm used by the UAV.

RESULTS

Results showed highly comparable and significant agreements between canopy temperatures obtained using the UAV, water deficits imposed to plants and ground truth thermal data (Fig.3 & 4).

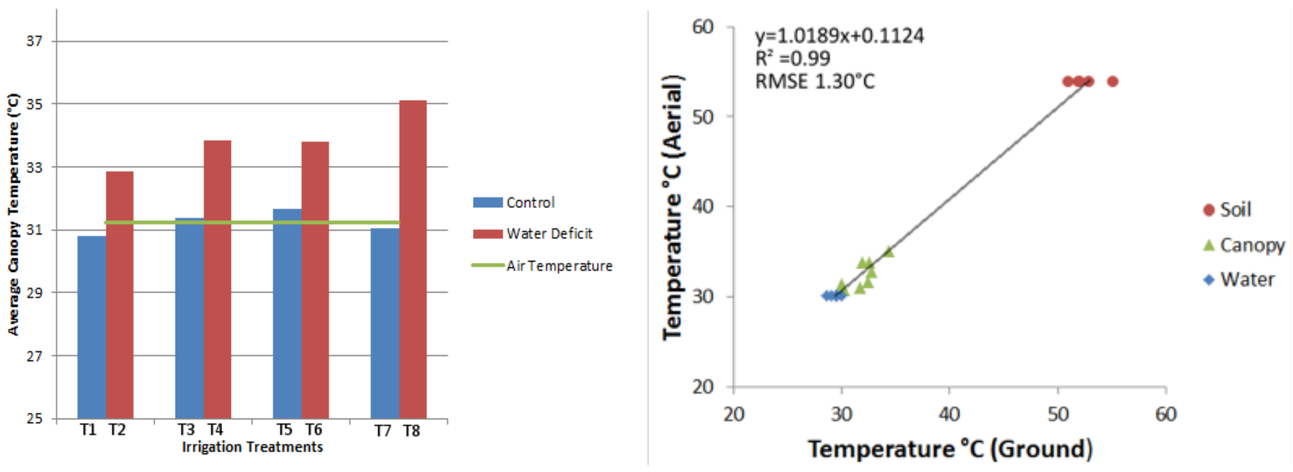


Figure 3. A comparison between air temperature and the average canopy temperature of treatment areas (left). Comparison between ground truth surface temperature and aerial thermal sensor measurement acquired at 100 m (right).

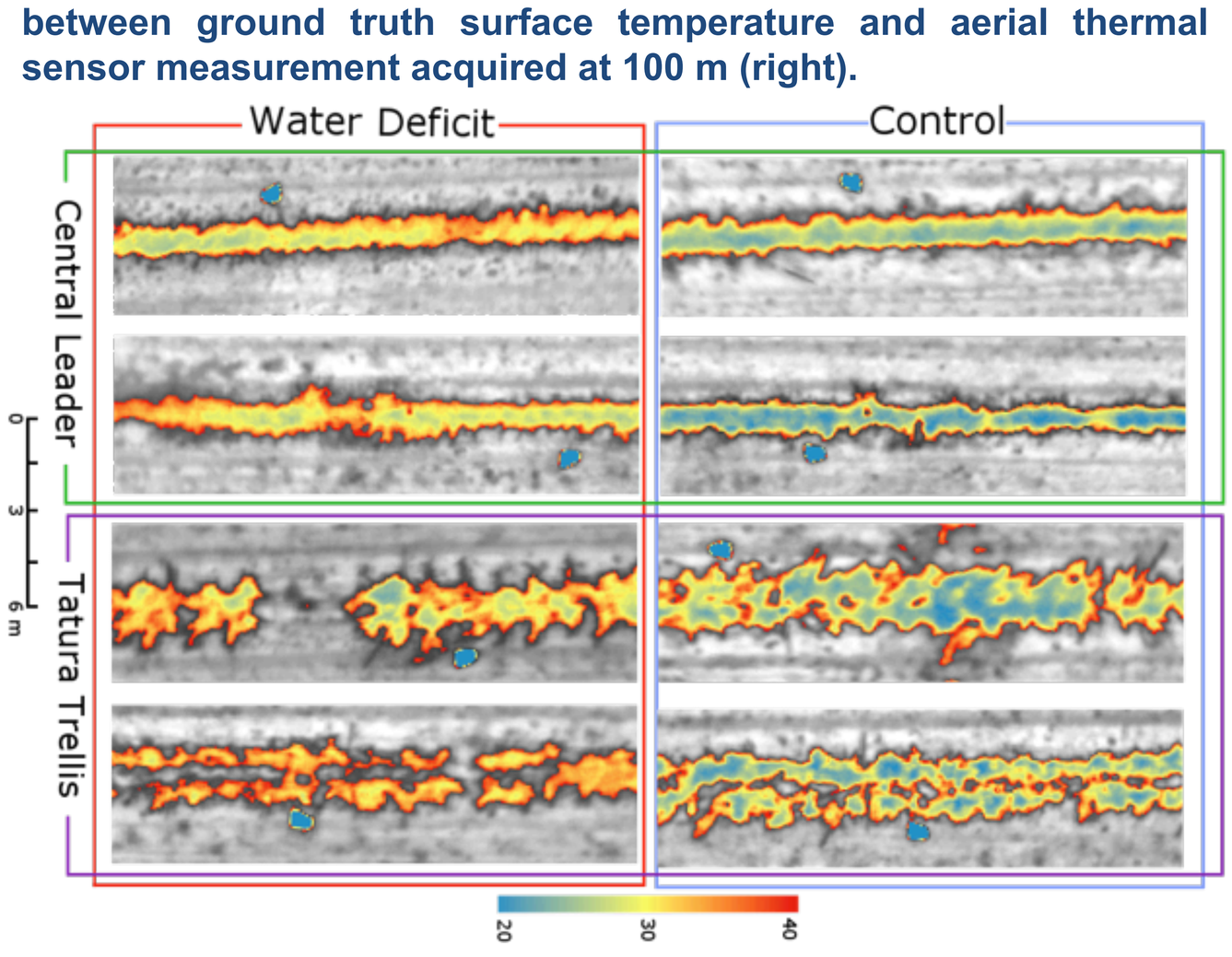


Figure 4. Thermal images from UAV showing control treatments (right) and water deficit treatments (left). Colour bar represents the temperature scale in °C.

CONCLUSIONS

The presented orchard case study confirmed the effectiveness of the multi-sensor (thermal & multispectral) UAV payload proposed for the estimation of biophysical parameters, such as water stress. The analysis of high spatial resolution thermal imagery confirmed that plants under water stress had a higher averaged canopy temperature (2.65°C) compared to air temperature, enabling the successful detection of water deficit plants.

ACKNOWLEDGEMENTS

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