Water Relations of Semillon Vines



FINAL REPORT to

GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION

Project Number: **RD 04/03-1**

Principal Investigator: **Suzy Rogiers**

Research Organisation: **National Wine & Grape Industry Centre**

Date: **August 2008**

Water Relations of Semillon Vines

Suzy Rogiers, Ron Hutton, Dennis Greer, Tony Somers

National Wine and Grape Industry Centre
Locked Bag 588
Charles Sturt University
Wagga Wagga, NSW
2678

August 2008

Disclaimer: The advice provided in this document is intended as a source of information only. The NWGIC, NSW Department of Primary Industries, Charles Sturt University and its employees do not guarantee that the publication is without flaw of any kind or is wholly appropriate for your particular purposes and therefore disclaims all liability for any error, loss of other consequence which may arise from you relying on any information in this publication.

Acknowledgements:

This research was supported by the Australia's grapegrowers and winemakers through their investment body the Grape and Wine Research and Development Corporation, with matching funds from the Federal Government.

We would like to acknowledge the growers of the Hunter Valley and Riverina regions for their excellent support and access to their vineyards during the course of this project. In particular special thanks to:

Patrick and Adrian DeMarko
Graeme Reid, Jeff Robinson and Nugan Foods Group
Peter Rohr and McWilliams wines
Ian Tinkler and Tinkler's Family Wines
Andrew Pengilly and Tyrrells Wines
Ken and Christine Brae
Andrew Drumm and Charles Sturt University
Brian Sainty
Paul Hutchinson, HUSSAT soil moisture monitoring
The Hunter Valley Vignernons Association.

Table of Contents

1. Abstract 4
2. Executive Summary 5
3. Background 8
4. Project Aims and Performance Targets 9
5. Methods 10
5.1 Vineyard trials 10
5.1.1 Locations 10
5.1.2 Soil properties 10
5.1.3 Soil Moisture 10
5.1.4 Canopy temperature and humidity 11
5.2 Semillon clone and rootstock experiments 11
5.3 Growth Cabinet experiments 12
5.4 Physiological measurements 12
5.5 Stomatal Density 12
5.6 Electrolyte leakage 13
5.7 Abscisic Acid 13
5.8 Yield and berry composition 13
5.9 Root density 14
5.10 Canopy size 14
6. Results and Discussion 15
6.1: Regional Study 15
A. Characterising the vineyards 15
B. Vineyard soil properties 19
C. Vineyard Soil Moisture 38
E. Canopy temperature and humidity 45
F. Vineyard Canopy characteristics 50
F. Vine Water Status 56
G. Vine Sap flow 67
H. Yield and berry composition 76
6.2: Semillon clones and interactions with rootstocks 90
6.3: Variety Comparisons of Field Vines 106
6.4: Variety Comparison Study- Growth Cabinet 124
Experiment 1 125
Experiment 2 131
Experiment 3 137
6.5: The role of ABA in Semillon vines 142
7. Outcome/Conclusion 148
8. Recommendations 150
Appendix 1: Communication 151
Appendix 2: Intellectual Property 152
Appendix 3: References 153
Appendix 4: Staff 156

1. Abstract

Drought induced water shortages are being experienced across many of the grape growing regions of Australia. Understanding varietal differences in water-use allows the grower to make strategic decisions and manage their way through this uncertain future. Semillon is one variety that has a distinctive susceptibility to low soil moistures and heat events. A field study across two regions of NSW indicated that water loss from Semillon leaves (transpiration) was tightly driven by vapour pressure deficit. Higher levels of transpiration were caused by open stomata, the pores on the leaf's surface. While stomata did respond to dry soils and low vine water status, closure was not to the same extent as in other varieties. This resulted in low amounts of carbon assimilation relative to water loss (transpiration efficiency) for this variety. Elevated soil moistures and reduced exposure alleviated leaf burn. Appropriate rootstocks, row orientation and canopy architecture is recommended along with focussed irrigation accompanied by precise soil moisture monitoring.

2. Executive Summary

Semillon is a variety originating from the Bordeaux region of France which is characterised by a climate with relatively mild average summer temperature, high humidity and precipitation. In vineyards of NSW and other warm grape-growing regions across Australia, Semillon vines exhibit symptoms of wilting and leaf burn, and this is aggravated by exposure to hot days during ripening. Other varieties grown adjacent to Semillon and managed similarly do not display these symptoms to the same severity.

Preliminary observations indicated that leaf burn can occur without extreme temperatures. Dormant cuttings incubated in water to stimulate root growth will, at budburst, exhibit leaf burn at 25°C, while adjacent cuttings of other varieties do not. Similarly, Semillon vines grown in a controlled environment with maximum temperatures limited to 25°C exhibited leaf burn when pots were allowed to dry down. These observations indicate that low leaf water status was the cause for the leaf burn. While exposure of vines to high temperatures did result in leaf burn, the damage was less severe when plants were well watered. Limited water at the leaf margins is the result of delivery rates not keeping up with evaporation rates from the leaf's surface. This may indicate that water flow through the vines to the leaf is less than adequate when compared with what is required to maintain leaves in a hydrated state.

The aim of the project was to understand the cause of Semillon's sensitivity to dehydration. A survey of seven vineyards across the Lower Hunter Valley and the MIA indicated that vine water status was predominantly driven by atmospheric demand and that low soil moisture heightened the water stress. Water flux through these vines followed a diurnal pattern, mimicking daily variation in VPD, while seasonal differences in the average amount of water transpired per day was also influenced by soil moisture levels. Leaf burn occurred after severe heat events in both regions. The leaf burn was more severe in those vineyards that experienced higher temperatures and on vines grown in soils with low water availability. One vineyard which applied over 40 L of water per vine over a 12 hour period through drip irrigation still had low vine water status because the soils had low water holding capacity, VPDs were extreme and transpiration rates were very high. High salt levels within the soils at some sites were correlated with smaller canopies and may have exacerbated leaf burn symptoms. Vines planted in N-S rows experienced higher levels of leaf burn than vines grown in W-E rows. Recovery of vine water status over night was limited in low soil moistures and when nights were warm and windy. Reworked vines had limited sap flow rates, possibly because of vine age or the sectorial nature of grapevines.

A comparison of harvest data from these regions over three seasons indicated that there were no consistent correlations between vine water status and yield or berry composition. Aside from smaller vines at a dry-land site, there were also no relationships between vine water status and canopy size, probably due to differences in vine age and different canopy management practises between vineyards. Within-vineyard variation in soil moisture, however, did have an effect on canopy size. Yield was correlated to canopy size and both these parameters differed greatly between the regions. Crop load, however, was fairly consistent. pH of berries was less for vines

with small canopies. There was also an interesting positive linear relationship between soil K concentrations and berry pH. The soils of the MIA vineyards had higher K levels along with other elements such as Na, Ca and Mg. In the Hunter Valley, however, Mn and Al levels were greater than the MIA and soil pH was lower by 1 to 2 units. The EC values between the two regions were not significantly different for depths beyond 20 cm. The MIA soils had higher clay content and a greater proportion of the soil particles > 2 mm. None of these soil parameters, however, were correlated with vine canopy size.

A comparison of Semillon field vines with nine other varieties within one site located in the MIA indicated that on moderate days the canopies were relatively cool due to the high transpiration rates. On hot days Semillon leaves experienced burning of the leaf margins, while the other varieties remained symptom free. Semillon leaves were not thinner than the leaves of the other varieties. In this variety block, Semillon vines did not have larger canopies, smaller trunk diameters or smaller root systems than the other varieties. Roots also did not exhibit symptoms of root-knot nematode infection. Nonetheless, midday and predawn leaf water potentials were more negative for this variety throughout the season. Leaf transpiration rates were relatively high, as was stomatal conductance, and the resultant transpiration efficiency was low for this variety. Higher transpiration rates were not due to higher stomatal densities. Leaves were also fairly rough and hairy indicating the capability for providing a reasonable boundary layer over the leaf's surface. We hypothesised that the high stomatal conductance may have been the result of underproduction of the water stress hormone, abscisic acid (ABA). ABA concentrations within the xylem sap, however, were not less than the other varieties and concentrations followed a diurnal trend.

