Mitigating Heat Stress in Vineyards

Sarah Keough, 2020 Scholar
South Australia

May, 2024
Nuffield Australia project number 2012

Supported by

Wine Australia

Scholar contact details

Name: Sarah Keough

Organisation: Bleasdale Vineyards

Address: 5 Stones Lane, Strathalbyn SA 5255

Phone: +614 2878 2225

Email: sarahk@bleasdale.com.au

Website: www.bleasdale.com.au

Social media: Instagram – @sarah.k71

NUFFIELD AUSTRALIA Contact Details

Nuffield Australia
Telephone: 0402 453 299

Email: enquiries@nuffield.com.au

Address: PO Box 495, Kyogle, NSW 2474

Executive Summary

Climate change continues to affect weather patterns across all regions in South Australia. Managing the increasing instances of heatwaves has become challenging, prompting researchers, viticulturists and winemakers to investigate practical strategies to mitigate the increase in frequency and intensity. The focus is to improve vine resilience, maintaining yield while preserving berry quality during these events.

According to the Bureau of Meteorology (BOM), a heatwave is defined as 3 or more days in a row when both the day and night time temperatures are usually high in relation to the local long term climate averages.

The BOM uses the ‘excess heat factor’ (EHF) index to monitor and forecast these events. The EHF combines:

- A comparison of the average temperatures for a 3-day period with what would be considered hot at that location
- The observed temperature at that location over the past 30 days. (www.bom.gov.au)

Recent heatwaves in 2019, 2020, and 2021 led to varying degrees of crop damage, ranging from minor to complete crop failure. Additionally, I have also observed instances of significant berry damage during isolated events with temperatures exceeding 38°C, particularly during the vulnerable stages of flowering and veraison.

There are many ways in which we can reduce the impacts of heatwaves including:

- Irrigation management - maintaining soil moisture levels enabling the vine to transpire (contributing to vineyard cooling), and to regain their turgor overnight (Hayman et al, 2012).
- Evaporative cooling – when water evaporates, it absorbs heat energy from its surroundings, thereby lowering ambient temperature.
- Canopy management – adjusting canopy density, row orientation, and canopy height, can regulate the amount of radiation reaching the bunches, reducing the risk of burn and excessive heat accumulation. Techniques such as leaf removal, trimming, and foliage manipulation applied to optimise canopy microclimates.
- Soil improvements – cover crops and mulches, to reflect solar radiation reducing heat absorption, reduce evaporation and maintain cooler soil temperatures alleviating heat stress on grapevine roots.
- Reflective materials - shade cloth, and sunscreens, reflecting solar radiation at the fruit zone.

This report outlines the techniques and strategies employed to manage heat in the countries visited. Nuffield travel was postponed due to the COVID 19 pandemic, allowing Bleasdale Vineyards the opportunity to adopt some of these findings. The report also details the advantages, and challenges Bleasdale Vineyards encountered implementing some of these practices.

Table of Contents

Table of Figures

Foreword

Upon completing my studies in Animal Production at Roseworthy Agricultural College (RAC) (the final cohort under the RAC banner), I obtained a position in the Roseworthy Plant Breeding Unit. While many of my winemaking peers from RAC journeyed to Coonawarra, South Australia (SA) for their vintage component, it was fellow Nuffield Scholar Liz Riley (1997) who encouraged me to join them. This marked my initiation into viticulture.

Beginning my career as a vineyard hand with 'Southcorp Wines', I set about learning the practical intricacies of vineyard operations. Progressing to the role of a Technical Officer provided me valuable first-hand exposure to various other aspects of viticulture. This included vineyard development, management, frost mitigation, pest and disease management, experimental trials, and my initial encounter with heat-related damage.

I went on to establish and managed a vineyard in Orange, NSW, then returned to my hometown of Strathalbyn, SA in the late '90s to again develop and manage vineyards in Langhorne Creek, SA. Alongside this, I completed a Graduate Certificate in Viticulture (2003) through Adelaide University.

The Millennium Drought in 2001 to 2009, alongside an increase in extreme heat events affecting both grape quality and yields, called for a review of management techniques.

Working with the Langhorne Creek Grape Growers Association our goal was to identify strategies not only to mitigate heat-related damage but also to improve water efficiency, while promoting soil and environmental health.

Responding to my growing concerns, I also pursued this Nuffield Scholarship to delve into these challenges and explore how grape-growing regions around the globe are addressing this issue.

Embarking on my Nuffield journey in 2019, my first destination was Israel, renowned for its exceptional irrigation practices, innovations, and products. Unfortunately, my travel was interrupted by the onset of the COVID 19 pandemic during the Contemporary Scholars Conference (CSC) in March 2020.

To maintain momentum, I ventured to Kangaroo Island in May 2021 to engage with regenerative farmers. Then in 2023, I explored vineyard regions in both New Zealand and America before participating in the Global Focus Programme (GFP). This program included visits to Zimbabwe, the United Kingdom, Spain, and Italy.

Private and Global Focus Travel

Table 1. Travel itinerary

Travel date	Location	Visits/contacts
Week 1 November 14-21 2019 **Week 2-3** November 21-30 2019	**Israel:** Tel Aviv Kibbutz Evron Kibbutz Ami'ad Kibbutz Kfar Haruv Kfar Tavor Kibbutz Magal	WATEC – Water Technology and Environmental Control Bermad Amiad Water Systems ARI Tabor Winery – Michel Akerman SuPlant - Agustin Pimstein Galil Mountains Winery - Ziv Charitt Netafim – Ziv Charitt
Week 4 May 10-15 2021	**Australia:** Kangaroo Island (COVID19)	False Cape Wines – Jamie Helyer Stranraer – Derek Wheaton Jenny Stanton Jamie Heindrick Carley Bussenchutt The Islander Estate – Yale Norris
Week 5-6 June 18-27 2023	**New Zealand:** Blenheim Gisborne	NZ Viticulture Organic Conference Thompson's Horticulture Ltd – Anita Ewart-Croy
Week 7-8 June 27 – July 9 2023	**United States of America:** Napa Valley/Davis University Clarksburg Paso Robles	ASEV Conference – Napa Valley Tom Merwin Vineyards Dusi Wines – Matt Dusi Coastal Vineyard Services – Lucus Pope Tablas Creek – Jordan Lonborg Treasury Wine Estate – (Comatta Hill Vineyards) Simon Graves
Week 9-12 September 23 - Oct-21 2023	**Global Focus Program** Zimbabwe United Kingdom Spain Italy	Highlights Berry Farming (various), Ranching, Chilli production Wold Top (brewing), Grazing systems & environment Agricultural Co-ops, dairy, Olive Farming Winery, truffle, Cheese, Pork and sheep - marketing

Acknowledgments

Thank you to the numerous individuals who have supported and encouraged me throughout this journey. I extend my gratitude to Nuffield Australia, the selection committee, Jodie Redcliffe, Nicola Raymond, Carol Millar, and Annette Votteler for their assistance.

This Scholarship would not have been possible without my sponsor, Wine Australia. Your support has been instrumental in facilitating my pursuit of this important topic.

I am deeply grateful to my employer, Bleasdale Vineyards. Bleasdale not only accommodated my time away but also embraced and implemented several recommendations stemming from this scholarship. The unwavering support from the management team and the board has been exceptional. I would also like to extend my appreciation to Scott Hocking and Shannon George for skillfully managing the vineyard operations during my absence.

Many thanks to the farmers, researchers, and industry leaders for dedicating their time, sharing insights, and the valuable information on this topic.

The GFP was a highlight of this Scholarship. The hosts in each country went above and beyond to ensure our days were enriched with inspiring experiences. Not only did we explore a fascinating variety of agricultural enterprises, our evenings also offered cultural immersion. I extend my thanks to the eight scholars (Figure 1) who joined me on this GFP adventure. From the beginning, it was clear that lifelong friendships were forming.

Finally, I would like to express my heartfelt gratitude to my exceptional family, Keely and Tom. Your support, which made my travels possible, meant everything to me. Your accomplishments serve as constant inspiration and I am profoundly proud of the paths both of you are pursuing.

The Nuffield Scholarship has been a long-held desire of mine. Although COVID 19 pandemic presented some challenges along the way, the overall experience was incredible. My enthusiasm for traveling and gaining insights from diverse agricultural industries and cultures remains steadfast.

Figure 1 - 2023 Zimbabwe GFP Group, Author top row second from right (Source: Author, 2023)

Abbreviations

BOM	Bureau of Meteorology
CA	California
COVID 19	Coronavirus Disease 19
CSC	Contemporary Scholars Conference
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EHF	Excess Heat Factor
GI’s	Geographic Indications
GFP	Global Focus Program
GST	Growing season temperature
GDD	Growing degree days
MJT	Mean January Temperature
PGPR	Plant Growth-Promoting Rhizobacteria
RAC	Roseworthy Agricultural College
SA	South Australia
UNE	University of New England
VSP	Vertical Shoot Position

Objectives

- Identify irrigation tools to reduce the impact of heat throughout the growing season.
- Explore cooling techniques to reduce canopy temperature during heat extremes.
- Could enhancing soil health contribute to vine resilience during periods of extreme heat?
- Other practices to enhance resilience to heat.

