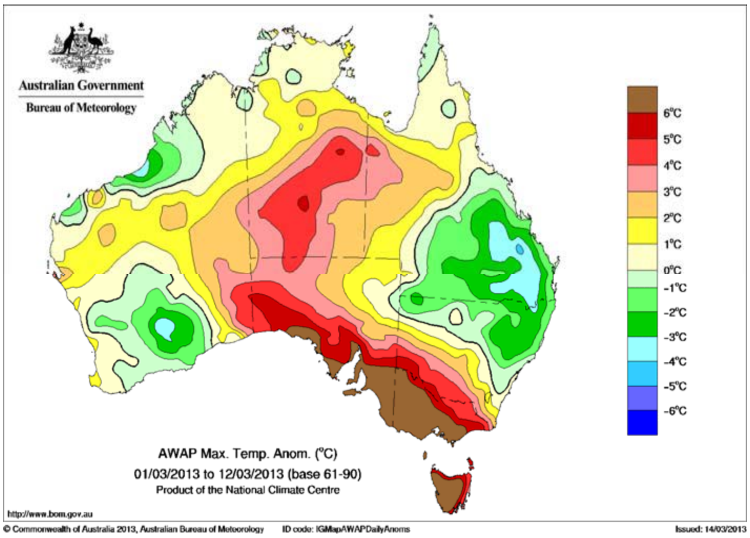
Cost-effective viticultural strategies to adapt to a warmer, drier climate



FINAL REPORT to AUSTRALIAN GRAPE & WINE AUTHORITY

Project Number: **SAR1304**

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Abstract

Australian wine grape growers have demonstrated an ability to adapt their vineyard management to help mitigate an increasing occurrence of extreme heat events driven by a changing climate. One such strategy is more timely and targeted irrigations before and during heatwaves. The impacts of heatwaves may also be reduced by the strategic use of water for evaporative cooling of vineyards during hot nights. Such use of water is a trade-off with water use efficiency as this water is specifically applied to evaporate, however, if successful, this technique may a have positive cost-benefit ratio.

Three large-scale field experiments were established, two in the SA Riverland and one in Coonawarra, to investigate the effectiveness of under- and over-canopy sprinklers on lowering vineyard temperature during hot nights experienced during a heatwave. Large temperature data sets were generated during several heatwave events during the 2015/16 season, however there was little effect on temperature and humidity within the meso-climate of the bunch zone and vine canopy. At the two Riverland sites there was a 20-30% increase in yield as a result of activating under canopy sprinklers on just six nights between December and harvest in late January/early February. The value of the additional crop far outweighed the cost of the water used for cooling. In addition, there was a significant increase in yeast available nitrogen in must, which resulted in more rapid fermentation. Early indications suggest differences in wine sensory attributes; these will be reported later.

In summary, this work has demonstrated that activating under canopy sprinklers only at night during heatwaves had only a minor impact on temperature within the canopy, however there was a large, yet unexplained, increase in yield and positive impacts on grape must and potentially wine quality.

Executive Summary

The initial hypothesis was that "the use of vineyard micro sprinklers at night to lower temperature and raise humidity during extreme heat events will mitigate impacts of these events". It was developed from the observation that several successive hot nights, rather than hot days, appeared to result in permanent damage to vine canopies and crop (leaf and berry scorch/sunburn). Evaporative cooling using sprinklers was considered one management option to lower night time temperature and raise humidity. Under-canopy sprinkler systems were considered a better option than over-canopy systems as the former do not result in leaf and bunch wetness that could increase disease pressure, and in regions with marginal quality water, minimise foliar uptake of salt. Irrigation to meet plant water requirement was to be by drip irrigation as this is the most widely used irrigation method.

As the investigation focused on the effectiveness of under canopy sprinklers for evaporative cooling, the experimental plots needed to be of sufficient size to eliminate 'edge effects'; and existing under-vine sprinklers at the sites were used to minimize capital cost and achieve project outcomes in a timely manner. Three suitable trial sites were identified, two in the SA Riverland and a third in Coonawarra. The Riverland sites were originally irrigated using under-canopy sprinklers, but when converted to drip irrigation most of the infrastructure was retained and it was a simple task to reactivate the sprinkler systems. In Coonawarra a vineyard with existing over-canopy sprinklers for frost protection was used and, with the generous support of Wynns Coonawarra Estate, a section of the block was converted to under-canopy sprinklers. At each site, masts containing temperature (and later humidity) sensors were installed to record parameters from ground level to three meters (above the canopy) in the approximate center of the experimental plots. It was planned to use these data sets to quantify the effectiveness of the sprinklers and subsequently develop a model to inform on the most effective timing and management of under-canopy sprinklers under a range of heatwave conditions.

Modifications to irrigation systems, including installation of remotely accessed irrigation controllers and construction of temperature monitoring masts and commissioning, were not completed until early January 2015. Uncharacteristically, the SA Riverland experienced a cool January with night-time temperatures below average; no cooling events were initiated before harvest, however the sprinklers were activated on several occasions during post-harvest heatwave events to quantify the effectiveness of night-time cooling. As these February heatwaves were pre-harvest in Coonawarra, over- and under-canopy sprinklers were activated on several occasions and fruit was harvested for small lot winemaking.

During the 2015/16 season the sprinklers were activated on a total of six occasions at the two Riverland sites and five occasions at the Coonawarra site. Comprehensive temperature and humidity data sets were collected. Analysis of these data sets indicated that the under-canopy sprinklers resulted in a small and transient reduction in canopy temperature, with a slightly more sustained increase in humidity within the canopy. The over-canopy sprinklers at the Coonawarra site resulted in a larger reduction in canopy temperature, however, the reduction was smaller than expected with evaporative cooling. The initial hypothesis (that "the use of vineyard micro sprinklers at night to lower temperature and raise humidity during extreme heat events") was rejected and consequently, with only short-duration impacts on canopy temperature and relative humidity, which were also smaller than predicted, no simulation modelling was undertaken as part of this project, However, there may be the opportunity of using the data sets from this project in the model developed for the new Wine Australia-funded project UA1502 "Using in-canopy misters to mitigate the negative effects of heatwaves in grapevines" which will continue data collection at the existing sites.

Despite the lack of a quantifiable and persistent reduction in vineyard/canopy temperature and an increase in relative humidity, at the two Riverland sites there were noticeable differences in overall vine canopy health, with less sunburn on fruit and leaf scorch in the "cooled" blocks. Infrared assessment of canopy temperature indicated lower leaf temperature the morning after the sprinklers were activated at one of the Riverland sites. Prior to harvest one of the sites was inspected by the grower liaison officer from the wine company contracted to purchase the fruit. He reported that fruit from the control plots had small berries with sour tropical characters whilst fruit from the cooled plots had fresh zesty citrus/soft stonefruit characters and the vines had good healthy canopies.

At harvest, based on the length of cordon picked to obtain sufficient fruit for small lot winemaking, there was a 28% higher yield (40.8 vs 31.9 T/ha) on the cooled block compared with control at one Riverland site and a 10% higher yield at the second site. Whole-of-row machine harvested fruit weights at the latter site however revealed a 21% increase in yield in the cooled block (31.5 vs 26 T/ha). The increased value of the crop at both sites exceeded the small additional cost of the water used by the sprinklers on the six nights they were activated.

Grape must analysis indicated a large increase in must nitrogen sources in fruit from the cooled Riverland sites. Yeast and amino acid-available nitrogen was 40-50% higher in must from the cooled blocks and ammonia nitrogen between 40 and 60% higher. These differences resulted in an increase in fermentation rate. Anthocyanins, tannins and phenolics were measured on the Cabernet sauvignon fruit for the Coonawarra site collected immediately prior to harvest in both seasons, however there was no clear difference between control and cooled blocks.

All small lot wines will undergo sensorial assessment by a trained panel at AWRI in early 2017 in addition to targeted wine chemistry. These results and interpretation will be a later addendum to this report.

Acknowledgments

We wish to acknowledge and thank the Yalumba Wine Company Oxford Landing Estate vineyard manager, Mr. Glynn Muster and his staff for assistance in site establishment and maintenance. Mr. Ashley Ratcliff, Ricca Terra vineyard, Barmera provided an experimental site and support.

Mr. Allen Jenkins, and Ben Harris, Wynns Coonawarra were instrumental in establishing the large experimental site in Coonawarra and Dr. Cath Kidman ably assisted in data collection and harvest.

Background

In response to a number of heatwaves such as the March 2008 and November 2009 events, which resulted in minor to severe damage in vineyards, in 2012 the GWRDC (now Wine Australia) produced a fact sheet containing advice on minimising heat damage to vineyards (Managing grapevines during heatwaves. Hayman, Longbottom, McCarthy & Thomas, January 2012). A number of management practises were suggested, including advice on irrigation management in the lead-up to a predicted heatwave and during the heat event. Irrigation during each night of the event was recommended. This advice was based on observations by grape growers who commented that a number of consecutive hot nights appeared to have greater impact on vineyard “health” than hot days (with cooler nights), and that there was some benefit if irrigation was applied at night during heatwaves. However, it was not apparent whether the beneficial effects of night time irrigation were from increasing soil water availability, lowering soil temperature or perhaps lowering vineyard temperature while raising relative humidity and allowing vines to “recover” prior to the next hot day.

Growers were using drip irrigation for overnight watering, but it appeared to offer minimal evaporative cooling benefit during extreme heat events, and with the exception of those vineyards with over-canopy sprinklers for frost protection (that could be activated at night during heatwaves), it was apparent that large-scale adoption of effective night-time vineyard cooling may be impracticable. Growers with over-canopy irrigation were also reluctant to activate sprinklers during the day of a heat event due to concerns around salinity damage or at night due to increased disease pressure resulting from extended periods of leaf and bunch wetness. These issues could be avoided through the use of full-cover under-canopy sprinklers and, if demonstrated to be effective, may justify the cost of retrofitting under-canopy sprinklers into vineyard blocks.

Project Aims and Performance Targets

The project reported here was one of two that comprised activities in the project “Cost-effective viticultural strategies to adapt to a warmer drier climate” funded by the Commonwealth Filling the Research Gap Program via GWRDC.

The overall project objectives were:

Validated, commercially viable vineyard management strategies and practical tools to allow Australian grape growing businesses to adapt to a water-constrained and hotter vineyard meso-environment.

Specifically:

(1) Novel canopy management strategies that can offset the effects of increased temperature on berry physiology, ripening and wine quality; and,
(2) Irrigation strategies to ensure long-term vine health, water savings and salinity mitigation in a hotter, drier climate.

This report covers objective (2) and specifically investigated the effectiveness of night-time evaporative cooling of vineyards using under- and over-canopy sprinklers to mitigate the impact of heatwaves.

Materials and Methods

Two suitable Chardonnay vineyards in the SA Riverland (Ricca Terra vineyard (Barmera) and Yalumba Oxford Landing Estate (Waikerie)) were identified. Both had previously been under-canopy irrigated with full-cover sprinklers prior to conversion to drip irrigation. During conversion the sprinkler irrigation infrastructure had largely been left intact consequently it was relatively simple to re-commission the sprinklers and install water meters (Figure 1).

Figure 1. Under-canopy sprinkler and adjacent drip irrigation line in the Ricca Terra Riverland trial site near Barmera, SA.