The water relations of Semillon were compared to Grenache, a near-isohydric variety, in a series of controlled environment studies. Pots were allowed to dry down over a 12 day period and leaf gas exchange and water potential was monitored. At all soil moisture levels transpiration, photosynthesis and stomatal conductance was higher for Semillon vines, resulting in more negative leaf water potentials both at midday and predawn. Root water potentials correlated well to leaf water potentials. ABA concentration in the xylem sap did not differ between the two varieties. The root/shoot and the trunk/root ratios were similar for both varieties indicating similar capability for water uptake and storage. The consistently high transpiration rates in Semillon indicate that root, trunk and shoot hydraulic conductance were not limited. Furthermore, excessive embolism formation was not likely a causal agent for the leaf burn because water flow through vines was not hindered. It was surprising that membrane damage of leaf cells as assessed by electrolyte leakage was higher for Grenache than Semillon leaves after the dry down.

A study assessing the impact of VPD on vine water relations indicated that over a VPD range of 0.5 to 4 kPa, stomatal conductance and transpiration were higher for Semillon, as compared to Shiraz or Grenache. Stomatal density did not appear to play a role in the higher transpiration rates since there were fewer stomata per leaf area for Semillon than Grenache. Semillon appears to be an 'optimistic' variety and not a conservative water-user, even under dry conditions.

A comparison of Semillon clones grown on rootstocks under deficit irrigation indicated that Macedone was more sensitive to leaf burn. All vines responded to the

deficit irrigation treatment with a decrease in stomatal conductance and transpiration rates. DA16162 grown on Schwarzmann, however, had the most negative leaf water potentials and also the highest stomatal conductances and transpiration rates. This rootstock does not appear to be appropriate for Semillon if vine water status is of concern to the grower. Across all the clone/rootstock combinations a mere two days of deficit irrigation after veraison resulted in smaller bunch and berry fresh weight. There were adverse affects on total soluble solids along with higher pH and lower titratable acidity. D10V12 vines had bunches with smaller berry numbers and this lead to higher total soluble solids with higher pH and lower titratable acidity.

In summary, the higher levels of leaf burn experienced by Semillon was due to the higher transpiration rates, effectively depleting soil and plant moisture reserves and resulting in lower vine water status. The high transpiration rates were at least partially due to higher stomatal conductance. The reason for the high stomatal conductance across a range of VPDs and soil moistures remains unclear. Although stomata did respond to high VPDs, conductances were still high. ABA appears to be produced at similar levels to the other varieties and is transported through the xylem stream at high concentrations during the middle of the day. ABA may however, not reach the guard cells in the right form to cause closure. The possibility also remains that other signals may be important in causing stomatal closure.

The lack of tight control over stomatal aperture indicates that vines are better suited to regions with consistent water supplies and without extremes in temperatures. Vines should be planted on soils with good water holding capacities. If a frequent and flexible water supply is available, drip irrigation is highly recommended with close soil moisture monitoring. One vineyard which converted from flood to drip irrigation had reduced levels of leaf burn in the following season. Avoidance of N-S rows is also advised. Drought resistant rootstocks are recommended, along with nematode resistant attributes since Semillon is susceptible to root-knot nematode.

Further field trials on clonal robustness and scion-rootstock interactions for Semillon are warranted. The positive effects of shading on leaf transpiration indicate that canopy manipulation trials to influence transpiration efficiency would benefit especially Semillon. Field trials on anti-transpirants may provide an effective solution to the high transpiration rates of this variety. Further work on signals produced during water stress is also required. While sap flow results allow better estimates for vine water use, vineyard characteristics such as cover crop and soil type will introduce enormous variation in the required amounts of water. Further work on vineyard ET is required. Because of the common practise of re-working vines in the Hunter Valley, a study on the effects of re-working on root growth and senescence and resultant water use efficiency would be useful. The interaction of soil K levels and berry pH found in this study would benefit from a broader survey across other Semillon sites and across other varieties.

This research was conducted at the National Wine & Grape Industry Centre. Partner institutions included the NSW Department of Primary Industries, Charles Sturt University and the NSW Wine Industry Association.

3. Background

Semillon has been grown in the NSW Hunter Valley and Riverina regions for many years and produces wines that are acknowledged as being unique and outstanding examples of Australian region specific wine styles. It is extensively blended with Chardonnay and other varieties to produce high quality white table wine as well as straight Semillon varietal wines of the Hunter region that have great ability for bottle age. In the Riverina, sweet dessert wines made from Botrytis style Semillon, have gained both Australian and international recognition.

There is considerable interest in Semillon, particularly in inland areas, where there is a short to medium term shortage of this variety (McGrath Kerr S. 2003). Semillon, however, has specific characteristics that have made its management difficult: it is particularly susceptible to water stress. Stress at early stages of leaf area development can reduce canopy development by arresting shoot growth. Results of a GWRDC funded project (CSU 99/2) on Semillon in the Riverina indicate that post-harvest accumulation of reserves to the roots is impacted by irrigation, and this has an effect on the following season's shoot growth and yield. Leaf petioles are fragile and high winds combined with hot weather cause leaf abscission. The physiological basis for this variety specific sensitivity to water stress needs further investigation. Preliminary work on Semillon indicates that it is much more sensitive to water stress than other varieties of wine grapes. Managing shoot growth and leaf health of this variety will assist the NSW industry both in the Hunter Region and the Riverina.

A preliminary phone survey across the grape growing regions of NSW indicated that leaf burn in Semillon occurs across a range of irrigation strategies, vine age and rootstocks. Seasonal differences in severity pointed to a climatic component to this occurrence. Differences in severity of leaf burn of vines grown on sites in close proximity to each other, however, indicated that management plays a role. Irrigation is critical to most grape growing regions across Australia. In the Hunter Valley, however, some vines are grown without supplemental irrigation. This is in contrast to the MIA where most vineyards are drip irrigated, however conversion from flood irrigation has not occurred in all vineyards. With the critical water shortages of recent years along with the rising costs of water, any attempts to maximise vine health and productivity per unit of water applied is of benefit to the viticultural industry. Understanding the conditions leading to sub-optimal vine health in Semillon will aid in the development of irrigation strategies specific to this variety both in the hot inland regions of NSW as well as the more humid coastal regions. The field survey proposed, covered Semillon on a range of irrigation strategies. In each vineyard, locations of high, intermediate and low soil moisture levels were compared. For simplicity all field vines were on their own roots.

Rootstocks are known to confer phylloxera and nematode resistance as well as drought tolerance. While some grapes in the Hunter Valley are grown on Schwarzmann to confer tolerance to phylloxera and root-knot nematode, this rootstock is not appropriate for drought conditions. To better understand the interaction of rootstock on Semillon water relations a pot trial was carried out using 6 different clone/rootstock combinations. This will provide the basis for further field trials to assess differences in water use and transpiration efficiency for clonal rootstock combinations.

4. Project Aims and Performance Targets

OUTPUTS	PERFORMANCE TARGETS	TARGET DATE	Progress towards Target (A/N/O/D)
1.Information on the impact of soil moisture on vine vigour, berry composition and yield	Data from the first year of the field treatments compiled by July 2005	July 2006	A
2.Information on the impact of soil moisture on vine vigour, berry composition and yield	Data from the second year of field treatments compiled by July 2006	July 2007	A
3.Information on the vine's physiological response to water stress	Data of the first year of pot study compiled by July 2006	July 2007	A
4.Information transfer of study results	Workshop conducted and industry journal publication submitted by September 2006	Sept 2007	A
5.Information on the impact of soil moisture on vine vigour, berry composition and yield	Data of the third year of field treatments compiled by July 2008	July 2008	A
6. Information on the vine's physiological response to water stress	Data of the second year of pot study compiled by July 2008	July 2008	A
7.Information transfer of study results	Workshop conducted, best management practise guide, and refereed and industry journal publication submitted by September 2008	September 2008	O

5. Methods

5.1 Vineyard trials

5.1.1 Locations

The trial sites were located in two grape growing regions of NSW, the MIA and the Lower Hunter Valley. There were 4 sites investigated in the MIA and 3 sites in the Hunter Valley. All the Semillon vines were on their own roots. An EM 38 survey delineated a low, intermediate and high EM location within the sites. Four vines were marked within each EM location. For characteristics of the sites please see the results section.