1. Introduction

Crop damage from heatwaves is not uncommon. However, in 2014, I was monitoring a vineyard in Langhorne Creek during a heatwave event and the damage that resulted from this event was devastating for this grower. It was a +40°C Day, and I observed what looked like fruit 'boiling' on the vines. There was an aroma of grapes 'stewing' and the berries were turning a pinkish-brown colour. Returning to this vineyard a few days later, it became clear that this heatwave had led to significant fruit loss.

In this instance the vines were going through the growth stage of veraison (Figure 2) which is the transition from berry growth to berry ripening, an important phase when berries undergo changes in colour, texture, and composition as they begin to accumulate sugars and develop flavour.

Figure 2 - Healthy Malbec bunch going through veraison pictured left and bunches affected by heat wave event pictured right (Source: Author)

While veraison marks a critical growth stage for heat damage, the potential for heat damage extends beyond this point. As depicted in Figure 3, the adverse effects of a heatwave on inflorescence pre flowering are evident, yet it's important to note that heatwave events can also affect bunches until harvest.

Figure 3 - Malbec bunch affected by heat at flowering (Source: Author)

Differences in genetic composition, physiological traits, and adaptability result in a varying level of heat resilience among grape varieties.

The first plantings in Langhorne Creek are believed to have occurred in the 1850's when Shiraz was one of the earliest varieties planted followed by Verdelho, Cabernet Sauvignon, Malbec, Merlot and Petit Verdot. These varieties thrive in the region today, although recent heatwaves pose challenges, particularly when they coincide with sensitive growth stages. As an example, Malbec, appears to be extremely vulnerable during veraison.

During vintage 2020 and 2021, Malbec vineyards throughout the region encountered significant decreases in yield as a result of heatwaves. Aiming for 10T/ha, in 2020, Bleasdale's Malbec yields fluctuated from zero to 5.9T/ha, with an average of 2.64T/ha. Likewise, in 2021, yields ranged from zero to 6.08T/ha with an average of 3.07T/ha.

Given these challenges, the question of why persist with this variety arises. The answer is clearcut: Malbec consistently delivers exceptional quality, often receiving trophies, gold medals, and high scores at wine shows across Australia. As I write this report Bleasdale's 2022 Generation Malbec clinched the 'New Holland Agriculture Best Malbec' trophy and the prestigious 'Multi-Color Corporation Wine of Show' at the Langhorne Creek Wine Show, along with the trophy for "Best Red Varietal in Show" at the National Wine Show, Canberra.

The 2022 'State of the Climate' report draws on the latest information from BOM and CSIRO. Observations from this report continue to support the ideology of long-term climate warming. According to the table provided (Figure 4), since official records began in 1910, Australia's climate has seen a temperature increase of approximately 1.47°C.

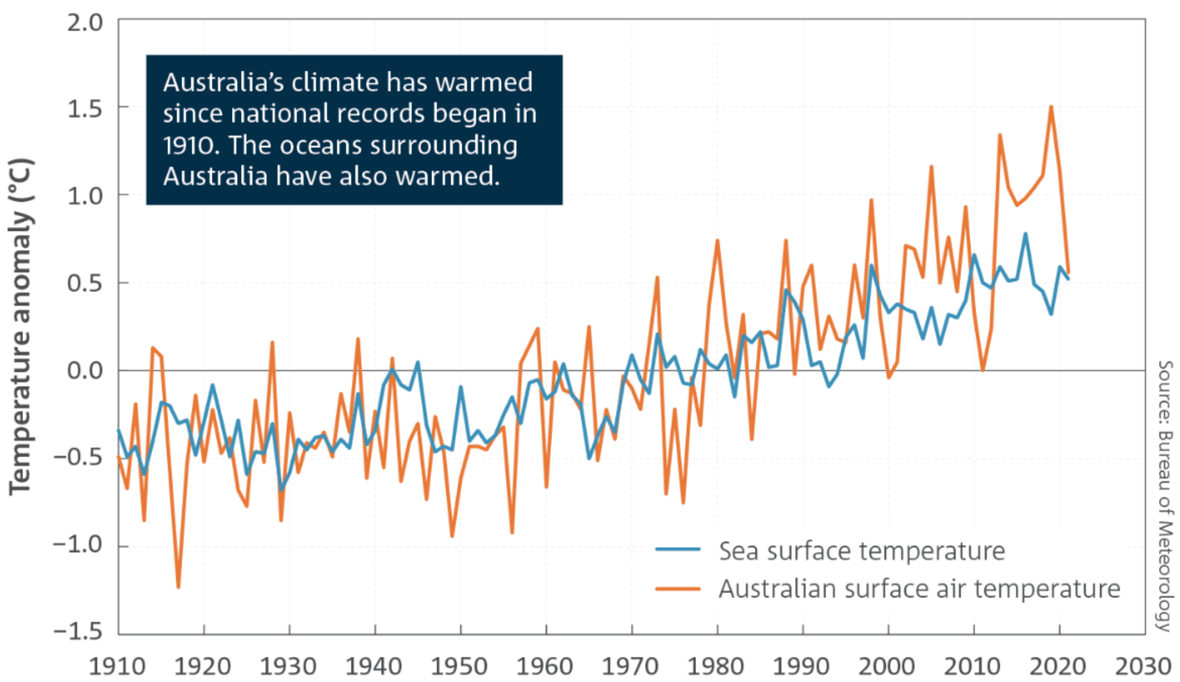

Figure 4 - Anomalies in annual mean sea surface temperature, and temperature over land, in the Australian region. Anomalies are the departures from the 1961–90 standard averaging period. Sea surface temperature values (data source: ERSST v5, www.esrl.noaa.gov/psd/) *are provided for a region around Australia (4–46 °S and 94–174 °E). © Australian Government (National Climate Statement (climatechangeinaustralia.gov.au)) Bureau of Meteorology 2022.*

Wine Australia recently engaged the University of Tasmania to examine the climatic trends affecting the Australian Geographic Indications (GIs) of the wine sectors to 2100.

The 'Australia's Wine Future – A Climate Atlas' provides detailed projections of the potential impacts of climate change on the Australian Wine Industry.

The projected mean potential refers to several aspects including:

- Temperature – growing season temperature (GST) and Growing degree days (GDD) Warmer temperatures can affect many aspects including yield, ripening period, style and quality.
- Rainfall, and evaporative demands – changes in water availability are crucial considerations for vineyard irrigation.
- Heat and cold extremes – essential for developing resilience strategies.