Remotely accessed irrigation controllers were installed at the two Riverland sites and temperature data from the nearby SAMDBNRM Automatic weather station was used to determine when the under-canopy sprinklers were activated. For the Riverland sites the triggers for activating the sprinklers were, (1) at least two consecutive days over 37^0C were forecast and, (2) the overnight minimum temperature was predicted to fall not lower than about 25^0C. Sprinklers were pulsed during the night beginning after sunset, and off before dawn (see details later). Each of the "cooled" plots were considered large enough at approximately 20 rows wide and 140-170 m long (row widths were 3.7 m and 3 m at the Ricca Terra and Oxford Landing Estate sites respectively) to minimize edge effects. All monitoring equipment was located centrally in each cooled plot. Due to the size of the plots no field replication was practicable. Similar monitoring equipment was placed in the drip-irrigated, non-cooled adjacent rows which comprised the remainder of the vineyard block.

The third trial site was at Wynns Coonawarra Estate (Coonawarra), where a block of mature (> 10 years old) Cabernet Sauvignon vines planted on Terra rossa soil approximately 91 by 3 m rows wide and 370 m long (O'Dea's Vineyard) was identified. This was divided into three similar-sized blocks comprising control, full cover over-canopy sprinklers and under-canopy sprinklers. For the latter, the existing over-canopy sprinklers were removed from the standpipe, a short section of poly pipe attached and a suitable sprinkler (Nelson Rotator 3000 ™) fastened to the standpipe post so that the sprinklers could irrigate underneath the vines. Monitoring equipment was installed approximately in the centre of the three plots as for the Riverland sites.

Environmental monitoring masts each comprising seven shielded thermistors connected to a data logger were constructed. The seven sensor shields (T2 –T8) were evenly spaced from approximately 20 cm above ground level to approximately 2.6 m in height (Figure 2), the latter being above the canopy at all sites. An additional thermistor (T1) was buried at approximately 5 cm depth close to the existing drip and sprinkler lines. All data loggers were programmed for 15 minute readings. Thermistors were housed in radiation shields supplied by Environmental Measurements Ltd for the two Riverland sites and DataMate ™ Data logger screens in the Coonawarra site. Data loggers and thermistors were supplied by Measurement Engineering Australia Pty Ltd and thermistor calibrations were checked prior to installation.

Canopy temperature readings at the Ricca Terra site were collected using a Fluke 62 mini IR Thermometer with the manufacturer's recommended emissivity of 0.95. Data was collected from two rows of vines, one treatment row and one control row. On each occasion, the temperature of a white piece of paper held loosely in the air in a sunlit position was recorded as a reference, at the beginning and end of measurements on the treatment row, and the beginning and end of measurements on the control row, giving four paper readings in total.

Maturity testing of berries was conducted leading up to harvest and yield measured at harvest. A group of adjacent, randomly selected panels were selected for hand harvest with sufficient vines harvested to yield 100 kg fruit. These parcels of fruit were immediately delivered to the Wine Innovation Cluster, Waite Campus, for small lot winemaking. Wines were subject to full chemical and sensory analysis. In 2015-16, the volume and associated cost of the additional water was also calculated in order to generate an estimation of the benefit or cost of undervine sprinklers on vineyard management.

Figure 2. Temperature and relative humidity recording mast located in the Ricca Terra trial site near Barmera, SA.

Results & Discussion

YEAR 1 (2014/15)

RIVERLAND
(TRIAL 1: Oxford Landing, Waikerie and TRIAL 2: Ricca Terra Farms, Barmera)

The temperature masts were not ready for installation until 5th January 2015 and unfortunately missed a heatwave event between the 1st and 3rd January. Uncharacteristically for the Riverland there were no heatwave events between 3rd January and harvest in early February 2015 (Figure 3), during which time the minimum overnight temperatures were below average. Post-harvest there were two days during which the daily maximum exceeded 40 °C and three nights when the overnight minimum was higher than 20 °C with the warmest night at 22.8 °C. The sprinklers were activated on these occasions to test the irrigation controllers and sprinklers and some preliminary data was collected (not presented). No small lot winemaking was conducted for the two Riverland sites.

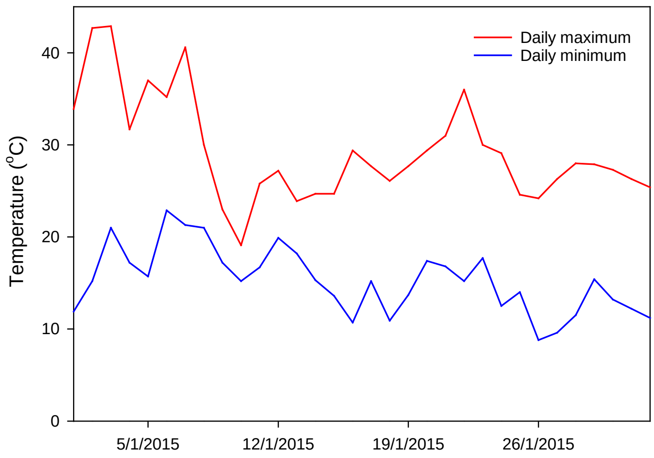


Figure 3. Daily maximum and minimum temperature during January 2015 recorded at the SAMDBNRM automatic weather station located near Barmera in the SA Riverland.

COONAWARRA
(TRIAL 3: O'Dea's Vineyard)

Similar cool conditions were experienced in Coonawarra during January and February 2015 and, with a later harvest, the hot days experienced in February occurred post-veraison during berry development. Nevertheless, the under-and over- canopy sprinklers were activated on three occasions (data not presented) and at harvest fruit was retained for small lot winemaking.

YEAR 2 (2015/16)

Temperature masts were re-installed in the two Riverland sites during October 2015 and Coonawarra in November. Additional relative humidity sensors (Tiny Tag Plus 2 ™) at ground level, within the bunch zone and above the canopy were installed at the Riverland Ricca Terra and Coonawarra sites. Under-canopy sprinkler maintenance ensured the systems were operational by 1st December for the Riverland sites, such that if any heatwave events occurred pre-veraison, the under canopy sprinklers could be activated.

RIVERLAND
(TRIAL 1: Oxford Landing, Waikerie and TRIAL 2: Ricca Terra Farms, Barmera)

The first heatwave event during which the sprinklers were activated occurred just before Christmas 2015 (Figure 4) and there were six subsequent occasions when the sprinklers were activated at both Riverland sites prior to harvest. The same timing and hours of sprinkler operation were kept as similar as operationally possible at both Riverland sites; the dates and details of irrigations are presented in Table 1.

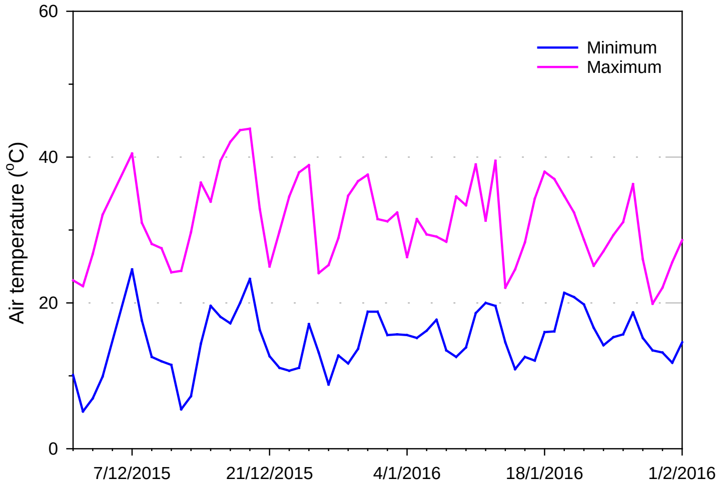


Figure 4. Daily maximum and minimum temperature for December 2015 and January 2016 recorded at the SAMDBNRM automatic weather station located near Barmera in the SA Riverland.

Date	Total Hours	Comments
17/18 December	4	Three cycles
18/19 December	2	Two cycles
24/25 December	2	Four ½ Hr cycles
30/31 December	2	Four ½ Hr cycles
13/14 January	2	Four ½ Hr cycles
14/15 January	2	Four ½ Hr cycles
18/19 January	2	Four ½ Hr cycles

Table 1. Dates and timings of sprinkler operation at the two Riverland sites December 2015 to 31st January 2016 .

Cooling data from the masts at the Ricca Terra site are presented below, as relative humidity sensors were not installed in the Oxford Landing site. During the first heatwave event on 17/18 December, the sprinklers were activated for one or two-hour intervals over three consecutive nights.

Relative humidity (RH) normally increases overnight as air temperature drops, however, activating the sprinklers resulted in a marked rapid increase in RH at ground level with smaller increases at canopy height and only on one occasion above the canopy (Figure 5). Reducing the period of sprinkler activation from two to one hour reduced the duration that RH was elevated.

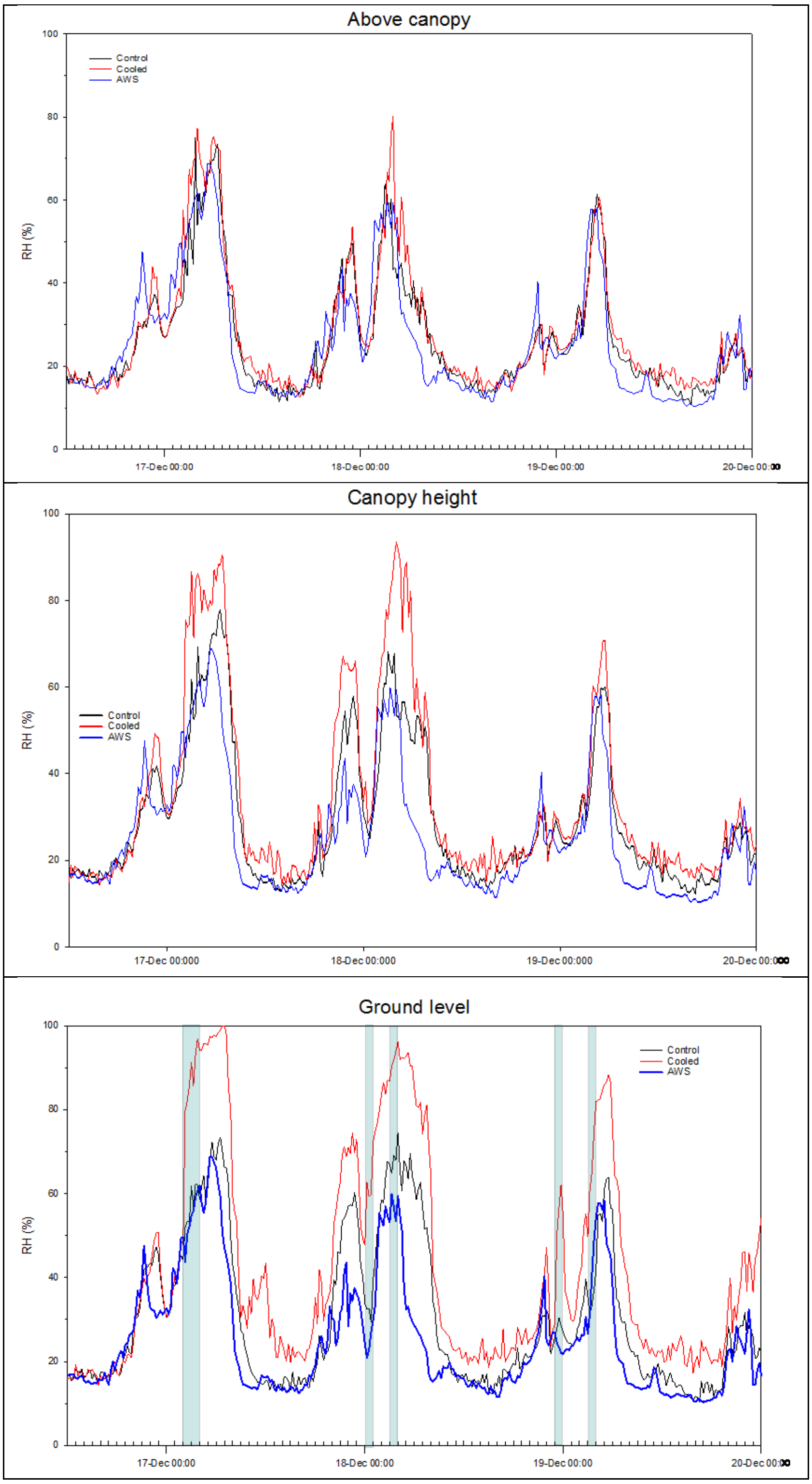


Figure 5. Relative humidity at ground level, canopy height and above canopy between 16th and 20th December in sprinkler and control plots in Ricca Terra vineyard and nearby AWS. Vertical bars in lower figure indicate periods when sprinklers were activated.