A replicated variety block located at Charles Sturt University, Wagga Wagga, NSW was used for variety comparisons. The replicated variety block consisted of 6 rows of 10 varieties at vine spacing of 1.5 m. Semillon was compared to seven other wine grape varieties, including Cabernet Sauvignon, Chardonnay, Merlot, Pinot noir, Riesling, Sauvignon Blanc, and Shiraz, and two table grape varieties including Sultana and Flame Seedless. Each variety panel consisted of 3 vines. The vines were on their own roots, were planted in E-W rows in 2005, and were 3 years old. The double cordons were trained along a single horizontal wire and were pruned to approximately 20 buds per vine. The vines were drip irrigated twice weekly overnight during berry development and ripening using 1.7 L/h drippers spaced at 50 cm intervals. The soil was uniform on the block and consisted of a sandy loam over very hard medium clay (80+cm). The inter-row area consisted of volunteer species and was regularly slashed.

5.1.2 Soil properties

Soils of the vineyard sites were collected from each EM location with a hand auger to a depth of 100 cm. The soil was collected in 10 cm intervals, placed in plastic bags and kept at 4°C for up to 2 weeks. The soils were dried at 60°C and then ground manually. Soil colour was assessed using the Munsell soil colour chart (MacBeth 1976). A sample was sent to a diagnostic laboratory (NSW Department of Primary Industries) for electrical conductivity, pH and effective cation exchange capacity analyses.

5.1.3 Soil Moisture

Soil moisture equipment was installed in each EM location within each site (HUSSAT Soil Moisture Monitoring Inc., NSW). Soil moisture was assessed with watermark sensors or gypsum blocks and microloggers transmitted the information to a nearby basestation. Using long wave radios the basestation then relayed the information to the internet for viewing.

Watermark® soil moisture sensors (Irrometer Co., Riverside, CA 92516, USA) were placed at 25, 50, 75 and 100 cm depths directly beneath a dripper in the four MIA vineyards. At the Hunter Valley vineyards there were two sets of sensors: Watermark® soil moisture sensors and Gypsum blocks for the 50-500 range.

The soil tensions were converted into soil water content by applying an estimate of the soil characteristic water release curve from the UNSODA database (USDA-ARS George E. Brown, Jr. Salinity Laboratory, 450 W Big Springs Road, Riverside, CA 92507-4617) based on a field determination of the soil texture. The soil water contents at each depth were then used to calculate the proportion of stored readily available water between each measured depth. In this analysis the readily available water (RAW) is defined as the volume of water available to plants in the root zone within a specified range of soil tensions, in this case from field capacity to -60 kPa. The proportion of readily available water (%RAW) in the profile was then determined by summing the stored readily available water between each measurement depth and normalizing this value by the RAW.

5.1.4 Canopy temperature and humidity

Within each site a weather station was placed at canopy height. It was equipped with a humidity and temperature probe (Intercap HMP50, Vaisala, Hawthorn, Vic) and logged at half hourly intervals.

5.2 Semillon clone and rootstock experiments

The following clone and rootstock combinations were obtained as bare-rooted vines from local nurseries:

- Macedone on own roots
- D10V12 on own roots
- DA 16162 on own roots
- DA 16162 on Schwarzmann
- DA 16162 on Ramsey

Vines were grown outdoors in a bird-proof enclosure in 40 L pots filled with a premium garden mix (60% compost: 20% screened loam: 20% washed river sand). Plants were drip irrigated three times daily for 20 minutes at 2L/h. The vines were 3 years old at the initiation of the experiment. Vines were pruned to two spurs and thinned to 6 shoots per vine which were tipped to maintain 14 leaves per shoot. Fruit were thinned to two bunches per shoot. The plants were distributed in a split-plot design of 9 replicates with irrigation (standard and deficit) as main plot treatments and rootstock/variety as subplot treatments.

Two dry down periods were applied, each lasting for two days. The first occurred in mid-January during the ripening phase of development while the second occurred in March, post-harvest. The standard irrigation treatment consisted of vines that were drip irrigated three times daily as described above while in the deficit irrigation treatment no water was applied to the vines for two days. Soil moisture was monitored with ML2x Theta Probes (Delta-T Devices, Cambridge, England) logged (Starlog Pro Model 7001A, Measurement Engineering Australia, Magill, SA) at 30 min intervals.

At the end of the experiment 4 replicates were separated in roots, trunk and shoots and these were dried at 60°C for 1 month and subsequently weighed.

5.3 Growth Cabinet experiments

Semillon and Grenache vines were two years old, on their own roots, and grown outdoors in 40 L pots in a premium garden mix (60% compost: 20% screened loam: 20% washed river sand). Plants were drip irrigated daily. Vines were pruned to four shoots per vine and all fruit was removed.

In December (Experiment 1) and February (Experiment 2), the vines were moved from outdoors into a controlled environment chamber (TPG-6000-TH, Thermoline Scientific, Smithfield, Australia). The growth cabinet was set to 35/20°C day/night temperatures and 35/65% RH. Plants were subjected to a 12 hour photoperiod of 450 μmol m^{-2} s^{-1} PAR at mid-canopy height.

In Experiment 1, 5 Grenache and 5 Semillon vines were monitored while the pots were allowed to dry down. No water was added for an 11 day period.

In Experiment 2, 10 Grenache and 10 Semillon vines were moved into growth cabinet. Five vines of each variety were assigned to a standard or deficit irrigation treatment. The standard irrigation treatment consisted of vines that were drip irrigated daily while in the deficit irrigation treatment no water was applied to the vines for 6 days. Soil moisture was monitored with ML2x Theta Probes (Delta-T Devices, Cambridge, England) logged (Starlog Pro Model 7001A, Measurement Engineering Australia, Magill, SA) at 30 min intervals. Vines of Experiment 2 were separated in roots, trunk and shoots and these were dried at 60°C for 1 month.

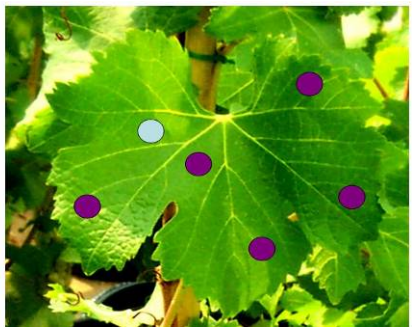
5.4 Physiological measurements

A Scholander pressure chamber (ICT international, Armidale, NSW) fitted with a Model 3015G4 specimen holder was used for leaf water potential (Ψ) measurements and xylem sap collection. An LI6400 gas exchange system (Li-Cor Corporation, Lincoln, NE, USA) was used to monitor photosynthesis, transpiration and stomatal conductance. The block temperature was held to 25°C and a red-blue light source was used at 1500 μmol m^{-2} s^{-1}. Canopy temperature was assessed with an infrared thermometer (Portix D, Keller GMBH, Germany) held 10 cm from the leaf. Leaf chlorophyll was assessed with a chlorophyll meter (SPAD-502, Minolta Co., Ltd., Japan). Vine sap flow was measured with Greenspan® SF300 sensors (Tyco Environmental systems, Milperra, NSW). Each system contained four probe sets with a single heat sensor and a logger. Each probe set was placed into a trunk at 40 cm from the ground and logging occurred at half hourly intervals for a 6 week period.

5.5 Stomatal Density

Fresh leaf samples of similar size, age and exposure were used for stomatal density measurements. For each variety, one leaf per vine was taken from three vines from each of the 6 rows in the replicated variety block. A comparison of 5 regions on the abaxial side of the leaf was made and no consistent differences were found between the regions. All data reported are for the central area on the right of the mid-vein. No stomata were found on the adaxial side of the leaf. Nail polish was applied to the leaf and allowed to dry for 10 minutes. Sticky tape was used to peel off the nail polish and this was pressed onto a microscope slide. The image was observed under bright field

microscopy (Olympus Provis AX70). Stomata were counted in three different areas within this central region of the leaf.



Locations of stomatal counts. The blue dot indicates the adaxial location viewed, while the purple dots indicate the abaxial locations viewed.