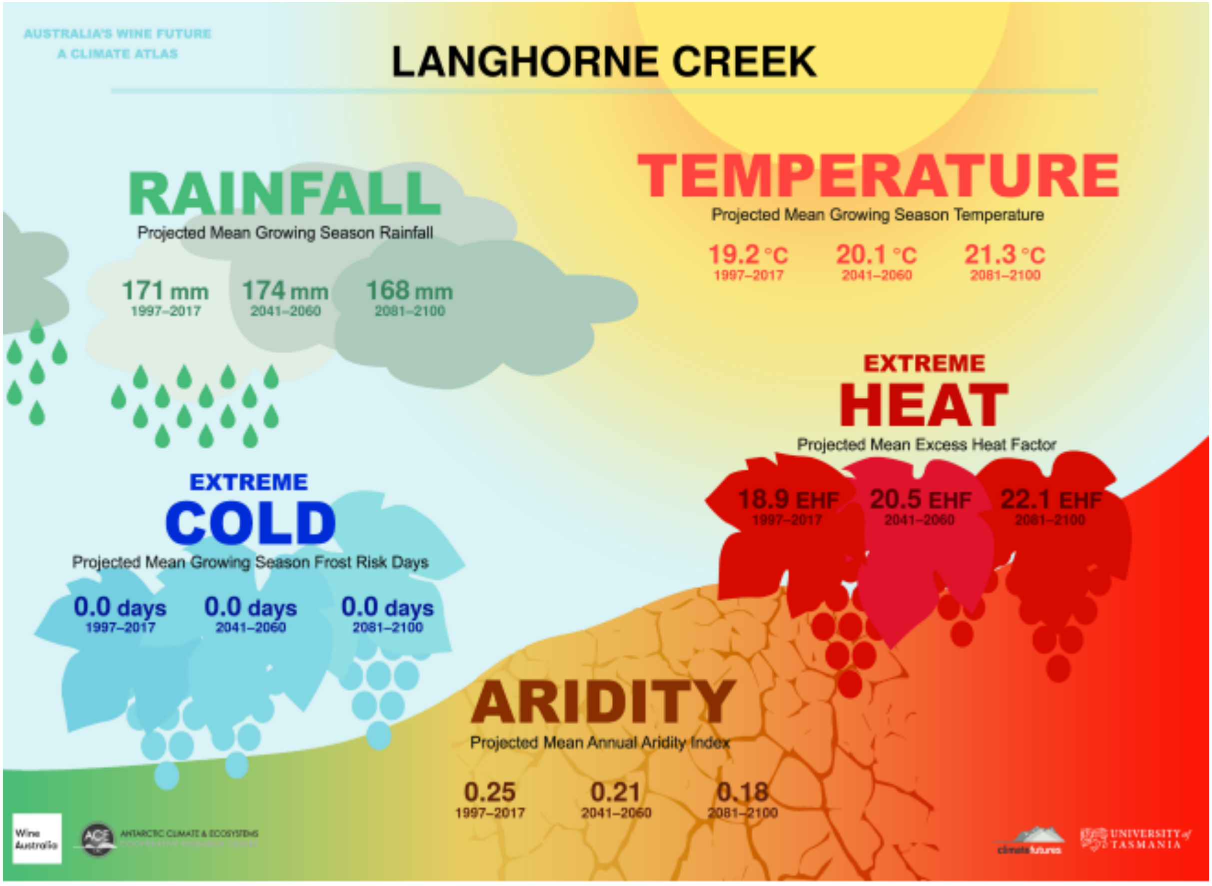

Figure 5 - the predicted Climatic trends for GI region - Langhorne Creek (Source: Wine Australia, Australia's Wine Future – A Climate Atlas, 2019)

Figure 5 indicates the projected Excess Heat Factor (EHF) for GI, Langhorne Creek. EHF, is an index that describes the severity of short term, acute heat impacts on humans during heat waves. It accounts for how hot any three-day period is in relation to an annual temperature threshold at a particular location, as well as how hot the three-day period is with respect to the recent past (the previous 30 days). This reflects the fact that people acclimatise, to a certain extent, to their local climate but may not be prepared for a sudden rise in temperature above that of the recent past. (Wine Australia, Australia's Wine Future – A Climate Atlas, 2019).

Bleasdale's former senior winemaker Paul Hotker, frequently emphasized the key role of Langhorne Creek's geographic advantage. Located in close proximity to Lake Alexandrina and the Great Southern Ocean, the region benefits from maritime influences.

Traditionally, these maritime conditions have been characterized by cool afternoon breezes and cool nights, playing a crucial role in slowing down fruit ripening. The gradual ripening process helps the grapes retain the aromatic characteristics of the varieties.

However, with the escalating frequency and intensity of heatwave events, as indicated by both the Bureau of Meterorology's 'State of the Climate' report and Wine Australia's, 'Australia's Wine Future – A Climate Atlas', there arises a need to address and mitigate the impact of these climatic challenges.

As temperature continues to rise, it becomes imperative for researchers, viticulturists and winemakers alike to explore adaptive strategies and innovative techniques aimed at safeguarding the integrity and sustainability of the regions precious resource.

2. Monitoring tools

During heatwave conditions, it is important for the vine to have optimum soil moisture levels. This ensures the vine has adequate moisture available to effectively transpire, cooling the vine. Sufficient water in reserve enables the vine to recover during the cooler nighttime periods, aiding in their overall resilience to heatwaves.

To support management decisions during these conditions, a range of instruments and technology is available to monitor soil moisture effectively. These tools provide growers with valuable insights into the moisture content of the soil, enabling growers to make informed decisions regarding irrigation practices and management strategies.

Soil moisture monitoring

The following devices are widely used in our industry and have been for many years. However, many growers have yet to adopt soil moisture monitoring devices, so they are still worth a mention. The following instruments are quite easy to use and give valuable information to the grower when scheduling irrigation events. Some of these include:

- Tensiometers – measuring soil moisture tension.
- Neutron Probes – using radioactive material for measuring soil moisture.
- Gypsum Blocks – measuring the electronic resistance between two electrodes.
- Capacitance-based technology – 'Sentek' probes, measuring soil profile continuously.

Sentek Probes

Among the options mentioned, the Sentek probe stands out as the most user friendly and the main device observed during my travels. This device continuously measures soil moisture to a nominated depth, providing growers with precise data on soil saturation levels, drainage, and plant water use.

By monitoring the depth reached during each irrigation or rainfall event, identifying the vine's moisture absorption zones, and assessing the absorption rate in real time, growers can obtain crucial insight. This information enables growers to make informed decisions regarding upcoming irrigation schedules, especially in preparation for a heatwave event.

Ag Tech solutions

Soil moisture monitoring devices have been a fixture in viticulture for many years. The question arises: How can we further enhance the data they provide?

While most companies supply software to complement their products there is a growing demand for comprehensive solutions that incorporate additional parameters relevant to irrigation scheduling.

Ag Tech companies such as Swan Irrigation (Western Australian based Ag Tech group) are stepping in to assist growers with data analysis and interpretation. By incorporating regional weather trends, these companies can predict current and future water requirements, thereby optimizing irrigation practices.

Monitoring soil moisture and weather are two pieces of the complex puzzle involved in scheduling water requirements. Various other factors including, tracking water budget, phenology, quality and yield considerations, vine monitoring, and type of irrigation method must all be considered and integrated into an integrated platform for effective management. (Wright, 2020)

Plant monitoring

Dendrometers

A dendrometer is an instrument used to measure the diameter or circumference of, in this case, a vine's trunk (Figure 6). It can also be used to measure shoots and fruit size.

During the day as the vine releases moisture through transpiration, it absorbs moisture and nutrients from the soil. When transpiration exceeds the rate of moisture and nutrient uptake, the trunk or shoot contracts. As the sun sets, transpiration ceases, the plant continues to absorb nutrients and water leading to trunk expansion.

Figure 6 illustrates a dendrometer placed on a vine trunk. As the trunk expands or contracts it detects and records these slight movements in real time.

Figure 6 – Dendrometer location on vine pictured left, and three Dendrometers alongside a soil moisture monitoring probe in Bleasdale Vineyards pictured right (Source: Author, 2021)

So given this information, how does a dendrometer assist growers make informed decisions regarding irrigation prior to a heatwave event?

As the vine experiences water stress, its trunk typically contracts. By continuously monitoring these changes, growers can detect early signs of water stress and adjust irrigation schedules accordingly. Additionally, dendrometer data can provide information about the rate of uptake and the effectiveness of an irrigation.

The COVID 19 pandemic presented an opportunity for Bleasdale to experiment with dendrometers following my visit to Israel. Dendrometers were installed in two locations, a Shiraz and a Malbec block. We strategically placed three dendrometers on vines alongside soil monitoring probes. These probes measured soil moisture levels, while the dendrometers observed and recorded the vine's response to irrigations and environmental conditions throughout the growing season.

The accompanying software provided by Phytech offered an easy reckoner colour coded system indicating water stress levels (as shown in Figure 7 and 8). This ready reckoner enables growers to quickly identify which blocks require irrigation. This information is available via a mobile app and a web base platform.

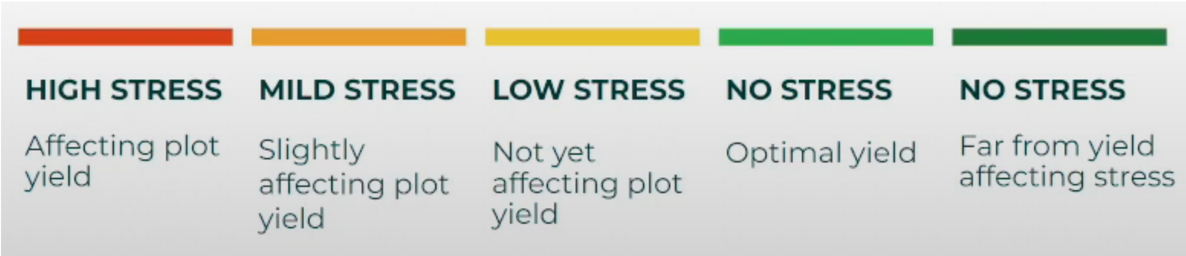

Figure 7 - Phytech automatically transforms data into stress alerts (Phytech, Youtube).