Sprinkler irrigation also had an impact on temperature data captured by the same data loggers (Figure 6; Figure 7). However, even at ground level there was only a minor dip in temperature when the sprinklers were activated. Within the canopy there was little impact on temperature and it was undetectable above the canopy.

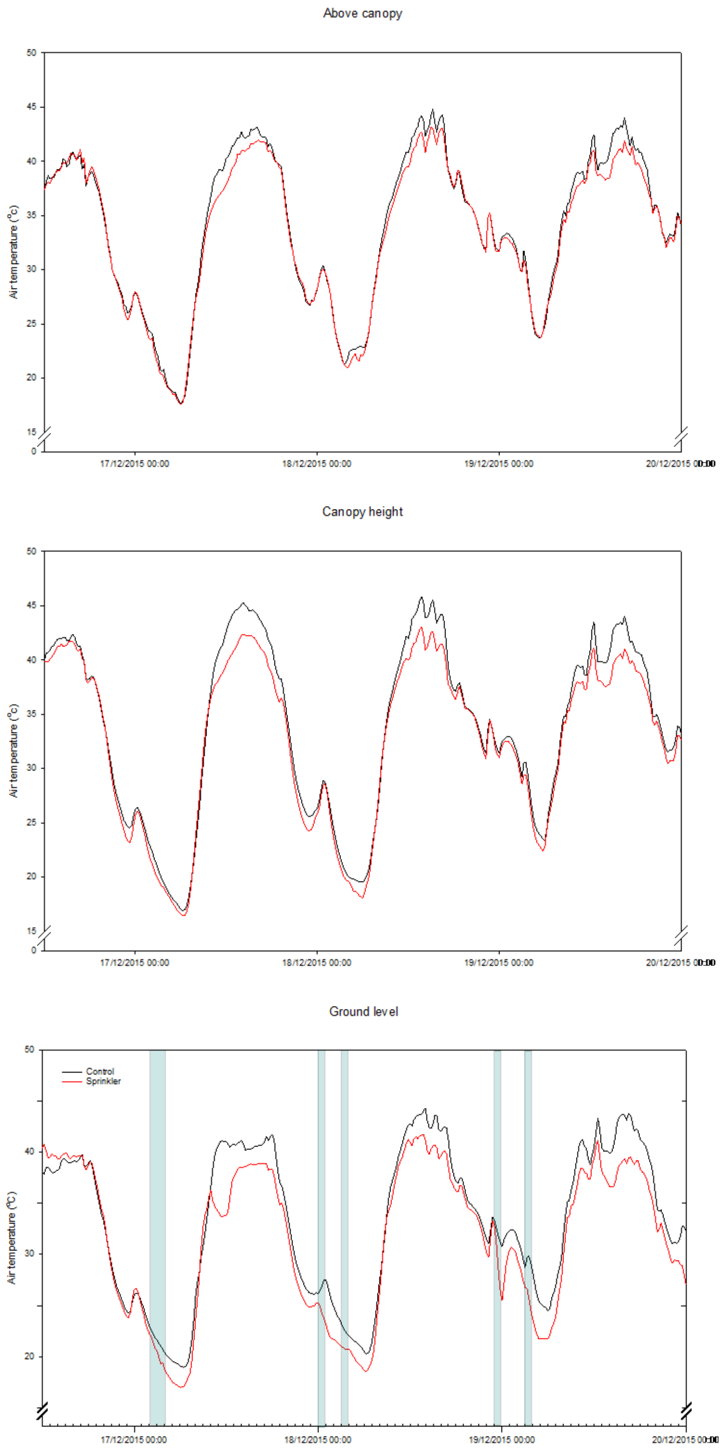


Figure 6. Air temperature at ground level, canopy height and above canopy between 16th and 20th December in sprinkler and control plots in Ricca Terra vineyard. Vertical bars in lower figure indicate periods when sprinklers were activated.

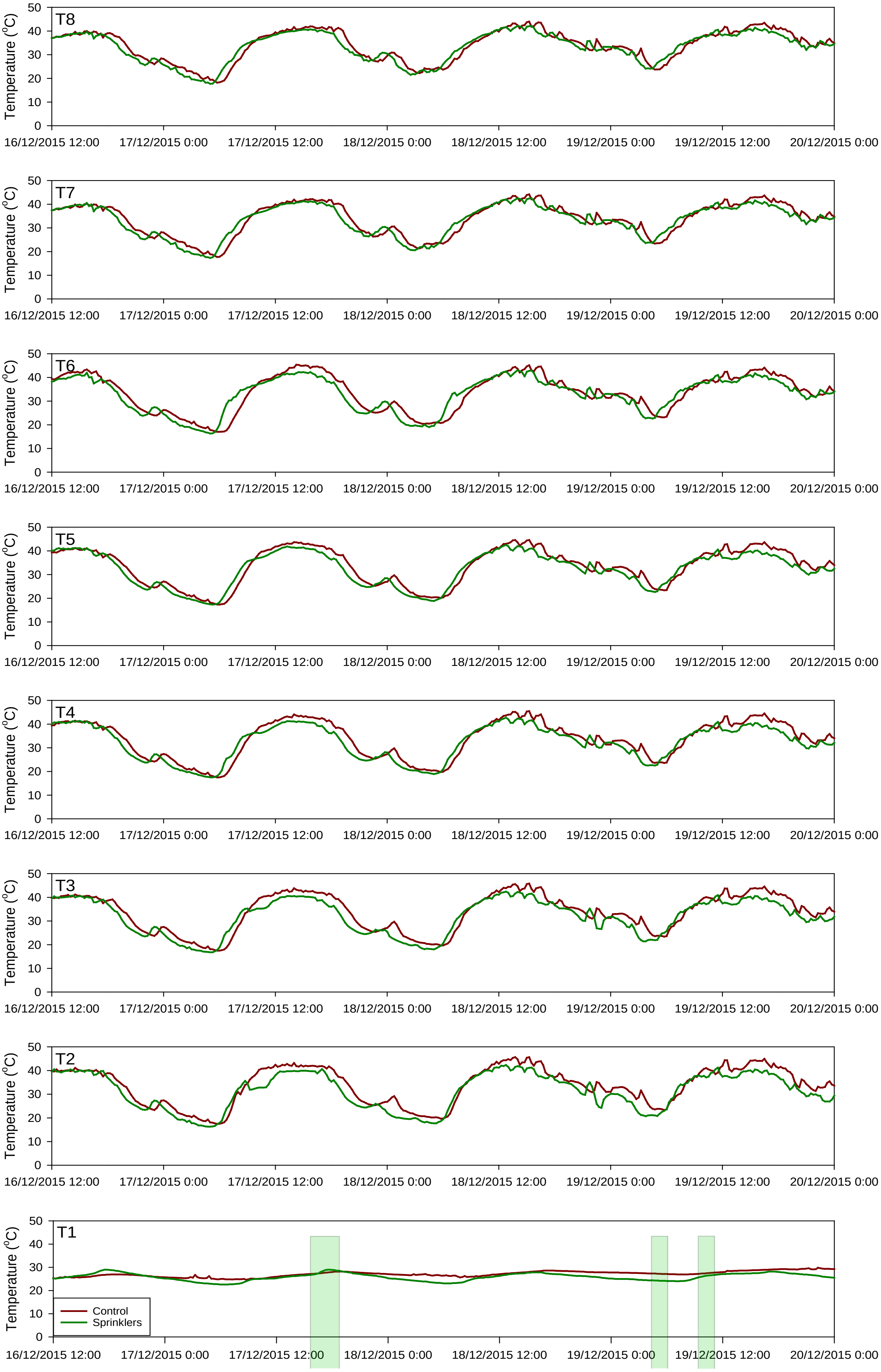


Figure 7. Ground temperature (T1) to above canopy height (T8) during the 17/18 December 2015 heatwave at Ricca Terra. Bars in graph T1 indicate the periods when the sprinklers were activated.

There were only small differences in the readings between the buried thermistors in the control and sprinkler plots and both showed a small diurnal pattern (Figure 7; T1). Soil temperature in the sprinkler plot was often slightly less than the control plot, but these periods did not always correspond to when the sprinklers were running. In hindsight, these thermistors should have been placed further into the mid-row and out of the zone of influence of the emitters, which were spaced to result in a continuous wetted strip along the under-vine area.

T2, T3, and T4 (20, 60 and 100 cm above ground respectively) indicated some response to activating the sprinklers, but the temperature suppression was small and transient (Figure 7). Temperature differences between control and sprinkler were often difficult to quantify because of almost-continuous changes in air temperature caused by slight changes in wind direction recorded at a nearby automatic weather station[1]. Temperature measured by thermistors T5, T6, T7, and T8 (140, 180, 220 and 260 cm above ground level respectively) were often lower in the sprinkler plots than in the control plots. However, they were also slightly lower than the control before the sprinklers were activated, suggesting that the sprinkler plot was inherently marginally cooler than the control plot.

There appeared to an impact on vineyard temperature at ground level and to a lesser extent in the canopy the day after activating the sprinklers, which was sustained through to the next cooling event in late December. This effect was not apparent before the heat event when the sprinkler plot was occasionally hotter than the control plot (Figure 8). This suggests that water in excess of evaporation was applied during nights when sprinklers were activated, which wetted and cooled the soil surface beyond the periods when the sprinklers were operational. The intermittent wetting of the soil surface resulted in weed germination in the sprinkler plots and the resultant ground shading may have also influenced surface soil temperature.