5.6 Electrolyte leakage

Leaf discs (10) of 1cm diameter were punched out of a leaf with a cork-borer. These discs were placed in dH_2O within a test tube and shaken overnight. Electrical conductivity of the solution was measured after 1, 3 and 24h. The discs were then boiled for half hour, allowed to cool and the conductivity was measured again. Leakiness was calculated according to Lutts et al., 1996.

5.7 Abscisic Acid

Xylem sap ABA was quantified using the ELISA technique (Mertens et al. 1983). The xylem sap was passed through a Sep Pak C_{18} cartridge (Waters, Inc.) pre-conditioned with 100% methanol and then dH_2O. The sample was loaded in 0.1 M citrate/ 0.2 M phosphate buffer (pH 2.8). After washing with 10% methanol, the ABA fraction was collected in 100% methanol. The sample was reduced to dryness with a centrifugal evaporator (Labconco Corp., Kansas, MO) and reconstituted in 1 mL of TBS buffer (TRIS-buffered saline; 150 mM NaCl, 1 mM $MgCl_2$ and 50 mM TRIS, pH 7.5). The sample was analysed by a competitive ELISA (Phytodetek®, ABA Test Kit, Agdia Inc., Elkhart, Indiana) and processed according to kit instructions. Absorbance was read with a µQuant microplate spectrophotometer (Bio-Tek instruments, VE). An internal ABA standard was used and results compared well to samples that had been analysed with the HPLC method.

5.8 Yield and berry composition

At harvest all bunches were removed from each vine and were counted and weighed. The sub-samples were transported on ice to the laboratory from the field. The fresh weight of a 50 berry sample was taken at random from two bunches per vine. Subsequently the sample was juiced and total soluble solids (TSS) were measured using a hand-held refractometer (ATAGO Co., Ltd., Tokyo, Japan). Titratable acidity and pH of the juice was measured with a TitraLab® 80 titration system (Radiometer, Copenhagen).

5.9 Root density

Roots of 6 vines for each of 5 varieties from the replicated variety block were sampled immediately after bunches had reached full ripeness. Vines with similar trunk diameters were chosen. A 30x30x 50 cm deep area was excavated under the dripper which was located 25 cm from the trunk of the vine. The soil was sifted and vine roots were weighed and then dried at 60°C for 3 weeks.

5.10 Canopy size

A regression of shoot length with leaf area as measured with a leaf area meter (LI-3100C, LICOR Biosciences, Lincoln, NE) was carried out for field vines in each experimental site. Pruning weights were taken from each vine during dormancy. The length of each shoot was determined and then they were dried at 60°C. Leaf area was determined from shoot lengths.

6. Results and Discussion

6.1: Regional Study
A. Characterising the vineyards

Semillon grown in vineyards of the Murrumbidgee Irrigation Area and Hunter Valley of NSW can undergo water stress during the growing season. This includes burning of leaf margins, slowed shoot development and sometimes delayed berry maturation and ripening. These symptoms can occur while other varieties grown in adjacent blocks with similar irrigation regimes remain free of any signs of water stress. In order to better understand the causes of these symptoms, the water relations of Semillon vines were assessed in a number of vineyards across the MIA and the Hunter Valley. The objective of this study was to compare blocks of Semillon vines exhibiting signs of vine water stress with those that remained relatively stress free. Soil moisture was monitored, along with temperature and relative humidity to better understand the external environment that the vines were experiencing. Vine physiology, in particular leaf water potential, transpiration, stomatal conductance and sap flow was assessed throughout the growing season.

The MIA is somewhat warmer than the Lower Hunter Valley throughout the growing season. In Cessnock (Lower Hunter Valley), the mean maximum during berry development (November to February) ranges from 27 to 30°C while the mean minimum ranges from 13 to 18°C. Average monthly rainfall ranges from 65 to 100mm. In Griffith (MIA) the mean maximum during berry development ranges from 28 to 33°C while the mean minimum ranges from 13 to 17°C. Average monthly rainfall is substantially less in Griffith and ranges from 27 to 33mm. Both the Hunter Valley and the MIA were in a drought declared area for the first two seasons of the project (2005-06 and 2006-07). In the third season, with rain in the Hunter Valley, this region was upgraded to satisfactory in terms of water status.

The soils in the Hunter are fertile. The vineyards are grown on alluvial loam flats and the surrounding gentle undulating hills. The hills are covered in loam-clays which overlay crumbly limestone. Over 90% of the vineyards surveyed in the Hunter Valley have root-knot nematode. The Riverina plains were deposited by the action of ancient streams upon the remnants of the Great Dividing Range. The alluvial soils are variable and sands and gravels are embedded in clays. A loamy surface 10-30 cm deep overlays a reddish-brown clay. This soil contains limestone rubble. The majority of the vineyards are planted on these free-draining soils.

The vineyards examined in the two regions consisted of Semillon vines that varied from no symptoms of leaf burn over several seasons to consistent leaf burn. All vines were on their own roots, but the Semillon clone varied, and most often was not known (Table 1). Vine age varied from 6 to 60 years. Yields varied greatly between the sites but were generally less in the Hunter Valley than in the MIA. A total of seven vineyards were assessed.

Table 1: Block size, Semillon clone, vine age, average yield and frequency of leaf burn in Semillon sites assessed in the Hunter Valley and MIA.

Region	Site	Block Size (acres)	Roots	Clone	Vine Age	Average Yield (t/acre)	Burning of leaf margins
Hunter Valley	Hillslope-drip	12	Own	Busby	25		Intermediate
	Riverflat-drip	10	Own	unknown	60	2.5	No
	Riverflat-dry	10	Own	DA 16162	15	4	Yes
MIA	Point-Drip	14	Own	unknown	10	6	Intermediate
	Yenda-Drip	4	Own	Macedone	35	10	No
	Yenda-Flood	20	Own	unknown	10	7.5	Yes
	Hillston-Drip	16	Own	unknown	6	18	Yes

The vineyard sites varied in their row orientation and vine spacing (Table 2). Vines were pruned to a greater number of shoots in the MIA sites and the resultant canopies were larger. Summer trimming was not carried out at any of the sites. Trunk diameter was smaller in younger vines, however re-working of older vines in the Hunter Valley also reduced trunk diameter above the point where the sucker was developed.

Figure 1. Hillston-drip site in the MIA. These vines are on drip irrigation, 6 years old, and on their own roots. The vines are grown in N-S rows and leaf burn is common.



Figure 2. The Dryland site in the Hunter Valley. This vineyard was on a river flat and grown without any supplemental irrigation. The vines are 15 years old, the clone is DA 16162. The vines are on their own roots, in N-S rows and leaf burn occurs regularly.



Table 2: Row orientation, trellis type, planting density and vine size in Semillon sites assessed in the Hunter Valley and MIA

Region	Site	Row Orient	Trellis	Row spacing (m)	Vine spacing (m)	Shoots/ vine	Trunk Diameter (cm)	Summer trimming	
Hunter Valley	Hillslope-drip	SE-NW	Double wire-vertical	3.3	1.5	20-25	10	No	
	Riverflat-drip	E-W	Double wire-vertical	4.5	1.8	20	10	No	
	Riverflat-dry	N-S	Double wire-vertical	2.8	1.2	10	5	No	
MIA	Point-drip	E-W	Double wire-vertical	3.3	1.6	20-30	5	No	
	Yenda-drip	SW-NE	Double wire-vertical	3.6	1.8	35	6.5	No	
	Yenda-flood	SE-NW	Double wire-vertical	3.65	1.82	30	6.5	No	
	Hillston-drip	N-S	Double wire-vertical	3.5	1.20	35	5	No	

The sites assessed were either dry-land, on drip or flood irrigation (Table 3). Irrigation ranged from nil to 12 h/day during the ripening phase of development. Most often the actual amounts applied were not recorded. Soil moisture monitoring did not occur in all vineyards prior to the initiation of the project, however most managers did monitor their blocks and used either gypsum blocks, C-probes or neutron probes. In some vineyards inter-rows were cultivated once to several times a season, while in other vineyards volunteer species were allowed to grow.

Table 3: Irrigation characteristics, soil moisture monitoring prior to the initiation of the project, and type of ground cover in the Semillon sites of the Hunter Valley and MIA. Frequency of irrigation was dependent on season.