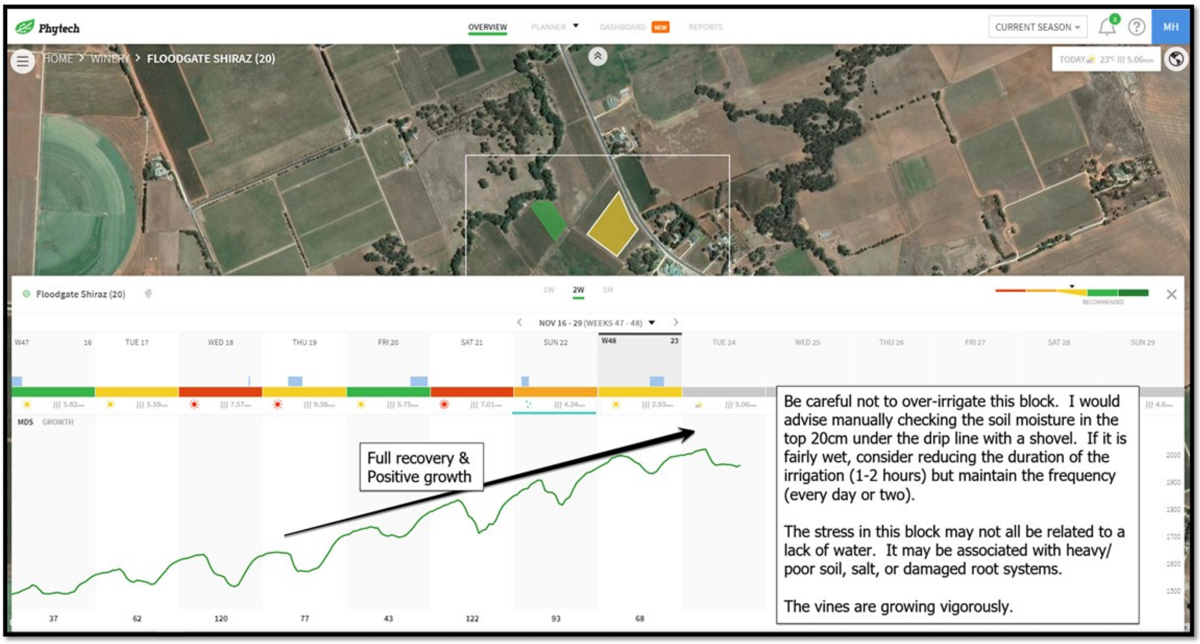

Figure 8 - Bleasdale dendrometer sites, green block is malbec and yellow block is shiraz. The table associated is shiraz during November a period of vegetative growth, prior to flowering (Source: Heyward, 2020)

With the introduction of every new tool, ground truthing data is crucial.

From the beginning of the growing season, the dendrometers indicated a healthy growth curve, which aligned with our field observations. However, as the season progressed, as illustrated in Figure 8, we encountered a discrepancy. Despite healthy vine growth, the program indicated low to high stress levels (likely due to high temperatures). Soil moisture probes indicated good soil moisture, and our field observation supported the theory of healthy growth. This led us to disregard the stress advice provided by the program.

Post flowering and berry set, some wine grape growers apply a practice of reduce deficit irrigation (RDI) to slow or cease vegetative growth, redirecting the vines resources towards the developing bunches. Despite this intentional reduction in water supply to reduce vegetative growth, the irrigation program continued to recommend we grow a 'healthy vine' and as a result we were once again issued 'High Stress' warnings. Given there was no heatwave on the horizon we chose to disregard this information, as it conflicted with our management strategy at this critical stage of growth.

However, with a heatwave imminent, this practice may have been called into question and a top up irrigation would have been applied to ensure vine health.

The program developed in this situation has been tailored for table grapes and almonds, where continuous growth is favorable. Some adjustments to the program to suit wine grape growing parameters would be beneficial, making this another valuable tool ensuring vine health.

Benefits of dendrometers include:

- Accuracy – accurate measurement of plant growth and accurately track changes.
- Real-time monitoring – enabling growers to make timely decisions regarding irrigation, canopy management and other cultural practices.
- Early Stress Detection – detecting early signs of stress by monitoring vine growth, assisting growers mitigate potential damage.
- Potentially Improve Fruit Quality – optimising vine growth and vigour through precise irrigation management.

Some disadvantages include:

- Complexity – interpreting the data required a certain level of expertise to translate it into actionable management decisions.
- Maintenance – some maintenance required including calibration, adding to labour cost.
- Environmental factors – external factors such as temperature, wind and, as we found, rain events can impact dendrometer measurements. Rain swelling the bark giving a false reading.
- Cost – can be expensive, potentially limiting adoption.

Sap flow sensor

Sap flow sensors measure the movement of sap within the xylem tissue of plants. Mark Heyward from Phytech Australia, explained that sap flow is calculated by measuring the temperature differential between a heated probe and a reference probe (Heyward, 2024). Again, these devices can be particularly beneficial for growers during heatwave events as they provide real time data on current requirements and how they respond to extreme temperatures. Once again assisting growers develop informed irrigation strategies to maintain plant health.

Barack from Tabor Winery located in the Lower Galilee region of Israel collaborated with ‘SupPlant’, an Agri-tech company, Israel, using sap flow sensors (Figure 9).

Traditionally, they were applying less frequent long irrigations, however, after introducing the sap flow meters, their irrigation strategy changed. The program directed Barack to apply shallow irrigations more frequently. The active rootzone is only 30cm so a maximum irrigation depth of 30cm was advised. As a result, internode lengths became more consistent, and vine health improved.

Despite also encountering heat related challenges during the 2019 vintage, Barack found these regular, shorter irrigation intervals not only conserved water but were sufficient for vine health during these events.

Figure 9 - Israel, Tabor’s Vineyard Agronomist, Barak with their sap flow meter pictured left, and right is the view from the vineyard looking North to the Sea of Galilee (Source: Author, 2019)

At the Gaili Mountain Winery, located 70km North of Tabor vineyards, irrigation requirements were assessed by sap flow sensors supplied by the Ag-tech company ‘Saturas’.

With a slightly different soil composition to Tabor’s, characterized by deeper soils with greater water holding capacity, they opted for less frequent but deeper irrigations. This approach was tailored to the vineyard’s specific soil conditions to ensure optimal water availability throughout the growing season.

Interestingly, in anticipation of a heatwave, additional water was applied if growth rates were less than 2cm per day, during the vegetative phase. This practice ensured vines were not under any stress during those events, safeguarding vine health (Vestrich et al., 2019).

Benefits of sap flow sensors include:

- Accuracy – accurate information about the rate at which water is being transported through the vine.
- Real-time monitoring – enabling growers to detect water stress early, allowing for timely irrigation adjustments.
- Early stress detection – detecting early signs of stress by monitoring vine growth assisting growers mitigate potential damage.
- Potentially improve fruit quantity, quality and vine health – optimising vine growth and vigour through precise irrigation management.
- Water saving – potentially avoid over watering, reduce the amount of water used. (Saturas-ag)

Some disadvantages include:

- Complexity – interpreting the data required a certain level of expertise to translate it into actionable management decisions.
- Maintenance – some maintenance required including calibration, adding to labour cost.
  Environmental factors – external factors such as temperature, humidity, and solar radiation can influence sap flow measurements. (Heyward, 2024).
- Cost – can be expensive potentially limiting adoption.

Pressure Chamber

Pressure Chambers similar to the picture displayed in Figure 10 have been used by scientific researchers and industry bodies for decades and is said to be the gold standard for measuring leaf or stem water potential.

Figure 10 - Netafim uses a pressure chamber to measure stem water potential in their company vineyards, 2019 (Source: Author, 2019)

Ziv Charitt, an Agronomist at Netafim in Israel, alongside Doris, Netafim's Vineyard Manager pictured in Figure 11, guided me through Netafim's corporate vineyards situated in Kabbutz Yiftach, Northern Israel. During the visit, they shared their expertise on vineyard practices tailored to their unique conditions.

Figure 11 - Ziv, pictured left and Dorris pictured right in front of their Shiraz vines, although post-harvest internode spacing and good size rachis demonstrated balanced vines (Source: Author, 2019)

Doris used the Pressure Chamber (depicted in Figure 10) to measuring the stem water potential of petioles every afternoon. This daily monitoring allowed Doris to gather crucial data on vine water status. With this information, Doris could strategically prioritise blocks within the vineyard and calculate the precise amount of water required.

Benefits of the pressure chamber include:

- Accuracy – accurate measurement of plant water status at that point in time
- Sensitive – can detect subtle changes in water potential enabling Doris to reduce water stress before visible symptoms become apparent
- Portable – although the chamber was located in one place in this vineyard, it is portable and therefore can be utilised in multiple sites.

Some disadvantages include:

- Time consuming – collection of petioles would be time consuming over a large area.
- Skilled operator – requires training and expertise to ensure accurate measurement.
- Localised indication – only supplies localised information regarding the sampled plant which may not be representative of the entire plant let alone the entire vineyard.
- Cost – can be expensive to purchase, and maintain let alone the time taken to sample and process
- Spot in time reference only – information taken at a point in time, not continuous.

Monitoring vine requirements using a Pressure Chamber would be highly labour intensive and unsuitable for our vineyard, which consists of forty-eight valves. This method would demand significant manpower and resources that would not align with our operation.