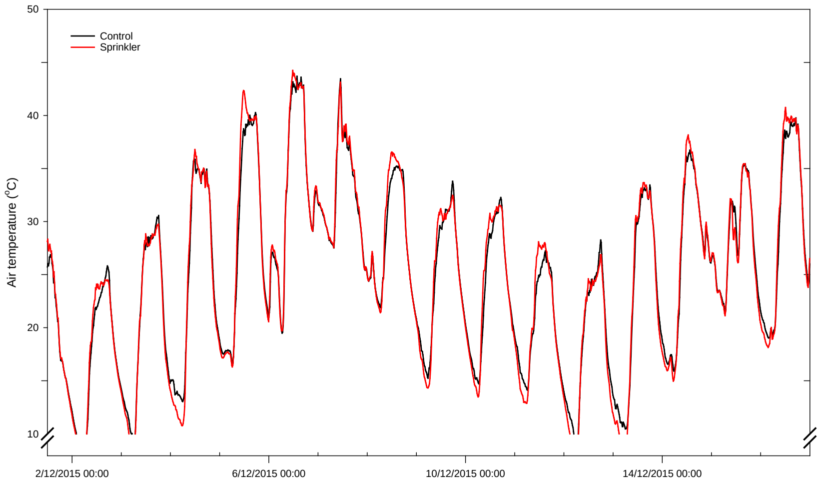


Figure 8. Ground level temperature of control and sprinkler plots from 1st December 2015 to prior to the first activation of sprinklers in Ricca Terra vineyard.

On subsequent occasions the sprinklers were cycled during the night more often while keeping the same total hours of irrigation (Table 1). On each occasion, the first cycle was shortly after sunset, and the last cycle before sunrise, with the other two cycles equally spaced between the first and last cycle. This timing was chosen to give a potential cooling effect for most of the hours of darkness. The sprinklers were activated over the night of 24/25th December and on this occasion the shorter irrigation cycles were less effective in supressing temperature or raising humidity in the sprinkler plot (Figure 9). The relative humidity in the cooled plot was slightly higher than the control prior to the first sprinkler cycle, and increase occurred prior to irrigation. The temperature at ground level in the cooled plot was lower than the control plot and did not change relative to the control after sprinkler activation.

[1] http://aws.naturalresources.sa.gov.au/samurraydarlingbasin/

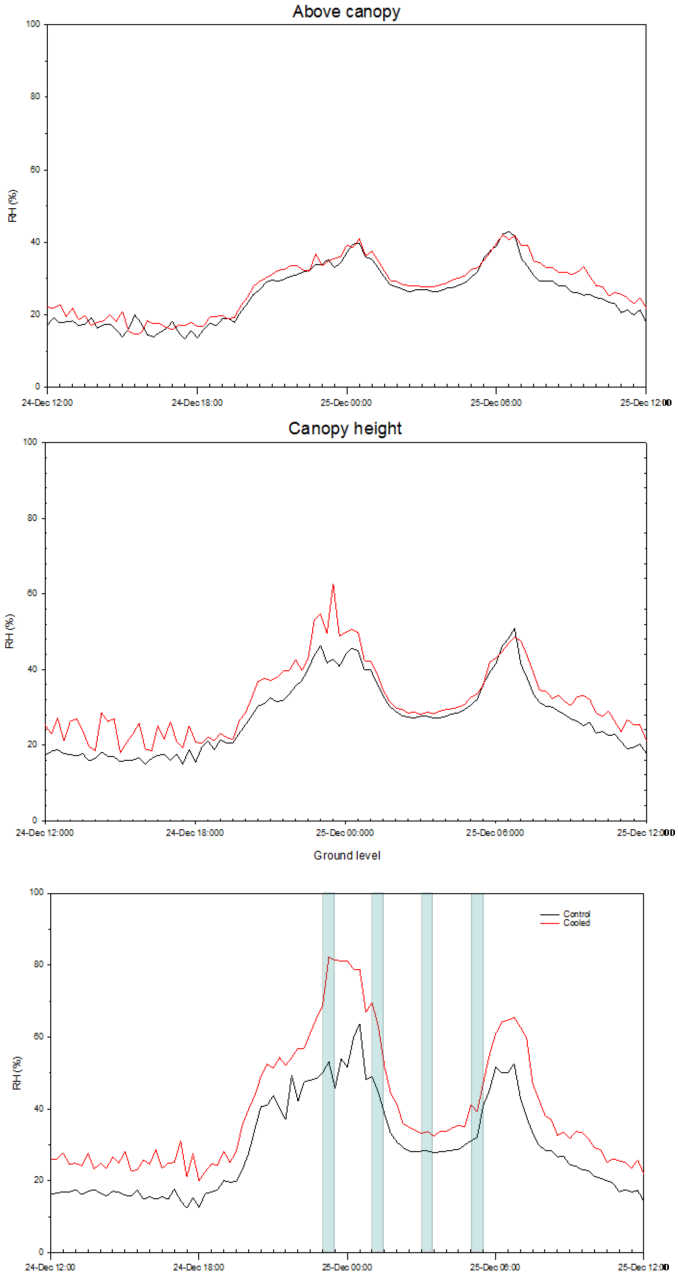


Figure 9. Relative humidity at ground level, canopy height and above canopy during the night of 24/25th December 2015 in sprinkler and control plots in Ricca Terra vineyard. Vertical bars in lower figure indicate periods when sprinklers were activated for 30 minute durations.

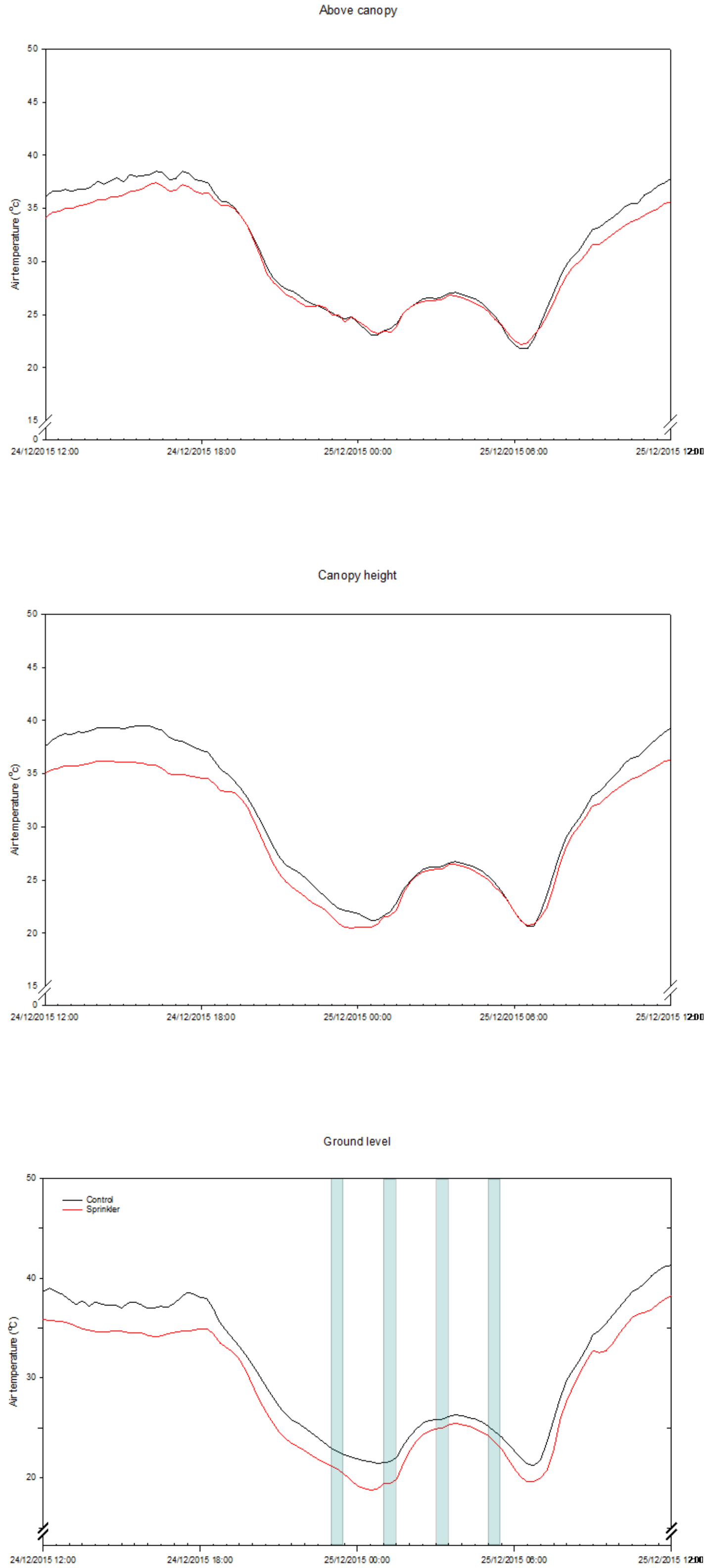


Figure 10. Air temperature at ground level, canopy height and above canopy between 16th and 20th December in sprinkler and control plots in Ricca Terra vineyard. Vertical bars in lower figure indicate periods when sprinklers were activated.

Relative humidity, however, does not truly describe the evaporative demand of the atmosphere, and thus plant water stress, as it is influenced by the atmospheric temperature. Vapour Pressure Deficit (VPD), which is an index of the absolute evaporative demand of the air, was also calculated using the temperature and relative humidity data from the Tiny Tag loggers for the night of 24/25th December 2015. While there was some depression, the VPD in the sprinkler plot was lower before the first sprinkler activation and the shape of the curves for the decline in night-time VPD was similar to those of the control (Figure 11).

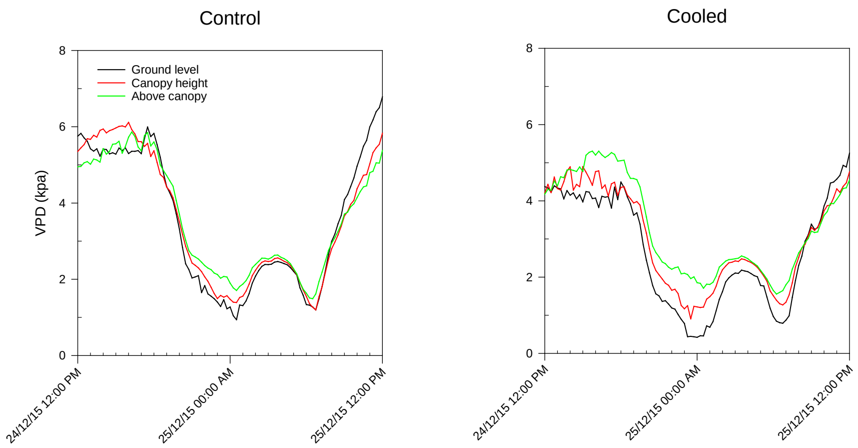


Figure 11. Atmospheric Vapour Pressure Deficit at ground level, canopy height and above canopy for control and sprinkler plots at the Ricca Terra site on the night of 24/25th December 2015

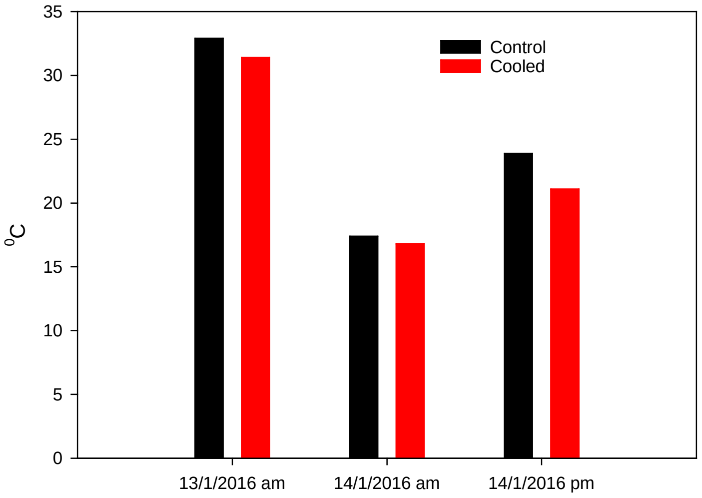
The sprinkler system was activated at the Ricca Terra and Oxford Landing sites on four more occasions between the 25th December 2015 and harvest in February using the same duration and frequency as reported in Table 1. Temperature and humidity responses were similar to those reported above and support findings from the first two cooling events that the under-canopy sprinklers had minimal effect on lowering overnight temperature or increasing humidity in the canopy bunch zone.