Region	Site	Irrigation	Frequency post-veraison	Soil moisture monitoring	Ground cover
Hunter Valley	Hillslope-drip	Drip	2-4 times per season	None	Volunteer species alternate rows
	Riverflat-drip	Drip 2 L/h 1m apart	Weekly for 8h	Gypsum blocks	Volunteer species alternate rows
	Riverflat-dry	Dry land	NA	None	None
MIA	Point-drip	Drip 60 cm	Twice weekly	C-probe	Volunteer species
	Yenda-drip	Drip 2.2 L/h 60 cm	8-12 h every 2 days	Neutron probe	Volunteer species
	Yenda-flood	Flood	Every 10-14 days	Neutron probe	None
	Hillston-drip	Drip 1.8 L/h 50 cm	Daily 12 h	C-probe	Volunteer species

6.1: Regional Study
B. Vineyard soil properties

An EM-38 survey was carried out across the seven sites. It was found that the EM values was generally lower in the Hunter Valley than in the MIA (Table 1). There was extensive variation across the block that was sampled, and also with depth (Fig 1). An analysis of the soil indicated that the blocks within the Hunter Valley ranged from sandy loams to sandy clays while in the MIA they were sandy clays to silty clays.

Table 1: Soil colour and texture of the Semillon sites of the Hunter Valley and MIA.

Region	Site	Soil Colour (Munsell)	Texture	
Hunter Valley	Hillslope-drip	Very dark brown to dark yellowish brown	Sandy clay or sandy loam	
	Riverflat-drip	Dark brown to dark yellowish brown	Silty clay or loamy sand to sandy clay	
	Riverflat-dry	Very dark greyish brown	Loamy sand to sandy loam	
MIA	Point-drip	Dark reddish brown to yellowish red	Sandy clay	
	Yenda-drip	Dark reddish brown to yellowish red	Silty clay to sandy clay	
	Yenda-flood	Dark reddish brown to reddish brown	Silty clay	
	Hillston-drip	Dark Greyish brown	Sandy clay loam	

Table 2: EM range of each block and low, intermediate and high EM points which were used as locations for vine testing.

Region	Site	EM range	Low EM point	Intermediate EM point	High EM point
Hunter Valley	Hillslope-drip	14-215	34	115	157
	Riverflat-drip	14-149	40	80	128
	Riverflat-dry	33-79	45	57	73
MIA	Point-drip	13-116	13	59	118
	Yenda-drip	25-90	30	56	93
	Yenda-flood	21-112	31	69	102
	Hillston-drip	14-90	25	58	78

Fig 1: An EM-38 map of a block surveyed in the MIA. The blue points indicate a low intermediate and high EM value.

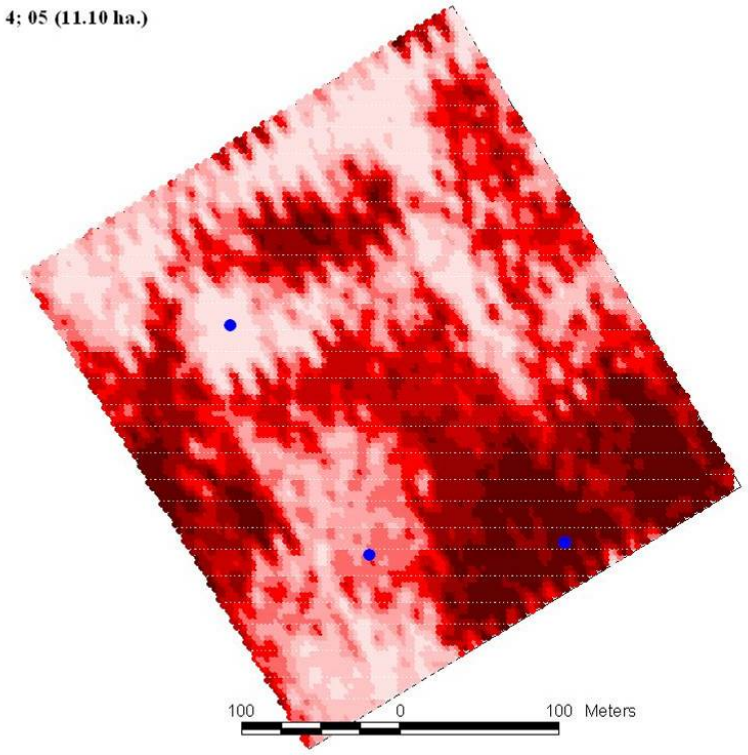


Table 1. Soil Properties of Seven Semillon Blocks in the MIA and the Hunter Valley. Measurements were taken at 10 cm intervals to a depth of 1m. (n.d.-not detected)

Site	EC mS/m	pH	pH ($CaCl_2$)	Ca cmol/kg	Mg cmol/kg	K cmol/kg	Na cmol/kg	Al cmol/kg	Mn cmol/kg
Riverflat Drip	50-450	5.6-8.3	5.2-7.7	2-20	0-14	0.3-1.0	0-3.5	0-0.08.	<0.06
Hillslope drip	50-800	4.5-7.7	4.0-6.7	4-23	3-23	0.2-1.4	0.5-6.5	0-1.2	<0.25
Riverflat dry	60-180	5.0-7.5	4.3-6.8	1-9	1-5	0.2-1.2	0.07-0.34	0-0.3.	<0.15
Point-drip	150-500	6.9-9.7	6.0-8.3	4-18	4-19	0.6-1.6	0.5-8	n.d.	<0.03
Yenda-drip	100-900	6.3-9.3	5.7-8.3	5-21	4-15	0.7-1.7	0.2-6.7	n.d.	<0.04
Yenda-flood	50-1000	5.6-9.3	4.7-8.3	4-17	4-14	0.9-2.6	0-8	0-0.08.	<0.06
Hillston-drip	100-550	8.1-9.7	6.8-9.8	5-18	5-9.5	0.4-2.4	0-7	n.d.	n.d.

The soil profile of a vineyard in the MIA (Hillston-drip site) is shown in Figures 1-4. EC values ranged from 100 to 500 mS/m (1 to 5 dS/m) and were in line with the EM survey (Figure 1). Na levels ranged from less than 1 to greater than 7 cmol/kg and were in parallel with the EC values (Figure 2). Ca concentrations were higher and ranged from 5 to 18 cmol/kg, and also matched the EM values and EC trends (Figure 3). While Na tended to increase with depth, Ca decreased with depth. K was less than 2 cmol/kg and was highest in the Low EM location (Figure 4). Mg increased with depth in the low and intermediate locations and was similar to Ca in that it ranged from 4 to 18 cmol/kg. The pH of these soils ranged from 7.0 to 9.5 without any real trends with depth (Figure 6).

A comparison of the Dryland vineyard with the Flood irrigated vineyard highlighted large differences in Na, Ca, Mg and K levels (Figures 7 to 9). In this Flood irrigated vineyard the Na levels were 20 fold greater than in the Dryland vineyard (Figure 7). Correspondingly the EC values were double to 8-fold higher in the Flood irrigated vineyard. Clay content was also much higher in the Flood irrigated vineyard, probably providing more sites for binding of ions. The water used for irrigating in the Flood vineyard likely increased the EC values of the soils. The pH of the soils from the Flood irrigated vineyard was alkaline while in the Dryland site it was acidic (Figure 10). This probably led to the mobilisation of Mn in the Dryland site.

An analysis of the soil from all sites indicated that Na levels followed the EM trends in the MIA vineyards, but not in the Hunter Valley vineyards (Figures 11 and 12). Across all sites, however, EC and Na levels correlated well (Figure 13). Within the high EM treatment the EC values and the Na levels usually increased with soil depth. In the high EM treatment, Ca was usually higher on the surface of the soil than at lower depths. K, pH and pH ($Ca\ Cl_2$) did not mirror the EM trends. Na and pH levels did correlate in a quadratic relationship (Figure 13B), with an increase in Na levels as pH increased as well. The clay content within the soil was very variable within a vineyard and with depth.

There were significant differences in soil chemistry between the two regions. In the MIA vineyards, Na, Ca, Mg and K were in higher concentrations at all depths, with the exception of Mg beyond 60 cm (Figures 14 to 16). The EC values between the two regions, however, were not significantly different for depths beyond 20 cm. EC was higher in the Hunter Valley for the 10 and 20 cm portions of the soil profile.