SupPlant's trial area displaying and comparing many sensors on the market

Figure 12 - SupPlant trial site at Kfar Yoshuah, Israel, numerous sensors and soil moisture monitoring instruments were strategically positioned both on and around this citrus tree. This design aided SupPlant in experimenting and enhancing their devices. (Source: Author, 2019)

3. Artificial Cooling

Misters/Overhead sprinklers

To address fruit damage caused by high temperatures during the 2013-2014 growing season. The Langhorne Creek Grape Growers Association in 2016 conducted a trial of under vine misters in a Malbec block at Bleasdale Vineyards. Their rationale was that by lowering temperature and increasing the relative humidity through evaporative cooling it may reduce the occurrence of fruit 'boiling' or 'shrivelling' observed during heatwaves.

Figure 13 - Undervine misters in Bleasdale's Malbec vineyard (Source: Author, 2021).

The misters would be activated once the temperature reached 35°C and remained on until the temperature fell below this threshold.

Thankfully, the region did not experience any extreme heat events during the 2-year trial. Nevertheless, since this trial concluded, the misters have been used on numerous occasions with a positive result. This observation is supported by the trial conducted by Pagay et al. (2018) where it was concluded that misting improved canopy microclimate and at least initially was effective in maintaining canopy temperature around 35°C. Leaf and bunch temperatures were also lowered by 3-12°C.

The flow required to operate the misters in this Malbec block comes close to matching Bleasdale's full flow rate. Consequently, once the misters are activated, no additional irrigation can be applied to other blocks.

Yet another grower in Langhorne Creek, B Wyatt, (pictured below), installed overhead ‘Wobble T’ sprinklers on his Malbec vineyard with great success. However with an output of 180l/hr, this once again was not a solution for our vineyards.

Figure 14 – pictured left, B Wyatt standing next to his Malbec block Langhorne Creek, and right, a Wobble T sprinkler installed in his vineyard. (Source: Author, 2021).

Figure 15 – pictured left, close up of healthy malbec within the circumference of the sprinkler, and right a vine, just outside the circumference where there was no overlap – berries affected by heat. (Source: Author, 2021).

Given cooling is so successful in mitigating heat, how can we reduce the flowrate required so we can expand this treatment to other vulnerable blocks?

While visiting the Netafim headquarters in Kibbutz Magal, Israel, they showcased various low output sprinklers. Regrettably, photography wasn’t permitted in the Netafim trial areas in 2019. However, these sprinklers are now available in Australia, and information can be found on their website.

A few sprinklers of interest include:

Mist Net™: Specially designed for under-canopy cooling, at relatively low pressure (15,25l/hr).

Gyronet™: Irrigation, Frost mitigation and tree cooling (10 different flow rates ranging from 27-300l/hr).

PulsarTM: Cooling and humidification of tree areas (8l/hr).

Upon returning from Israel, and with guidance from our irrigation expert and installer, Marc Brehin, SOS irrigation, we installed a sprinkler system using Nelson R10 Rotator sprinkler heads. Each sprinkler covers three rows with a slight overlap as depicted in Figure 16 below.

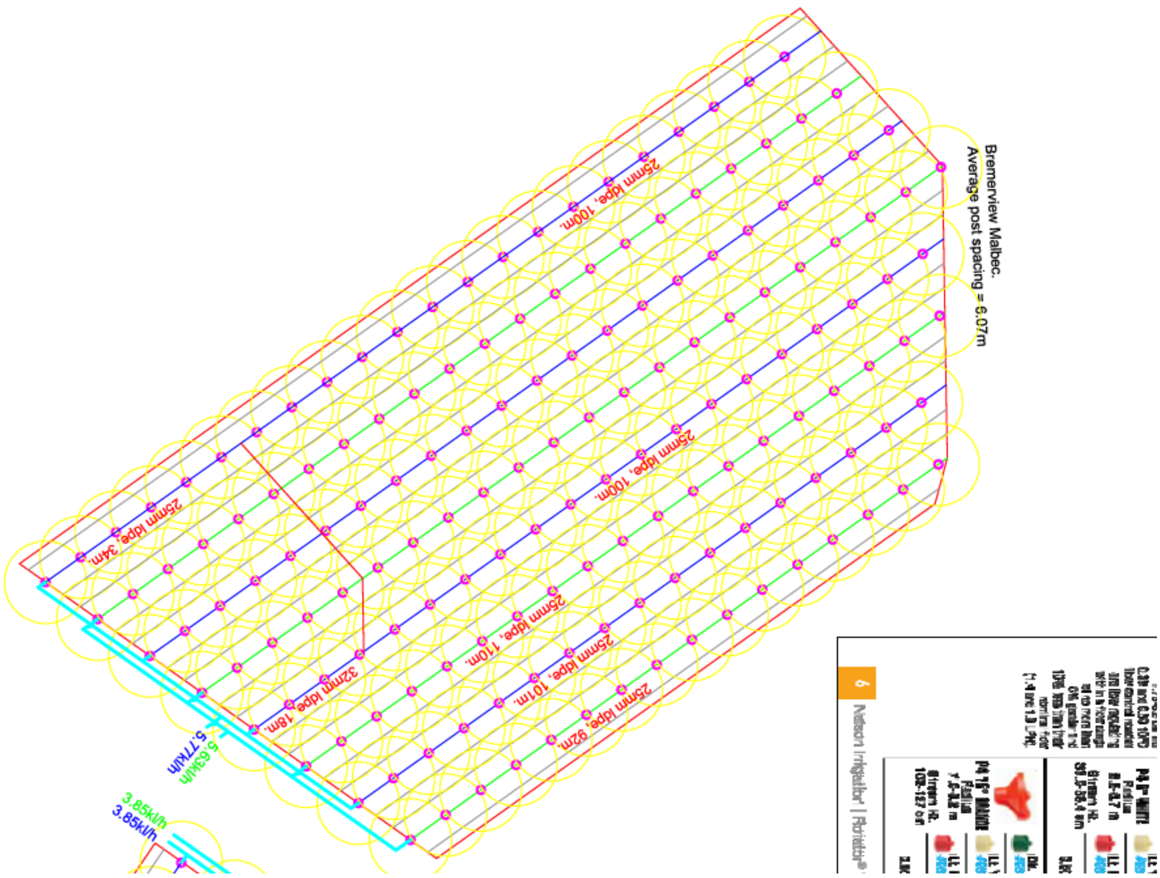

Figure 16 - Design of one of our blocks using a Nelson R10 Rotator Sprinkler (Source: Irrigation SOS, 2021).

Within each block, two valves manage every second sprinkler line effectively allowing us to cover a significantly larger area. These valves alternate their operation, with each being active for a 5 minutes interval. During the past 3 seasons this method of cooling has consistently been run and has proven highly successful in reducing temperatures of fruit by up to 5°C.

Due to the extreme heatwaves affecting California in 2020, and whilst on my GFP, I felt sure I would find vineyards, berry farmers or other industry using a cooling technique similar to this.

Lucus Pope, representing Coastal Vineyard Services, in Paso Robles, CA, guided me through a vineyard where they had installed undervine misters for cooling purposes. However, that was the extent of evaporative cooling in vineyards on my travels. In contrast, other vineyards relied on cultural practices, such as shading, to mitigate heat.

Derek Ackerman from Mushandi strawberry farm in Macheke, Zimbabwe, used large sprinklers positioned at the end of each strawberry tunnel. The tunnels were orientated in the direction of the prevailing winds. By employing sprinklers at the tunnel ends, they effectively channeled cool air down the rows, cooling the strawberry plants.

Figure 17 - Mushandi Strawberry Farm, Zimbabwe. Tunnels orientated in the direction of the prevailing winds, and note the sides could be lifted to increase airflow (Source: Author, 2023).

A dairy farm (unnamed) in Castilla la Mancha, Spain, also employed evaporative cooling to cool their dairy cows. The set up included nozzles in front of large fans situated throughout the pens. On closer inspection, they appeared to have also installed what resembled the Netafim Coolnet^{TM} Pro superfine misters on the external sections of the pens. I must confess that standing next to these on the hot 35°C day provided welcome relief.

Figure 18 - Dairy farm in Castilla la Mancha, Spain. Fans with misters (Source: Author, 2023).

4. Soil Health

After many years managing meticulously groomed vineyards with well-manicured mid rows and bare undervine strips, it wasn't until I began my current role that I questioned the impact of these management practices on our soils and vine health. Certainly, during heatwaves, damage seemed far greater in blocks where the undervine area was hardened, and midrow vegetative matter was sparce.

So, can improving soil health contribute to vine resilience during heatwaves?

Soil moisture retention is key during heat waves (Hayman, 2012). Healthy soil, with adequate organic matter content, good structure, and high microbial activity, has the capacity to retain moisture more effectively. This is vital for vines as it ensures a stable water supply, even during prolonged periods of high temperatures and drought stress. Degraded soils with poor structure and low organic matter content are more prone to water loss, exacerbating the stress experienced by vines during heat waves.

The structure and composition of the soil directly influence root development and function. Healthy soils provide an optimal environment for root growth, allowing vines to establish extensive root systems that can explore a larger soil volume for water and nutrients.