Measurement of canopy temperature was carried out at the Ricca Terra site on three occasions during 2015/16 (Table 2).

Date	Time	General Conditions
13/1/2016	09:20 – 10:00	Hot, full sun
14/1/2016	09:20 – 09:45	Cool, full cloud cover, no direct sun
14/1/2016	16:30 – 16:50	Cool, windy, partial cloud cover, sunlight variable

Table 2. Date, time and weather conditions on days of IR canopy temperature measurements.

The 13th & 14th January were days before and after the sprinklers were activated (Table 1). Canopy temperature readings were taken directly in front of the canopy wall (at 90° angle) at a distance of approximately 1.5 m, and targeting an area of approximately 150mm diameter of relatively continuous canopy (i.e. no gaps). For each row, 12 locations were measured in total, six on the north side and six on the south side of the canopy. At each location, two or three readings were taken and an average figure recorded and presented in Figure 12.



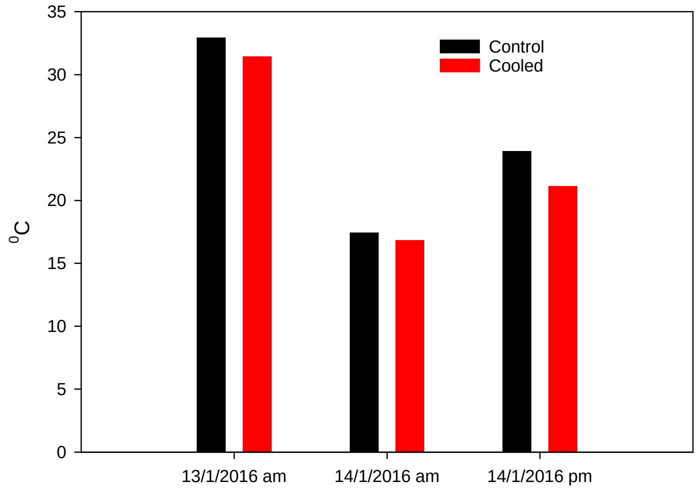


Figure 12. Canopy temperature measure with a hand-held Infrared gun of control and cooled plots at the Ricca Terra site measured on days before and after operation of sprinklers.

The previous cooling event was over the night of the 30th & 31st December (14 days prior) and the average maximum temperature in the intervening period was about 32°C. The 13th January was a hot and sunny day (air temperature and humidity during the recording period was 33.7 °C and 26 % relative humidity) and under these conditions the cooled canopy was a significant 1.5 °C lower than the control (Figure 12). During the morning after activating the sprinklers, the cooled canopy was 0.6 °C lower and by afternoon, 2.8 °C lower. These differences were statistically significant and although only measured on one occasion, indicate both an immediate and long-lasting effect on canopy temperature. Lower leaf temperature is the result of increased evaporative cooling of leaves due to increased stomatal transpiration.

Chardonnay berries were harvested on 27th January 2016 at Oxford Landing and 4th February 2016 at Ricca Terra, as described in Methods. Harvested fruit from cooled plots had visibly less sunburnt or shrivelled berries than control vines and were fresher and greener in appearance (Figure 13). This supports the vineyard appraisal by a grower liaison officer from the wine company contracted to purchase the fruit who, without prior knowledge, described the control plots as having damaged leaves and smaller berries with sour tropical characters compared with cooled plots having good healthy canopies and a good crop with fresh zesty citrus/soft stonefruit characters.

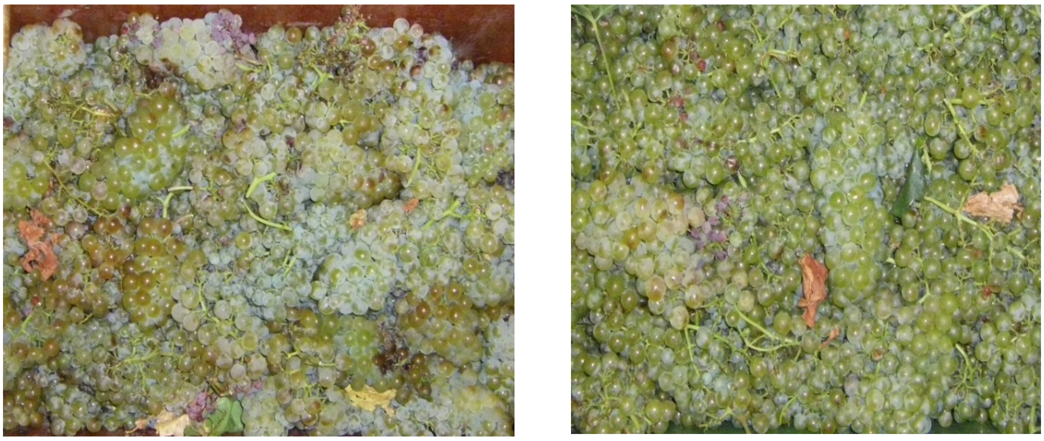


Figure 13. Hand harvested Chardonnay fruit from the Ricca Terra site prior to crushing indicating less sunburn and greener colours for cooled fruit (right) compared with fruit from control vines (left).

Fruit yields (T/ha) were calculated from the measured length of cordon harvested and row spacing. In addition, whole-of-row machine-harvested fruit weight was collected during harvest at Oxford Landing for comparison with hand-harvest data (Table 3).

	Calculated yield (T/ha) from hand harvest (TRIAL 1)	Calculated yield (T/ha) from whole-of-row weights (TRIAL 1)	Calculated yield (T/ha) from hand harvest (TRIAL 2)
Control	35.8	26.03	31.9
Cooled	39.4	31.54	40.8
Improvement in yield	10%	21%	28%

Table 3. Calculated yield/ha of control and cooled plots at Oxford Landing (Trial 1) and Ricca Terra (Trial 2) from whole-of-row machine-harvested fruit weight and hand harvest in 2016.

Significantly, vines that had received the overnight irrigation yielded 21% more fruit than control vines in Trial 1 and 28% more fruit in Trial 2 (Table 3).The whole-of-row weights give a more representative estimate of yield as these are based on a number of 170 m long rows compared with a single section that was hand harvested. Hand harvested fruit included all bunch rachis compared with machine harvest which did not remove all the rachis. The 21% increase in yield reported at Oxford Landing is therefore comparable to the 27% increase in yield at Ricca Terra.

The benefit or cost of additional irrigation water was calculated to determine the net gain or cost of undervine sprinklers for a grower. At Oxford Landing, both control and sprinkler plots received 4.074 Ml/ha between budburst and harvest and the sprinkler plot received an additional 0.88 Ml/ha which resulted in an additional 5.5 T/ha. Based on $300/T for Riverland fruit the additional income/ha was $1653/ha for an additional water cost of approximately $170-265/ha based on $200-$300/Ml for temporary water. At Ricca Terra, an additional 0.54 Ml/ha irrigation yielded 8.9 T/ha fruit. Based on $300/t for Riverland Chardonnay the additional income/ha was $2670/ha for an additional cost of water between $100-150/ha based on $200-$300/Ml for temporary water. For both Riverland sites there may be additional benefit with improvements in wine quality.

Weekly bunch samples were collected from both Riverland sites from early January until harvest for later chemical analysis. At both Riverland sites there were minor differences in the ^{o}Brix and pH of the grape must while other measures were higher in fruit from the sprinkler plots (Table 4).

Trial site		^{0}Brix	pH	TA7[a]	TA8.2[b]	Malic[c]	YAN[d]	AAN[e]	NH3[f]
Ricca Terra	Control	20.4	3.8	3.2	3.5	1.8	200.5	174.0	32.5
	Cooled	20.7	3.8	4.7	5.0	3.7	310.0	265.5	54.0
Oxford Landing	Control	18.8	3.6	3.6	3.7		141.0	103.0	46.5
	Cooled	19.0	3.6	3.9	4.1		198.5	144.0	66.5

Table 3. Grape sample crush data for the two Riverland sites.
[a] Titratable acidity (g/L) at pH7, [b] Titratable acidity (g/L) at pH 8.2, [c] Malic acid (g/L) [d] Yeast available Nitrogen (mg/L), [e] amino acid available Nitrogen (mg/L), [f] Ammonia Nitrogen, (mg/l)

The higher concentration of YAN, AAN & NH3 resulted in more rapid fermentation, with grape must from sprinkler plots completing fermentation 2-3 days earlier than the control ferments with Oxford Landing fruit (Figure 14). This is likely to have resulted in differences in wine sensory and chemical properties however; these data will not be available until early 2017.

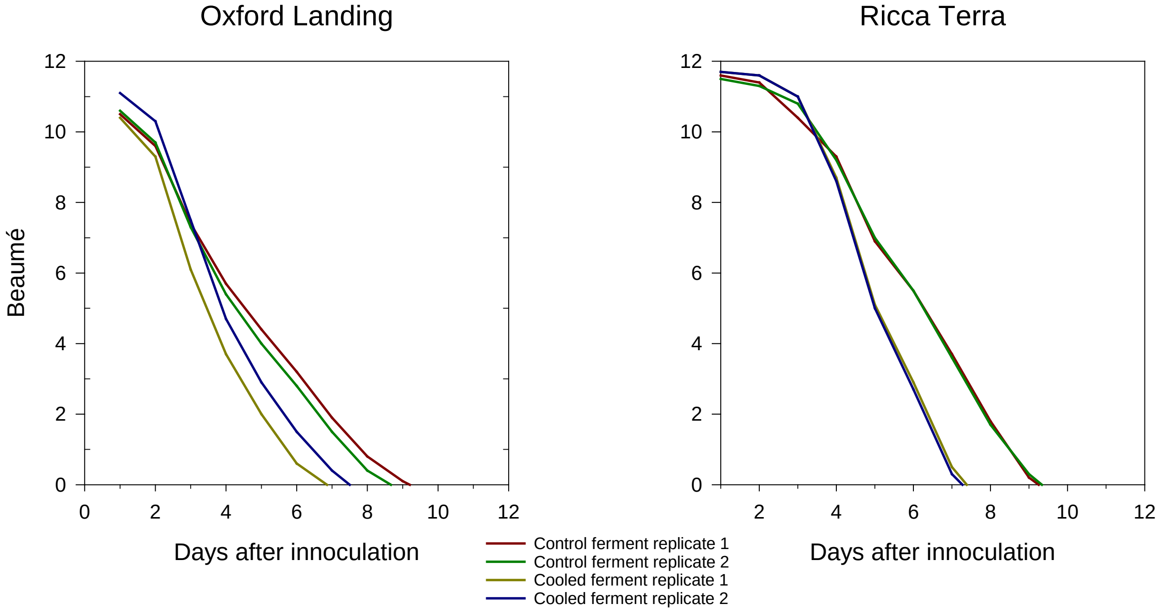


Figure 14. Change in Baume during fermentation of must from Control and Sprinkler plots at the Oxford Landing and Ricca Terra sites**.**

COONAWARRA
(TRIAL 3: O'Dea's Vineyard)

The synoptic conditions that result in heatwaves in the SA Riverland also cause periods of hot weather in Coonawarra, which is approximately 300 km south of the Barmera AWS. Night-time temperatures in Coonawarra are, however, generally lower than the Riverland (Figure 4; Figure 15).