Vitis vinifera varieties on their own roots undergo a decline in yield with salinity values greater than 3.6 dS/m (360 mS/m). Salts dissolved in soil water can also result in leaf burn and reduced vine vigour. Since the ranges reported here sometimes exceed these values, salinity may be a problem. The flood and some of the drip irrigated vineyards tended to have higher salinity, probably due to the use of saline irrigation water. The increase in Na and EC with depth is a common occurrence and is likely due to leaching.

The soils in the Hunter Valley tended to have lower pH values and higher Mn and Al levels as compared with the MIA soils (Figure 17). Al did not change much with depth but Mn declined beyond 20 cm. pH was higher in the MIA by 1 to 2 units (Figure 18). The pH did not change significantly with depth in the Hunter Valley. However, in the MIA pH tended to increase with depth. The MIA had higher clay

content and a greater proportion of the soil particles > 2 mm (Figure 19). Mn and Al toxicity are a problem in acid soils at pH less than 5.5 and 4.5, respectively, inhibiting vine growth and berry ripening. The Hunter Valley soils also had somewhat lower K levels, perhaps due to lower fertiliser application rates.

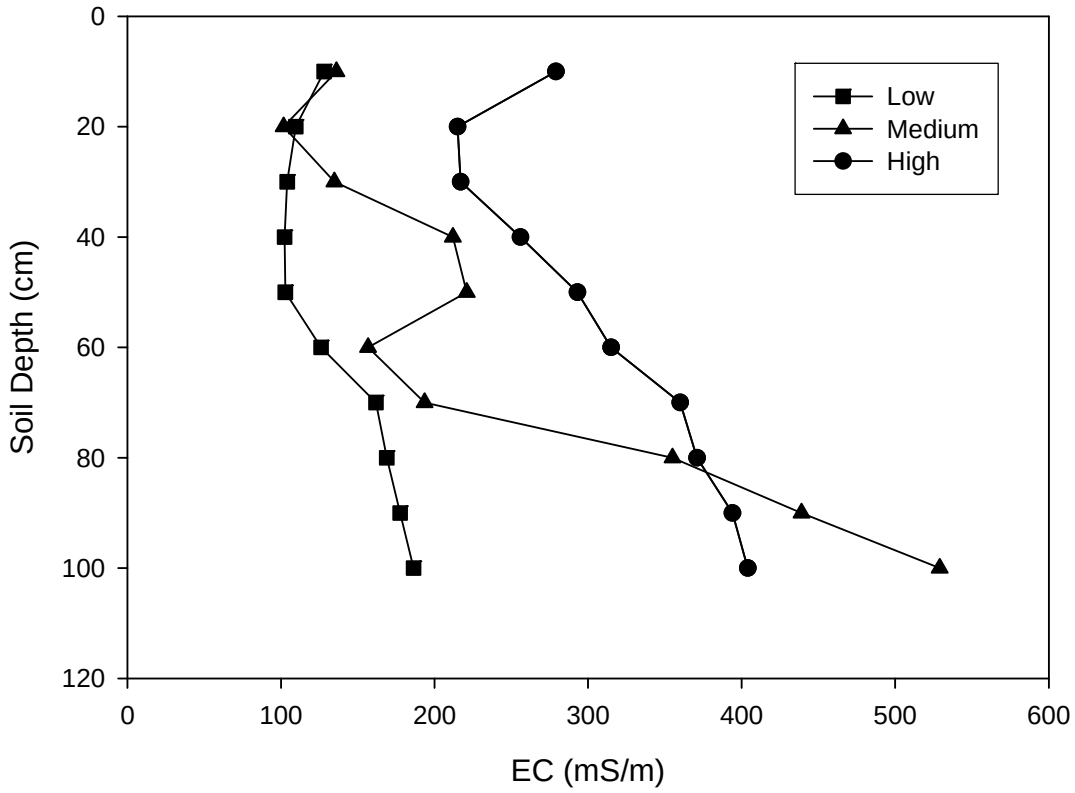


Figure 1. EC of soils at 3 locations of the Hillston-drip site, MIA at a depth of 0-100 cm. Each location corresponds to a low, medium and high EM value.

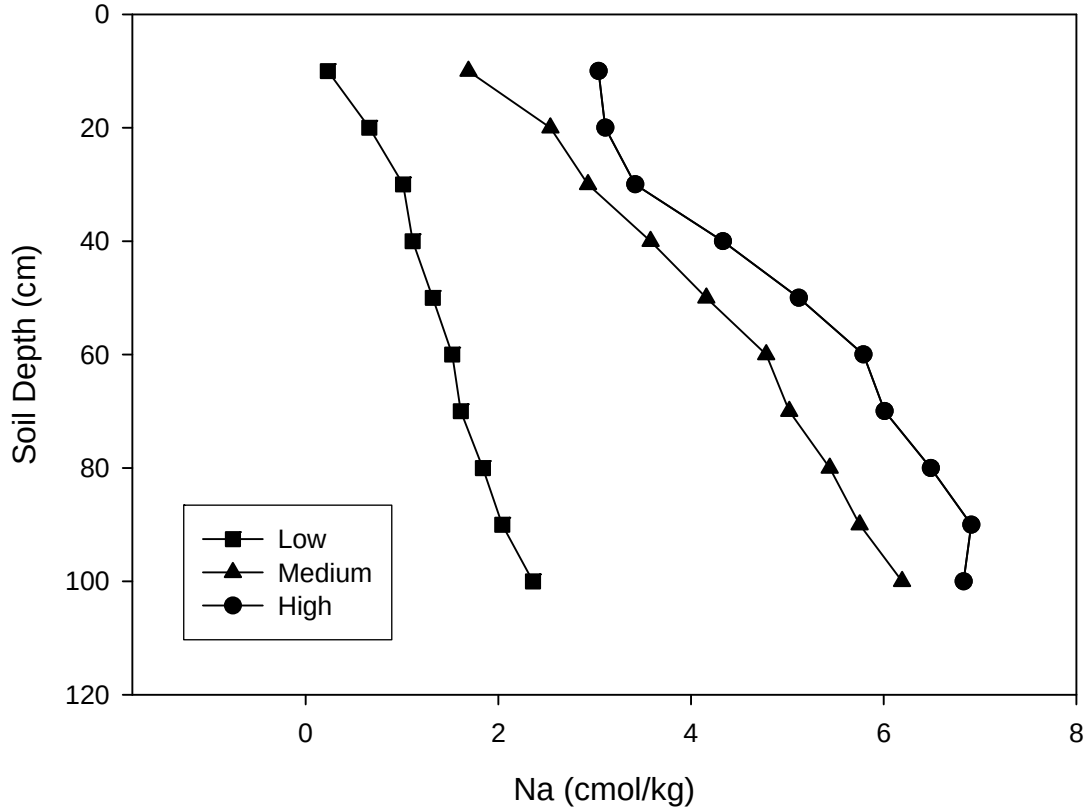


Figure 2. Na concentrations in the soils at 3 points at the Hillston-drip site, MIA at a depth of 0-100 cm. Each location corresponds to a low, medium and high EM value.