Observing the resilience of our dry grown vineyards during heatwave events, it becomes evident that their extensive root systems are particularly beneficial. These roots have the ability to tap into moisture reserves deep within the soil, which remains relatively unaffected by surface evaporation. Additionally, well-structured soils with adequate permeability promote good root aeration, preventing root suffocation and enhance nutrient uptake, all of which are essential for vine resilience.

Regenerative farming is becoming extremely popular around the world. With the principle of 'keeping the soil covered at all times', I was intrigued by the level for cultivation throughout Spain and California, in particularly in Paso Robles.

One grower explained that in their case, cultivation served the purpose of reducing evaporation. "The cracking clay soils often form deep cracks during dry conditions, increasing the exposed surface area resulting in increased water loss through evaporation. Cultivation creates a continuous buffer zone 10-20cm above the cracks decreasing the exposed surface area, hence reducing evaporation. Cultivation also disrupts surface crusting, improving infiltration."

However, is this practice creating and intensifying the problem?

Jordan Lonborg, Viticulturist at Tablas Creek Vineyards in the Adelaida sub-region of Paso Robles, was among growers who practiced minimal cultivation.

Lonborg walked me through many sections of their vineyard. Remarkably, in these areas, also featuring 'Cracking Clays', deep cracks were notably absent (Lonborg, 2023).

Figure 19 - Pictured on left cultivated vineyard in Paso Robles and Lonborg, in Tablas Creek Vineyard's new planting. Natural vegetation on right (Source: Author, 2023)

Lonborg's statement to me was "we have formed the deep cracking clays by degrading the soil structure".

Lonborg also went onto talk about cultivation disrupting soil structure increasing the surface area from which water can evaporate, thus enhancing the rate of evaporation. Cultivation breaks down soil aggregates important for maintaining soil structure leading to soil crusting. It also removes plant residue important for reducing evaporation and cooling soil.

While heat damage to berries was observed in cultivated vineyards, I found it very difficult to find damage in the Tablas Creek vines.

Mycorrhizal Fungi

Organic & Biodynamic Winegrowing Conference, New Zealand, 2023

Can improving the Mycorrhizae levels in the soil assist vine resilience during a heat wave event?

Dr Hicham Ferhout, head of bio fertilisers and microbial bio stimulants at Agronutrition in France, spoke passionately about the advantages of Mycorrhizal fungi.

Ferhout explained that mycorrhizal fungi are crucial components of the ecosystems, forming symbiotic relationships with the roots of most plants, including vines. These fungi play a complex role in plant health and resilience, including nutrient uptake, stress tolerance, and disease resistance.

Ferhout, explained the symbiotic relationship between Mycorrhizal fungi enhancing the vine's ability to absorb water and nutrients and in return, supplying the fungi with carbohydrates. Mycorrhizal fungi can extend the effective root surface area, facilitating access to a much larger area for water and nutrient uptake.

Another crucial mechanism by which mycorrhizal fungi assist vines during heatwaves is through providing a physical barrier, insulating the roots from variation in soil temperature. This buffering effect not only helps mitigate the impact of soil temperature extremes, but covering the root can also act as a barrier against pathogens.

Mycorrhizal fungi play a pivotal role in the establishment and maintenance of soil microbial communities, which contribute to soil health and resilience. By promoting the growth of beneficial bacteria and other fungi, mycorrhizal fungi enhance nutrient cycling and organic matter decomposition in the soil. This microbial diversity can increase the availability of organic nutrients and enhance soil fertility, supporting vine growth and productivity, particularly during periods of environmental stress.

Ferhout refers to mycorrhizal fungi as the “internet for plants”. They can communicate and exchange resources among plants. These fungal networks enable ‘plant to plant’ signalling and resource sharing, allowing vines to communicate their physiological status and allocate resources. During heatwaves, this network communication can facilitate the redistribution of water, and nutrients, among vines within the same vineyard or even across different plant species.

So how do we build our Mycorrhizae levels, and can you have too many mycorrhizae fungi?

Ferhout spoke about a simple system where mycorrhizal fungi was injected 30cm from the roots into the soil behind a ripper. Ferhout, explained that “higher doses of spores may not always give you the best result. A high level of mycorrhizae can use a lot of energy and therefore not always produce the desired effect.”

Biochar

Biochar is a charcoal like substance made by burning organic material from agricultural/forestry waste in a controlled process called pyrolysis.

By incorporating biochar into the soil, it can:

- enhance soil water holding capacity and water infiltration
- improve nutrient availability
- increase soil organic matter content
- increase microbial activity, leading to improved soil structure

- potential to enhance plant resilience to extreme temperatures
- increase soil carbon

Although biochar adoption in the vineyards and farm visited internationally was limited, I observed firsthand the benefits of biochar on a broadacre property about 10 years ago.

In Langhorne Creek, a local broadacre farmer Colin Candy, in collaboration with, Mark Hall, the principle of VBH Supplies, incorporated biochar in soil prior to planting a wheat crop. The contrast between traditional planting methods and the biochar section was remarkable, with plants in the biochar treated area noticeably stronger and healthier.

Changing our cultural practices 'on the ground'

Once again, a positive outcome of the COVID 19 pandemic prior to drafting this report was the opportunity to enhance soil health. We have embraced a few of the Regenerative principles described in Richard Leask's Nuffield report (Leask, 2020):

- Keeping the soil covered
- Increasing plant and microbial diversity
- Incorporating living roots into the farming system all year round
- Minimising soil disturbance

Mid rows were initially cultivated and planted with multispecies blends including:

- Ryegrass
- Clover
- Medic
- Legumes such as peas and beans
- Brassica
- Radish
- Vetch

Figure 20 - Pollinator blend – established in November (left) and post flowering of radish, the sward is rolled (right), creating a dense vegetative mat with the clovers, medics and ryegrasses able to grow through providing a secondary flush of flowering plants from December through to late January. (Author, Sept 2020)

The benefits we are observing from the multi-species blend include:

- Vines health has improved (particularly a reduction of vine scale),
- ‘Smart Radish’ taproots are breaking through hardpan layers, and once the microbes have destroyed the taproot it opens up the soil to improve water infiltration.
- Predatory insect levels have increased, decreasing pest levels.
- Once rolled, they create a dense plant mat that provides fodder for invertebrates, bacteria and fungi over summer whilst keeping the soil cool.
- Improved infiltration of flood water – has reduced the need to pump out pools of water in the vineyard following a flood event.

Figure 21 - Bleasdale's test for microbes, as part of the 'Soil Your Undies' campaign by the University of New England (UNE) and Cotton Info. Pictured left is a pair of 'Bonds' underpants buried under the cover crop. These cotton underpants were left under 10cm of soil for 2 months. Right is the result, a very crude but effective way of indicating the presence of soil microbes (Source: Author, 2020)

Decreasing, and in some areas, completely eliminating the application of undervine herbicides has led to the growth of vegetation undervine. This vegetation is now mown for frost mitigation, and prevent taller plants from encroaching into the canopy reducing airflow.

Benefits of reduced herbicide applications in the Bleasdale vineyards included:

- The hardpan under the vines, which developed over decades of herbicide use, has vanished, leading to improved irrigation efficiency.
- Improved irrigation efficiency has resulted in fewer wheel ruts, as there is less runoff of irrigation water from the hardpan into the vehicle wheel lines.
- Over the last five years, we have witnessed a variety of plants thriving in the undervine area. Many of these are desirable species such as medics, clovers, and native grasses like windmill grass (Chloris truncate) as pictured in Figure 22.
- Generally better vine health and reduced pest levels.

Figure 22 - Mullianna Cabernet Sauvignon, previously a bare hardpan, now features naturally established windmill grass (Chloris truncate), leading to enhanced soil and vine health (Source: Author, 2020)

While the benefits mentioned are valuable, how have these practices contributed to heat mitigation?

One significant impact is the reduction in surface temperature observed in the undervine area during heatwaves. Figure 23 illustrates this effect, highlighting that ground temperature in exposed soil was remarkably higher compared to the shaded and vegetated area undervine.

Figure 23 - Left, infrared temperature on bare ground undervine compared to the temperature of undervine with actively growing ground cover, 30th January 2020, 39°C (Author, 2020)

5. Trellis Systems and Cultural Practices

Training systems

Many different training systems were on display across California. The following are examples of those viewed:

- Single wire
- Single high wire
- Vertical shoot positioned (VSP)
- VSP at 60 and 80%
- Echalas (also known as staked vine)

In Sacramento I visited fellow Nuffield Scholar Tom Merwin, Merwin Wines. Many of Merwin's vineyards were on high T trellis systems.

The high cordon can allow better air circulation around the vine. It positions the bunches higher above the ground where they are less exposed to radiant heat from the soil and provided great natural shade as pictured below in Figure 24.