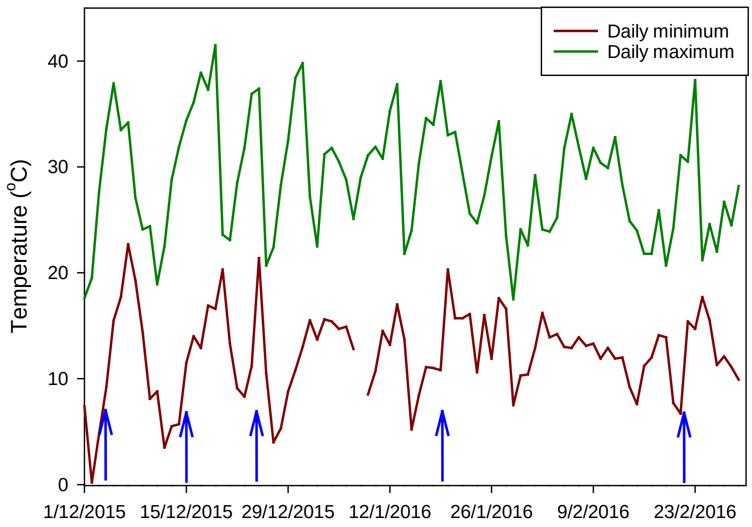


Figure 15. Daily minimum and maximum temperature from 1 December 2015 to 29th February 2016 recorded at Coonawarra BOM AWS station located approximately 1km south of the experimental site. Blue arrows indicate approximate times when sprinklers were activated.

Three experimental treatments were imposed in the O'Dea's vineyard in Coonawarra, namely a control, over-canopy cooling (using the existing frost protection sprinklers) and a block converted from over-canopy to under-canopy by lowering the sprinkler height (see Methods). The two sprinkler plots were manually activated on selected nights. Between early December 2015 and the end of February 2016 (prior to harvest) the sprinklers were activated on five occasions (Table 6). On each occasion, sprinklers were turned on for a single two-hour shift commencing at 8:30 pm. The timing and duration the sprinklers were activated was constrained by irrigation requirement across the remainder of the vineyard. Three of these occasions corresponded to nights the sprinklers were activated at the two Riverland sites.

Date	Total Hours
5-6 December	2
16-20 December	2 (each over four nights)
30-31 December	2
19-20 January	2
23-24January	2

Table 4. Dates and timings of sprinkler operation at the Coonawarra site during December 2015 and January 2016.

Temperature and relative humidity data (from noon on the day the sprinklers were turned on to noon the day after) for each of these cooling events is presented in Figures 16 to 20 below. On each occasion, an immediate change in relative humidity was observed which was more long-lasting than the impact on temperature. The over-canopy sprinklers generally had a greater impact on overnight temperature and relative humidity in the canopy bunch zone, with under-canopy sprinklers having minimal effect, as observed previously.

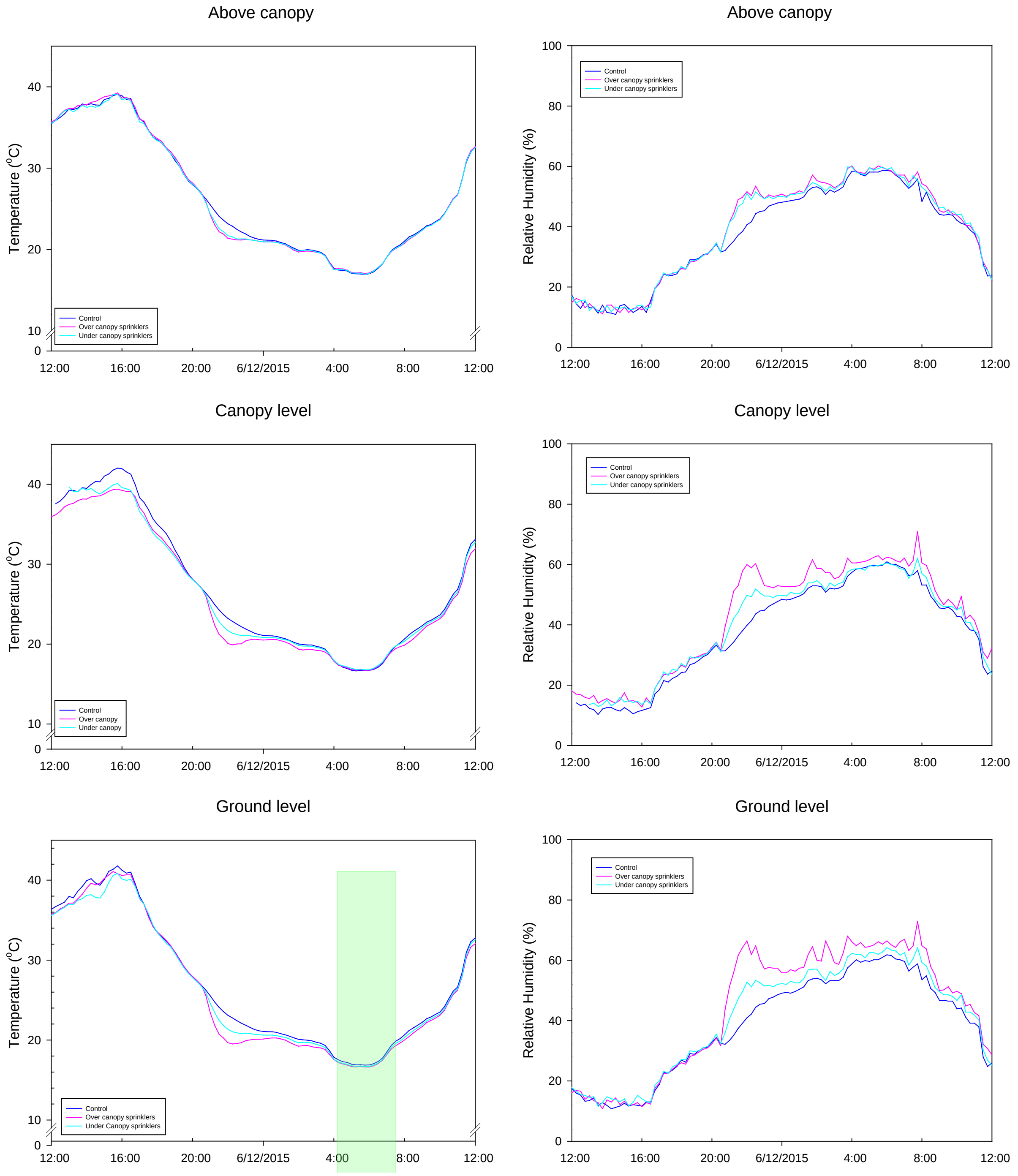


Figure 16. Air temperature and relative humidity at ground level, canopy height and above canopy on the 5th and 6th December 2014 in sprinkler and control plots at the Coonawarra site. Vertical bar in lower figure indicate periods when sprinklers were activated.

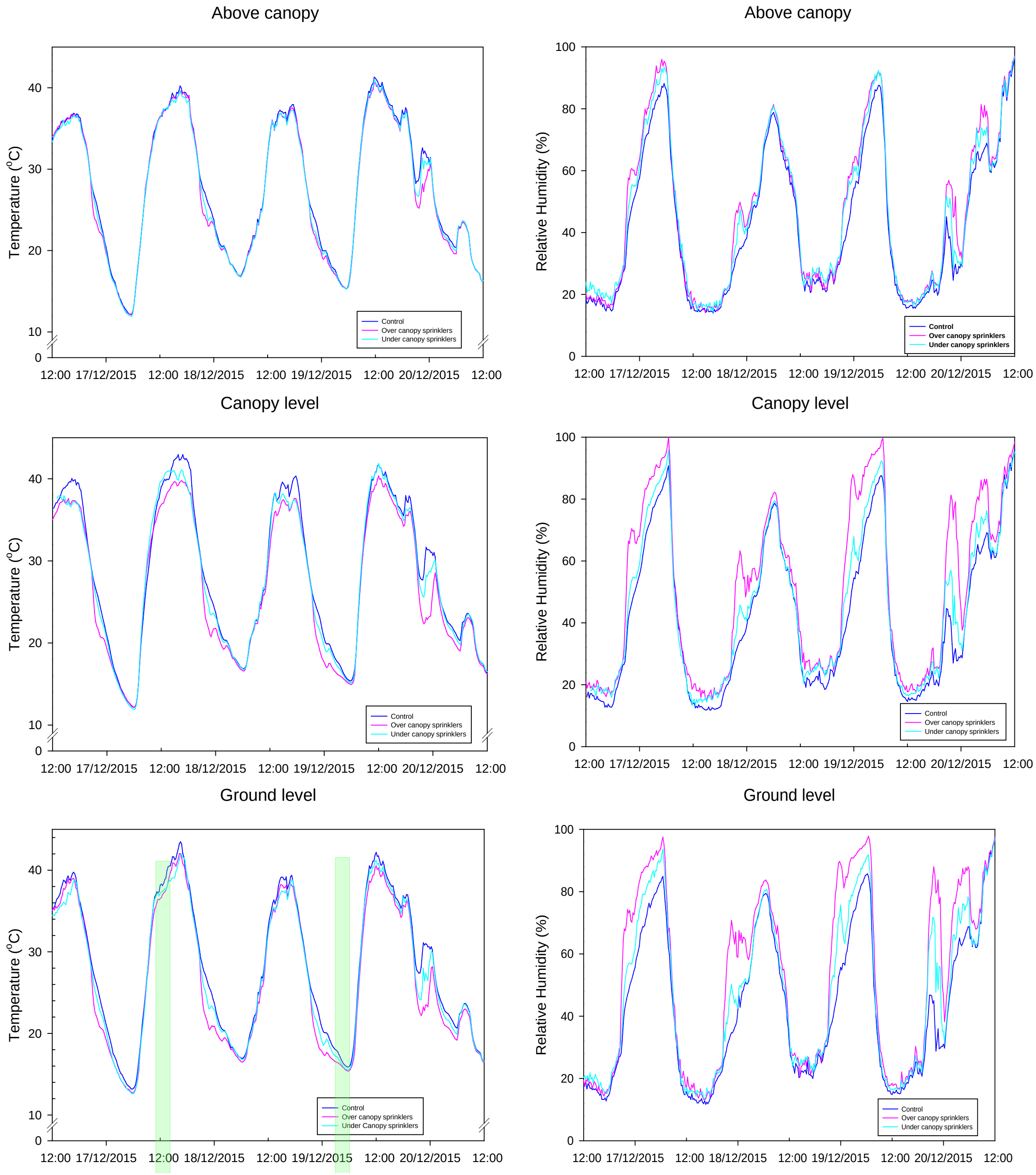


Figure 17. Air temperature and relative humidity at ground level, canopy height and above canopy between the 16th and 20th December 2014 in sprinkler and control plots at the Coonawarra site. Vertical bar in lower figure indicate periods when sprinklers were activated.