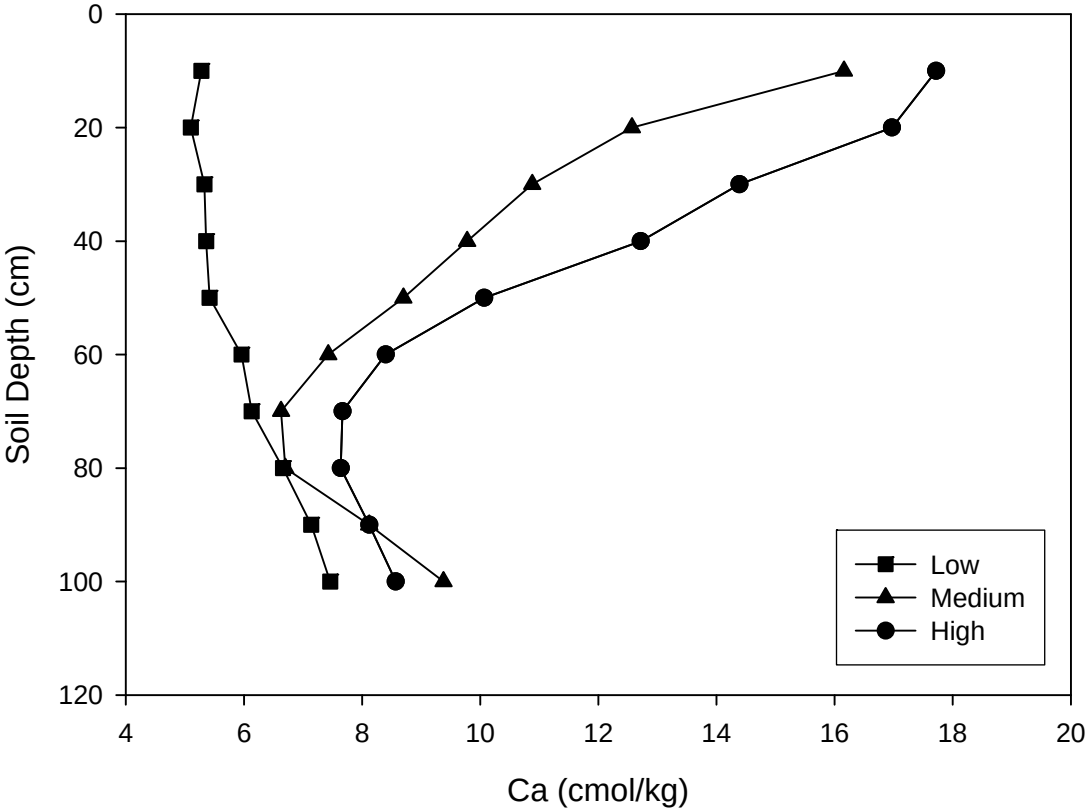


Figure 3. Ca concentrations in the soils at 3 points at the Hillston-drip site, MIA at a depth of 0-100 cm. Each location corresponds to a low, medium and high EM value.

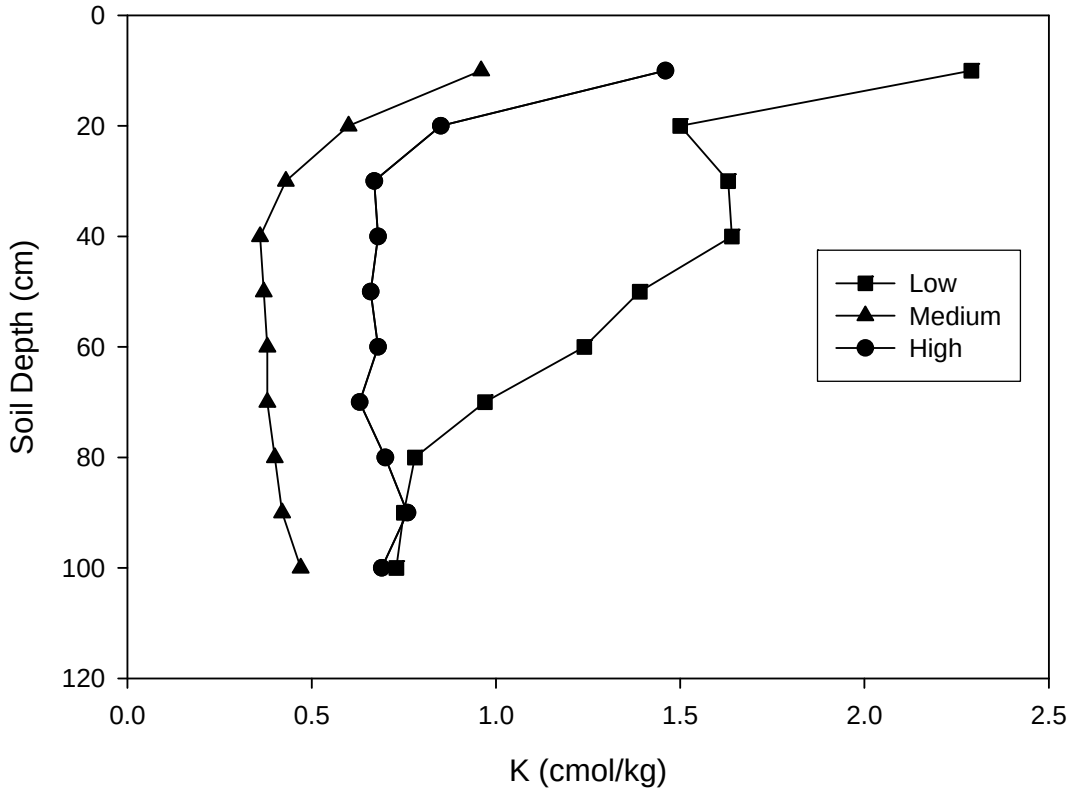


Figure 4. K concentrations in the soils at 3 points at the Hillston-drip site, MIA at a depth of 0-100 cm. Each location corresponds to a low, medium and high EM value.

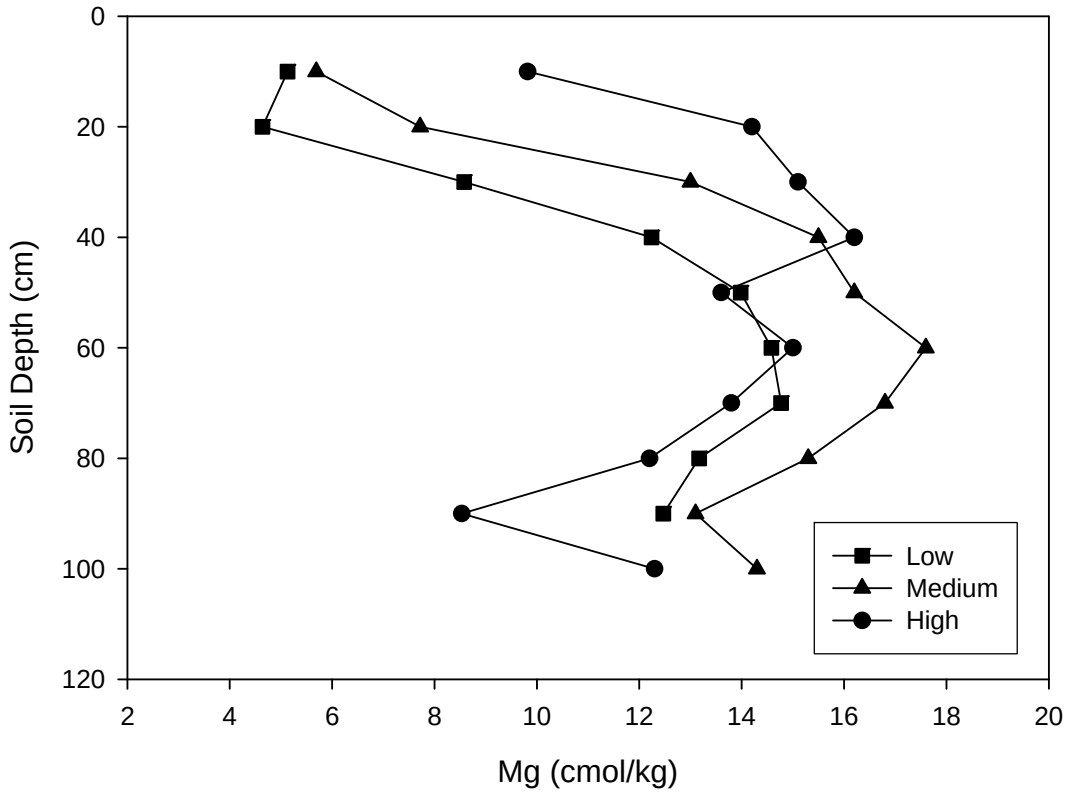


Figure 5. Mg concentrations in the soils at 3 points at the Hillston-drip site, MIA at a depth of 0-100 cm. Each location corresponds to a low, medium and high EM value.