Figure 24 - T trellis in Clarksburg, CA (Soure: Author, 2023)

In Paso Robels the Echalas system was widely utilised, and planted as high-density vineyards (2.1m-2.4m rows with 0.9m-1.2m vine spacing) as well as very low density (3.6m x 3.6m). This system is ultimately a bush vine developed next to a pole/post, however there are fewer bearers and the bearers are positioned closer together. The shoots are then tied to the post. The grapes ripen in a microclimate that is well-aerated with filtered light penetrating the canopy from all directions.

To increase shade in the closely planted blocks managed by Pope (Coastal Vineyard Services, CA), instead of tipping they would pull the vines together, providing extra shade.

Figure 25 - Pope pulling Echalas shoot tips together to increase shade on closely planted block and typical echalas vine at Tablas Creek vineyard, Paso Robles CA, (Source: Author, 2023)

Leaf removal

Leaf removal was widely adopted as a management technique to mitigate the impact of heat in many vineyards as it:

- Increased airflow
- Reduced canopy density
- Improve vineyard microclimate

Gaili Mountain Winery, Yir'on, Israel, vertical shoot position (VSP) canopies run in two directions, east-west and north-south.

In numerous vineyards, leaf removal typically took place when berries were at pea size. However, at Gaili Mountain's, leaf removal in the white varieties occurred during flowering. This practice resulted in looser bunches, improving airflow around the berries.

Leaf removal for red grapes then occurred 2-3 weeks prior to veraison. In rows orientated east to west, leaves from the bunch zone on the eastern side were removed (morning or less exposed side). Leaves on the western side were retained to shade grapes from direct afternoon sunlight. In rows orientated north-south, leaves were selectively removed from the centre of the canopy. This method improved airflow while still providing essential shading from the outside.

Tom Merwin, Clarksburg, CA also leaf plucked around the bunch zone on the morning side of the canopy. The T trellis provided great natural shade for bunches, however the additional removal of leaf assisted with airflow and cooling. This was once again performed at berry pea size.

Figure 26 - Tom Merwin's vineyard, Clarksburg, CA. Leaf plucking on morning side of vines (Source: Author, 2023)

Reflective Sprays or Sunscreen

Whilst kaolin-based products such as Surround® and Screen® are utilised in Australia, it's worth noting that a number of growers in Israel, and California also found the reflective sprays beneficial in reducing radiation, reflect UV and infrared, and reduce transpiration loss during heatwave events.

Particularly useful after leaf removal growers applied sunscreen initially at this time (berry pea size), then every 10-14 days up until harvest or prior to a heat wave event.

Figure 2727 – A semillon bunch following the application of a sunscreen product (Riley, 2014)

Shade Cloth

Galil Mountain wines, Israel, and vineyards managed by Pope, in Paso Robles, CA used shade cloth to shade the bunches during heatwaves.

Starting from when the berries are at pepper corn size, the shade cloth is raised to cover the fruit zone before a heatwave occurs and then lowered shortly after the event.

When queried about this practice, Lucus explained that lifting and lowering the shade cloth is necessary to prevent it from rubbing against the berries and causing damage to the fruit.

Figure 28 - Shade cloth stored neatly near the drip line ready to be lifted prior to a heatwave, Paso, Robles (Source: Author, 2023)

As you can see in Figure 28, green and black shade cloth was used on this vineyard. Research by Kurtural et al. from UC Davis found that any colour shade cloth was better than no shade cloth.

Kurtural et al's trial four different coloured shade cloths against a control including:

- Uncovered
- 20% shading factor white (Pearl)
- 40% shading factor black,
- 40% shading factor blue
- 40% shading factor aluminet.

Black was more effective at reducing temperature in the fruit zone and led to higher anthocyanin content in berries at harvest.

Interestingly, while the aluminet filtered out light, it also reflected light back into the canopy and inhibited berry growth resulting in lower berry mass.

The trial indicated a 33% reduction in temperature at 2 and 4pm using black shade cloth compared to the control, as indicated in Figure 29 (Martinez-Luscher et al. 2017).

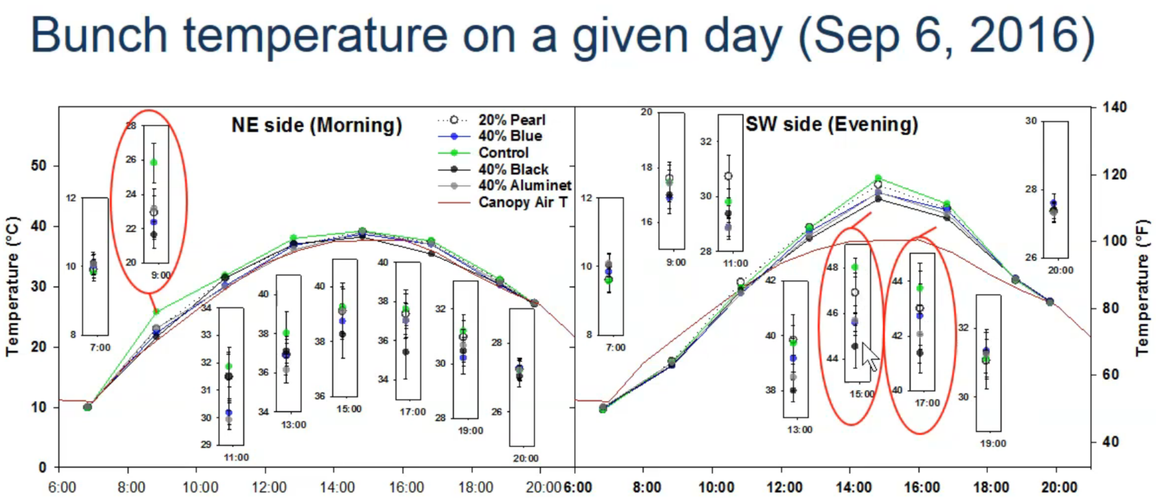

Figure 29 - Shade Net Trial, 40% Shading factor – Blue (Source: Martinez-Luscher et al. 2017)

Pope described the technique of lifting and dropping nets as "effective but expensive" (Pope, 2023). This statement was reinforced by Advanced Viticulture, CA, summarising Kurtural et al. research on their website, stating, "if you can manage to cover your fruit with a relaxed VSP or sprawl, that would be better than hanging your fruit out in full sun. With the price of shade cloth and labour being what they are, you might just want to work with the shade nature gives you in the first place." (Advanced Viticulture, CA)

Figure 30 - Shade Net Trial, 40% Shading factor – Blue (Source: Martinez-Luscher et al. 2017)

New Research

Marine Plant Growth-Promoting Rhizobacteria Consortia

In an innovative study to reinforce grapevine resilience during heatwaves, Carreiras et al, University of Lisbon, Portugal, explored the use of plant growth-promoting rhizobacteria (PGPR), which are known for enhancing plant health and stress tolerance.

The experiment involved inoculating grapevines with compatible marine rhizobacteria isolated from salt marshes and exposing them to simulated heatwave conditions in a controlled environment.

Two PGPR consortia or groups were developed. The Bacterial strains were chosen for their great potential as bioinoculants and grouped for their different complementary activities and traits with no conflicting effects between them.

The trial revealed notable improvements in the heat stress resilience of grapevines treated with marine PGPR groups. Inoculated grapevines exhibited significantly superior photoprotection and membrane stability and displayed a notable amelioration in the oxidative stress experienced when exposed to a heatwave stress. In essence improved plant health.

Interestingly, selected bacterial strain combinations revealed similar potential in vitro assay. When grapevines were inoculated and exposed to a heatwave event, group 1 presented heatwave stress tolerances (stress avoidance), and group 2 presented heatwave improvement (increase resistance), (Carreiras,J. et al, 2023).

Rootstocks

Grafting grapevines scions onto various rootstocks (eg Paulsen 1103) can modify the root structure, maximising root surface contact with soil and enhancing water absorption from deeper soil layers, thereby increasing drought tolerance (Ferlito et al, 2019).

Extensive research is being conducted worldwide on rootstocks that exhibit tolerance to drought conditions, with one such trial underway at Davis University. Assistant professor, Megan Bartlett, is leading a study evaluating traits to enhance rootstock drought tolerance.

Bartlett's research looks to:

- Improve rootstock drought tolerance
- Identify traits that improve rootstock performance
- Evaluate candidate rootstock traits for the ability to maintain photosynthesis and growth under water stress conditions

Bartlett states, "the living cells in the root are a significant bottleneck for water uptake from dry soils, but the traits that capture the responses of these cells to water stress have never been evaluated as potential drivers of rootstock drought tolerance" (Bartlett et al,).

The findings in this research reveal that the vines root system is complex, capable of redistributing water from wet to dry zones to sustain more roots. However, this process can also draw down on plant resources as respiration of these root can account for up to 70% of the imported carbon used for photosynthesis.

Studies have shown that rootstocks with higher drought tolerance, prioritises concentrating carbon and water in wetter zones by "dumping" roots in the drier zones. Additionally, these drought tolerant rootstocks exhibit rapid recovery of root growth when soil moisture levels increase, replenishing roots in “dumped” zones and restoring photosynthesis more swiftly compared to less drought tolerant varieties.