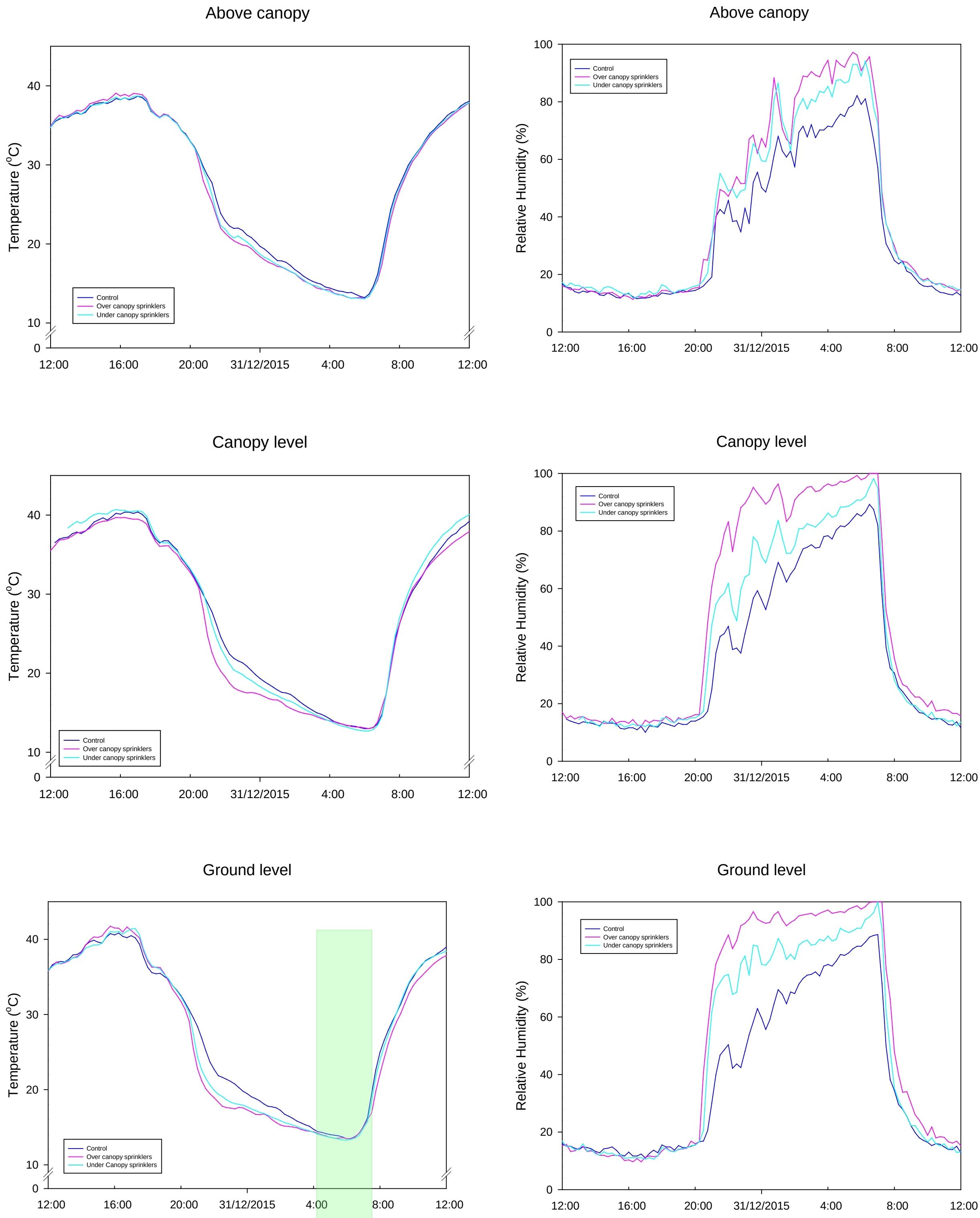


Figure 18. Air temperature and relative humidity at ground level, canopy height and above canopy on the 30th and 31st December 2014 in sprinkler and control plots at the Coonawarra site. Vertical bar in lower figure indicate periods when sprinklers were activated.

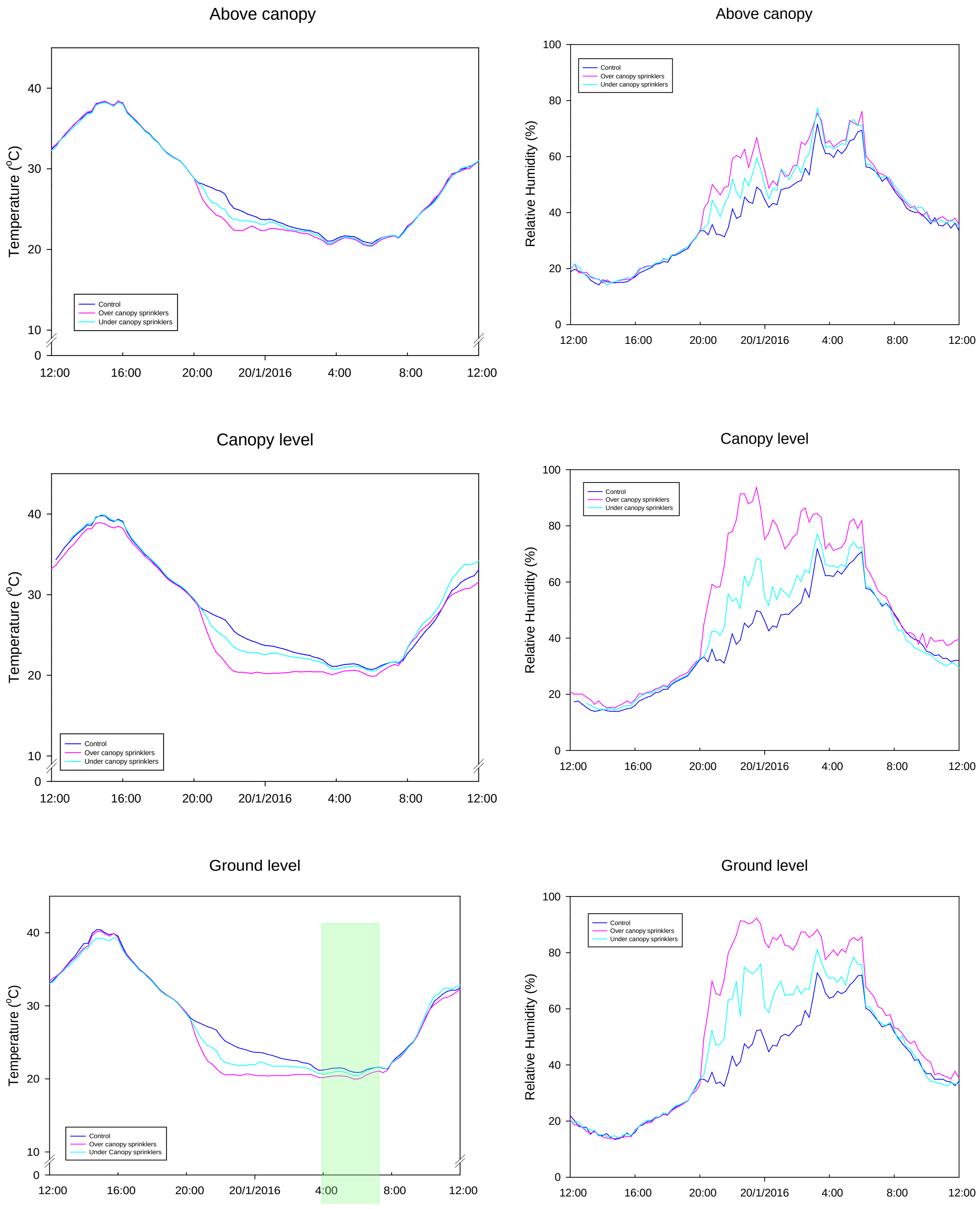


Figure 19. Air temperature and relative humidity at ground level, canopy height and above canopy between the 19th and 20th January 2015 in sprinkler and control plots at the Coonawarra site. Vertical bar in lower figure indicate periods when sprinklers were activated.

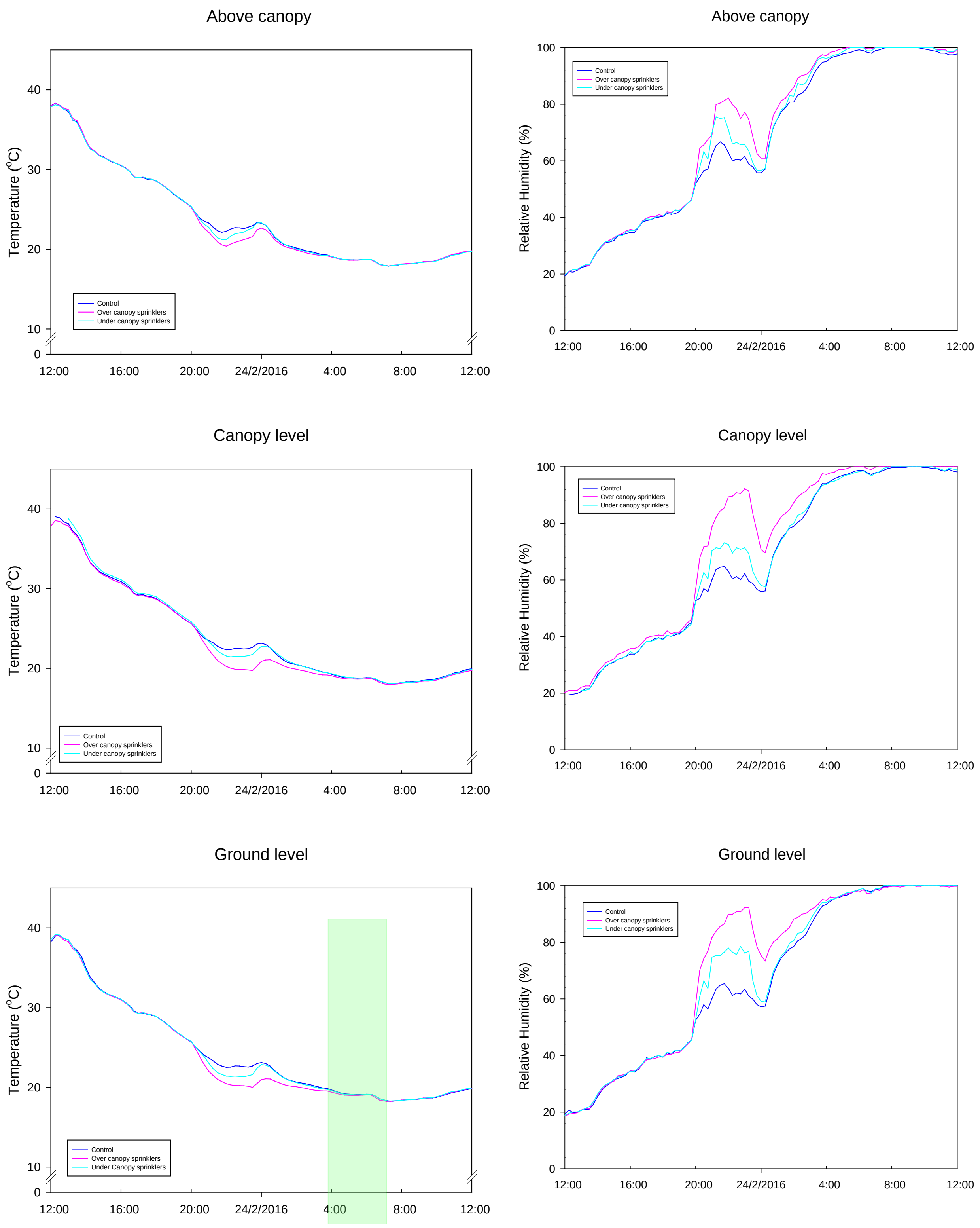


Figure 20. Air temperature and relative humidity at ground level, canopy height and above canopy between the 23rd and 24th January 2015 in sprinkler and control plots at the Coonawarra site. Vertical bar in lower figure indicate periods when sprinklers were activated.