Bartletts continued research includes looking at:

- Is it better for the vine to ‘dump’ the stressed roots in dry conditions in all environments, and will this perform differently in different environments?
- Can we improve on these trait values?
- Are there other traits worth targeting?

Conclusions

I didn't quite stumble upon the groundbreaking method I had hoped for to enhance our vines resilience to heatwaves. Nonetheless, by incorporating minor adjustments in the vineyard, we have improved our vines resilience.

Changes we have implemented have included:

- Increasing the number of soil moisture probes to ensure we have a better understanding of water use, and soil moisture status prior to a heatwave event.
- Prioritising irrigation to blocks prone to damage, and those that are at a vulnerable growth stage.
- New plantings with drought tolerant rootstocks.
- Canopy management techniques such as leaf removal to improve airflow while maintaining shade to bunches directly affected by the afternoon sun.
- Application of sunscreen to vulnerable blocks.
- Trimming to increase airflow, and creating a 'veranda' on the evening side for shade.
- Lazy foliage wire lifting on the afternoon side of canopy increasing shade.
- Ensuring the mid rows and undervine areas are cover with vegetation, improving infiltration rates, and reducing soil and ground temperatures.
- Groundcovers improving soil health, possibly increasing mycorrhizae fungi levels enabling increase access to water and nutrients.
- Installing overhead irrigation for cooling in highly susceptible varieties.

Gradually making small improvements is effectively contributing to our efforts in achieving greater resilience to heat waves. What's particularly advantageous about these improvements is their affordability, ease of implementation, and positive impact on soil, environmental, and personnel health.

Exploring grapevine varieties and clones that could better withstand higher temperatures is also another avenue to assist growers to mitigate heat stress. If you are interested in delving deeper into this topic, my colleague, Martin Gransden a 2018 Nuffield Scholar looked into "Alternate Varieties for The Australian Wine Industry - Varieties to help Australian wine grape producers in a changing environment and market." Gransden's report can be found on the Nuffield Australia web site.

Recommendations

Committing to gradual improvements, however small, not only assists with heat related issues but also aims to foster healthier vines and environments.

Adaption

Altering vineyards can be a difficult and expensive endeavor.

Making minor adjustments to existing operating practices and vineyard framework, as outlined in the Conclusion, can be achieved at a relatively low cost and with ease. Additionally, many of these practices contribute to enhancing soil and environmental health leading to improved vine health and resilience.

Financial support for innovation – the missing link, research to practice

An obstacle hindering many growers from implementing cutting edge research is often insufficient funds, the necessary technical expertise in program adaption and engineering skills essential to develop practical application methods.

A lack of funding not only delays the adoption of these solutions but also limits our ability to address challenges specific to our industry. Offering financial incentives aimed at bridging the gap between research and practical implementation would encourage growers to embrace new research.

Unique plant growth-promoting rhizobacteria (PGPR) in Australia

Australia is a land of many distinct environments, each presenting its own challenges for agricultural production. Plants native to Australia have adapted to endure extremes such as droughts, floods and heatwaves.

What potential do we have in our back yards?

Plant growth-promoting rhizobacteria indigenous to our regions may help our vines cope with heatwaves while supporting nutrient uptake, improve water efficiency, and enhance overall resilience to environmental stresses.

References

Ackerman, D 2023, Personal visit – GFP, 'Mushandi Strawberry Farm, Macheke, Zimbabwe'.

Advanced Viticulture 2022, Ask a Viticulturist: Cut from the same shade cloth, viewed 5 June 2024, https://advancedvit.com/shade-cloth-does-color-matter/#:~:text=As%20far%20as%20what%20was

Barak 2019, Personal interview, 'Use of Sap Flow meters in a commercial situation, Lower Galilee, Israel'.

Bureau of Meteorology 2022, *State of the Climate 2022: Bureau of Meteorology*, Bom.gov.au, Bureau of Meteorology, viewed 30 May 2024, http://www.bom.gov.au/state-of-the-climate

Carreiras, J, Cruz-Silva, A, Fonseca, B, Carvalho, RC, Cunha, JP, Proença Pereira, J, Paiva-Silva, C, A. Santos, S, Janeiro Sequeira, R, Mateos-Naranjo, E, Rodríguez-Llorente, ID, Pajuelo, E, Redondo-Gómez, S, Matos, AR, Mesa-Marín, J, Figueiredo, A & Duarte, B 2023, 'Improving Grapevine Heat Stress Resilience with Marine Plant Growth-Promoting Rhizobacteria Consortia', *Microorganisms*, vol. 11, no. 4, p. 856, viewed 17 February 2024, https://www.mdpi.com/2076-2607/11/4/856

Charitt, Z & Doris 2019, Personal interview, 'Netafim - Heat mitigation solution, Kabbutz Yiftach, Norther Israel'.

Dairy Farm, 2019, Personal visit – GFP, 'Dairy in Castilla la Mancha, Spain'.

Dasi, M 2023, Personal interview, 'Dusi Vineyards, Paso Robles, CA'.

Ferhout, DH 2023, Organic and Biodynamic Winegrowing Conference, Blenheim, New Zealand, 'Mycorrhizae and their drivers: The vine case'.

Ferlito, F, Distefano, G, Gentile, A, Allegra, M, Lakso, AN & Nicolosi, E 2019, 'Scion–rootstock interactions influence the growth and behaviour of the grapevine root system in a heavy clay soil', *Australian Journal of Grape and Wine Research*, vol. 26, no. 1, pp. 68–78.

Gordon, J & Wright, D 2022, *On the application of SWAN Systems to the Wine Industry Globally*, 25 November, viewed 1 June 2024, https://www.swansystems.com/wp-content/uploads/2020/11/On-the-application-of-SWAN-Systems-to-the-Wine-Industry-Globally_JW_25.11.2020.pdf

Hayman, P, Longbottom, M, Mccarthy, M & Thomas, D 2012, *Managing grapevines during heatwaves*, January, viewed 9 June 2024, https://www.mvwi.com.au/wp-content/uploads/2021/07/Managing-grapevines-during-heatwaves.pdf

Leask, R 2020, *Is Being Sustainable Enough for Australian Wine?*, Nuffield Australia Farming Scholarship, p. Piii, P20-24.

Lonborg, J 2023, Personal interview, 'Tablas Creek Vineyard, Adelaida sub-region, Paso Robles, California, USA'.

Martínez-Lüscher, J, Chen, CCL, Brillante, L & Kurtural, SK 2017, 'Partial Solar Radiation Exclusion with Color Shade Nets Reduces the Degradation of Organic Acids and Flavonoids of Grape Berry (Vitis viniferaL.)', *Journal of Agricultural and Food Chemistry*, vol. 65, no. 49, pp. 10693–10702.

Napa Valley Vintners 2020, *Evaluating candidate traits to improve rootstock tolerance*, YouTube, viewed 12 June 2024, https://www.youtube.com/watch?v=JpN2kMI4Zew

Pagay, V & Australia, W 2018, *Using in-canopy misters to mitigate the negative effects of heatwaves in grapevines (UA 1502) FINAL REPORT TO WINE AUSTRALIA*, 10 August, viewed 2 June 2024, https://www.wineaustralia.com/getmedia/1e529802-c9be-450d-a92a-2b76e2c8f5d0/UA-1502-Final-Report

Phytech - Plant Based Farming n.d., *Phytech Viticulture Webinar: Strategies to Boost Berry Development*, YouTube, viewed 31 May 2024, https://www.youtube.com/watch?v=NlWJk0Yr6Sg&t=144s

Pimstein, A 2019, Personal interview, 'Dendrometer and Sap Flow devices - SupPlant, Kfar Yoshuah, Israel'.

Pope, L 2023, Personal interview, 'Vineyard tour of various Paso Roble Vineyards - heat mitigation'.

Riley, L 2014, 'Sunscreen for winegrapes: demonstration trial', Wine Australia https://www.wineaustralia.com/getmedia/77df1eb2-63f8-491b-aaa5-783461ceb7a4/201411-Sunscreen-for-winegrapes.pdf

Saturas, viewed 2 June 2024, Our Technology n.d., https://saturas-ag.com/our-technology/#:~:text=Saturas%E2%80%99s%20patented%20sensor%2C%20the%20StemSense%E2%84%A2%2C%20is%20the%20first

Vestrich, B & Avery, M 2019, Personal interview, ‘Sap flow sensors to assist with heat mitigation, Gaili Mountain Wines’.

Wine Australia, Australia’s Wine Future A climate Atlas 2019, https://wasydprodwebparent.blob.core.windows.net/media/wineaustralia/wineaustralia/pdf/growing-and-making/climate%20atlas/australia-s-wine-future-a-climate-atlas.pdf.

Wyatt, B 2021, Personal interview, ‘Vineyard Cooling via Wobble T sprinklers, Langhorne Creek, SA’.