Immediately prior to harvest for small lot winemaking, randomly selected whole bunches from the panels to be harvested were subject to standard measures used by Wynns Coonawarra. With only a single sample per treatment, no statistical analysis is possible. However, control samples had the highest anthocyanin concentration whilst samples from the under-canopy cooled plots had the highest concentrations of tannin and phenolics (Table 7).

Treatment	Anthocyanin (mg/g)	Tannin (mg/g)	Phenolics (AU/berry)
Control	2.04	5.09	1.39
Over-canopy sprinklers	1.66	5.07	1.31
Under-canopy sprinklers	1.68	5.69	1.42

Table 5. Harvest sample analysis of selected berry quality measures of bulked samples collected from each of the three treatments in O'Dea's Coonawarra vineyard in 2015.

In 2016, samples from the over-canopy sprinkler plots had the heaviest berries, higher tannin and phenolic concentration and the lowest anthocyanin concentration compared with the other two treatments (Table 8). These measures will be repeated on wines in early 2017.

Treatment	Av berry wt. (g)	Anthocyanin (mg/g)	Tannin (mg/g)	Phenolics (AU/berry)
Control	0.84	1.84	6.30	1.31
Over canopy sprinklers	0.92	1.77	6.45	1.44
Under canopy sprinklers	0.83	1.86	6.22	1.29

Table 6. Harvest sample analysis of selected berry quality measures of bulked samples collected from each of the three treatments in O'Dea's Coonawarra vineyard in 2016.

Plots were hand harvested on 15th March 2016 using the same procedure used for the two Riverland sites, however four to five times the length of row was required to yield the required 100 kg of Cabernet Sauvignon fruit. In each section of the rows harvested there were vines with unproductive cordons due to Eutypa infection, so the length of unproductive cordon was measured and subtracted from the total length to derive a fruit weight/m cordon and a calculated yield (T/Ha) (Table 9)

Treatment	Kg/m cordon	Calculated T/ha
Control cooling	2.3	8.2
Over-canopy sprinklers	2.1	7.5
Under-canopy sprinklers	1.8	6.4

Table 7. 2016 yield/m cordon and calculated yield/ha from Control and the two sprinkler plots at O'Dea's Coonawarra vineyard

In contrast to results from the Riverland, neither of the cooled plots in the Coonawarra out-yielded the control plots. Differences in yield observed between the three plots is most likely due to spatial variability which, in Coonawarra, is primarily driven by the depth of the Terra Ross topsoil over limestone. This spatial variability is evident in satellite imagery of the block (not shown). Based on yield these results would result in a small negative benefit/cost as a result of the additional pumping cost when sprinklers were activated. Wine sensory assessment, which will be conducted by AWRI in early 2017, will determine any impact on wine "value" and hence benefit/cost.

Small-lot winemaking was carried out for the control and two treatments as per the Riverland trials. Three of the six small lot wines completed fermentation approximately three days earlier than the other three (Figure 21), however, there was no apparent correlation with YAN as was observed with the Riverland ferments (Table 5). Must YAN for the Coonawarra samples ranged from 134 to 174 mg/L and there was no effect of over- or under-canopy sprinklers on YAN. Values were in the range recorded in the Riverland control plots where under-canopy sprinklers resulted in nearly 50% increase in YAN.

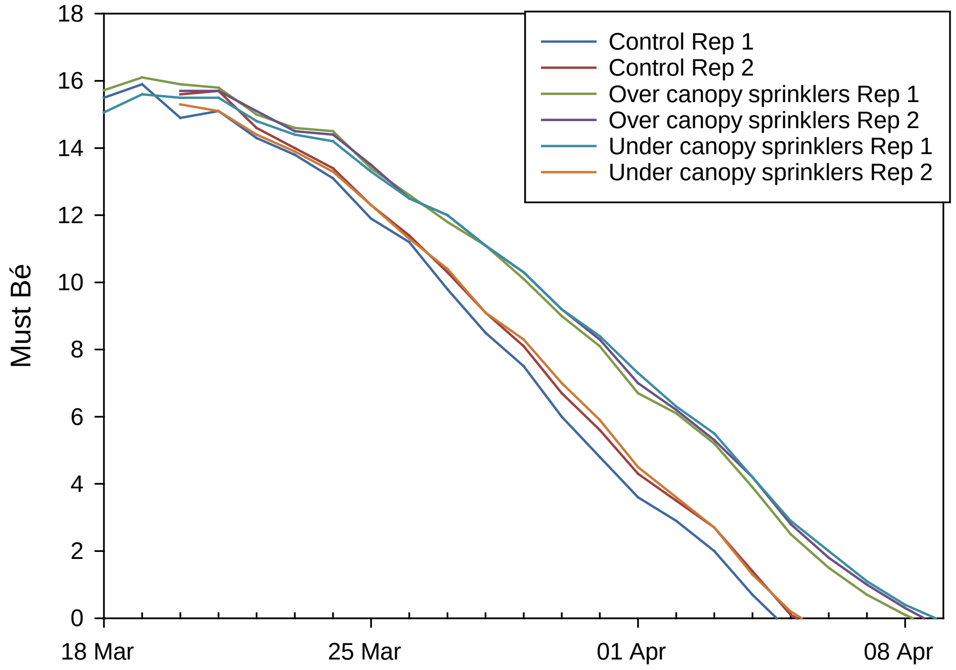


Figure 5. Change in Baume during fermentation of must from control and sprinkler plots at O'Dea's Coonawarra vineyard.

Outcome/Conclusion

During the 2014–15 season, there were only a limited number of extreme heat events which initiated vineyard cooling events. At the Coonawarra site (Trial 3), overhead canopy cooling appeared to result in a greater and more sustained temperature depression than under–canopy cooling. There was a positive increase in canopy humidity which was less transient than the temperature depression. Data from the Ricca Terra site (Trial 2) in the Riverland indicated a minor effect on canopy temperature but a larger positive impact on relative humidity in response to a two–hour irrigation cycle, suggesting that evaporative cooling may have a role in mitigating some of the negative impacts of extreme heat events.

This hypothesis was tested during the second year of the trial, 2015-16, during which several heatwaves resulted in cooling events prior to grape harvest at all three trial sites. Surprisingly, results indicate that the use of under-canopy sprinklers had minimal impact on micro-climate within the critical bunch-zone area. For example, the over-canopy sprinklers at the Coonawarra site lowered canopy temperature by less than 5^0 C, and the temperature had returned to that of the control plots within hours, such that by sunrise the following morning there was no lasting effect. It appears that little benefit will be gained from attempting to model the impacts of evaporative cooling on vineyard microclimate using under-canopy sprinklers.

However, this is at odds with the large increase in yield obtained (or prevention of yield loss) in the two sprinkler blocks in the SA Riverland. Vines which received overnight irrigation yielded up to 28% more fruit than control vines. Furthermore, there was less sunburn damage on fruit from sprinkler blocks, and preliminary wine data indicates significant, potentially positive impacts on quality of Riverland Chardonnay. In addition, the yield increases completely offset the cost of the additional irrigation water, with an additional estimated income for a grower of up to $2600 per hectare. Further value may be added with improvement to wine characteristics, yet to be determined.

Recommendations

Results from three trial sites over two seasons have demonstrated that, contrary to the initial hypothesis, night-time irrigation with sprinklers does not significantly lower vineyard temperature. However, even though bunch zone microclimate was not appreciably altered, we observed a significant improvement in yield, a positive cost/benefit, a reduction in sunburn and early indications of improved wine quality at the two Riverland sites. These effects are unlikely to result from the relatively small additional volume of irrigation water supplied by micro-sprinklers, suggesting that some other unforeseen plant physiological response has occurred.

It was noted that the under-canopy sprinklers were effective in wetting the entire vineyard floor when activated, unlike drip irrigation, which was used to supply most of the vine water requirement and rewetted a smaller soil volume in the immediate vicinity of dripper outlets. It is possible that re-wetting the entire vineyard floor results in a yet to be defined response in vine root physiology which increases plant resilience to hot conditions.

Clearly, further studies are required to investigate the results described here. Of particular interest is the impact of wetting and cooling the entire vineyard floor, and impacts on the physiology of impacted mid-row roots that are normally outside the wetted zone of the drip irrigation system. The preliminary data collected on differences in canopy temperature warrant further investigation, in particular the duration of any cooling effect. These studies should also include other plant physiological and chemical measures. An experiment in which similar volumes of water used by the under-canopy sprinklers are applied by drip only would test whether the responses reported were indeed the result of increased irrigation. Field experiments should continue for a number of seasons to establish the longevity of the responses reported here.

An AGWA-funded project, UA1502, commenced in July 2016 and will utilise two of the existing trial sites and extend over two seasons to investigate the effects of vineyard misting on the mitigation of heatwave effects in grapevines.

Appendix 1: Communication

- McCarthy M (2016) A hot summer perfect for research, AGWA R&D eNews, January 2016 http://research.wineaustralia.com/a-hot-summer-perfect-for-research/
- 16th Australian Wine Industry Technical Conference Workshop presentation July 2016
- McLaren Vale Regional Technical Seminar September 2016
- Treasury Wine Estates internal annual technical seminar November 2016

Appendix 2: Intellectual Property

None identified

Appendix 3: References

Hayman P., Longbottom M., McCarthy M. & Thomas D. (2012). Managing grapevines during heatwaves. GWRDC Factsheet January 2012

Vineyard cooling – A literature review. (2003), Swinburn, G.P. Prepared for the Victorian and Murray Valley Winegrape Growers Council by Scholefield Robinson Mildura. And references contained within.

Appendix 4: Staff

Dr. M McCarthy, Principal Scientist Viticulture SARDI, Project Leader

Mr. Mark Skewes, Research Scientist, Water Resources, Viticulture and Irrigated Crops, SARDI, assisted in data collection and advice on operation of the under-canopy sprinklers at the three sites

Appendix 5: Additional Material

Results of sensory analysis of small lot wines from the 2015 and 2016 harvest will be reported when completed in early 2017.