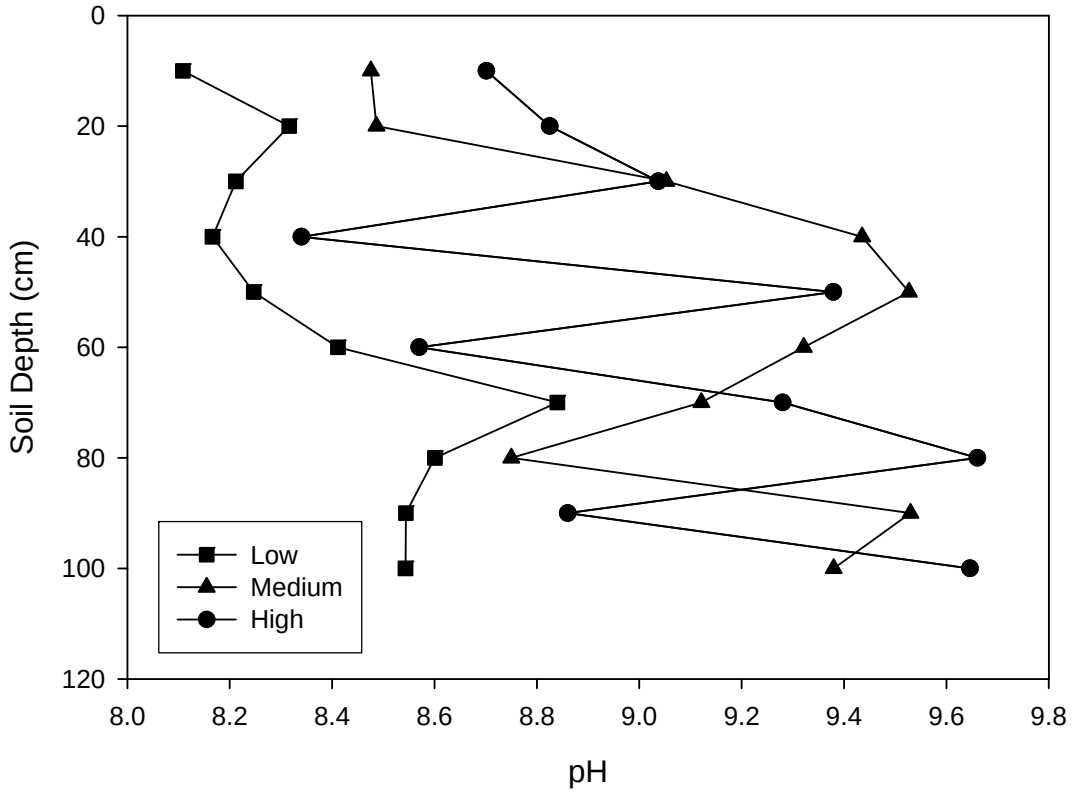


Figure 6. Soil pH at 3 points at the Hillston-drip site, MIA at a depth of 0-100 cm. Each location corresponds to a low, medium and high EM value.

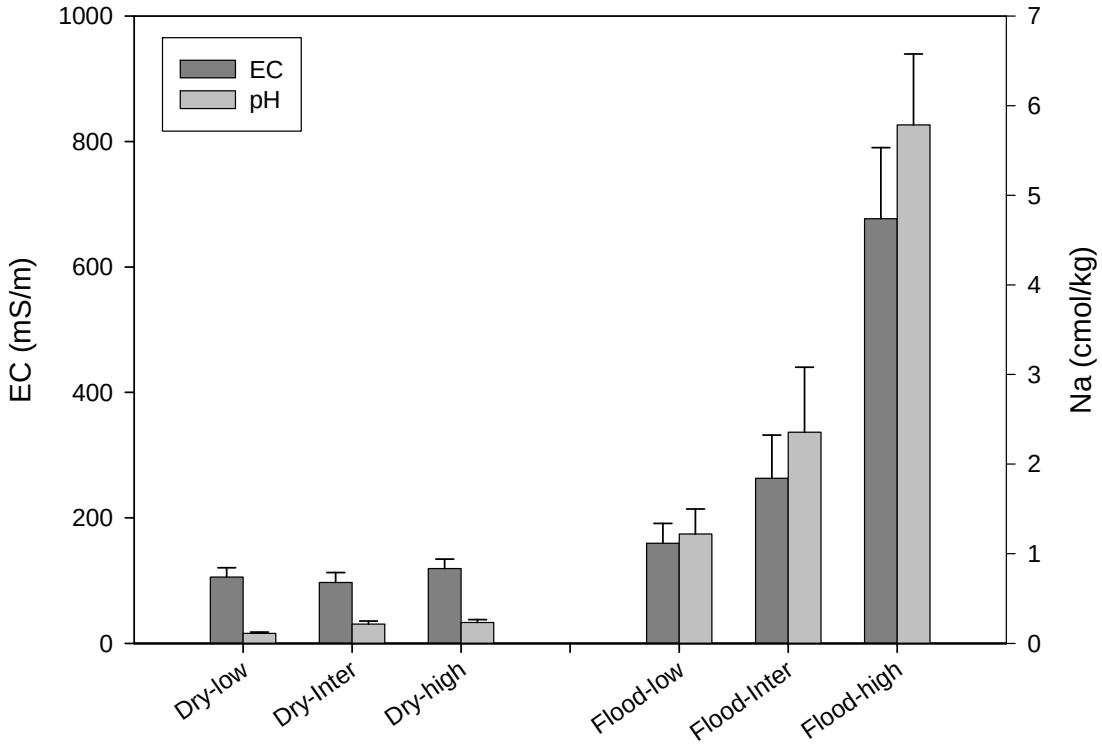


Figure 7. EC and Na levels of soils at the low, intermediate and high EM locations within the Dryland and Flood irrigated vineyards.

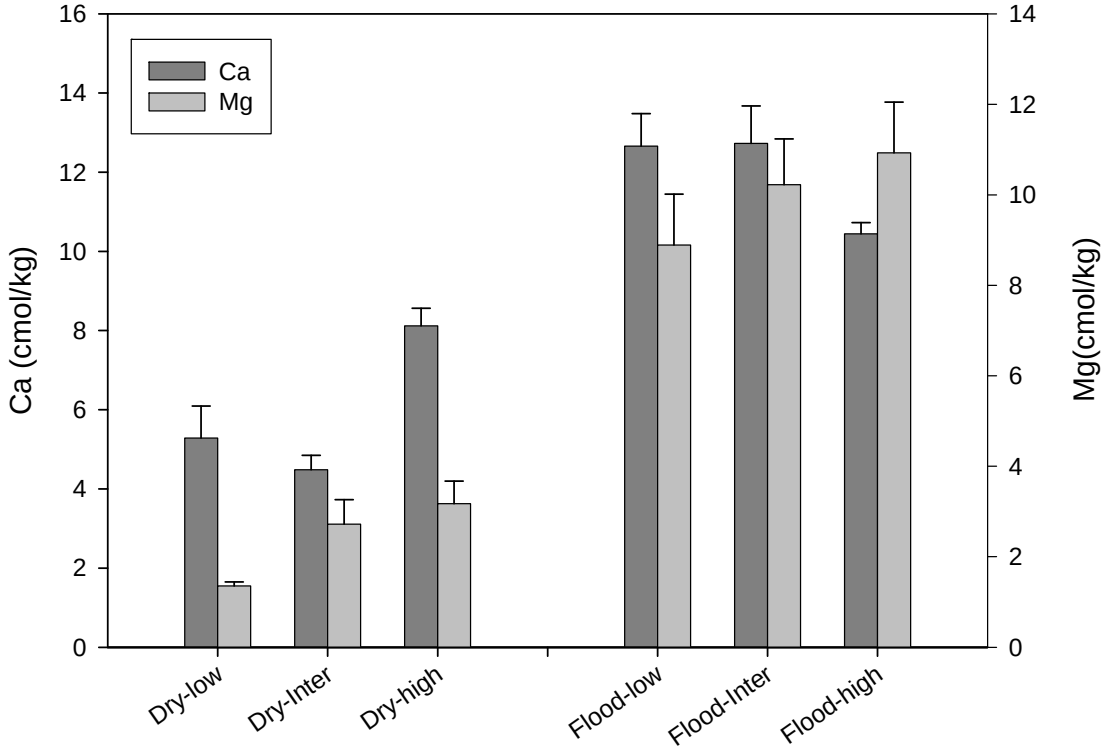


Figure 8. Ca and Mg levels of soils at the low, intermediate and high EM locations within the Dryland and Flood irrigated vineyards.

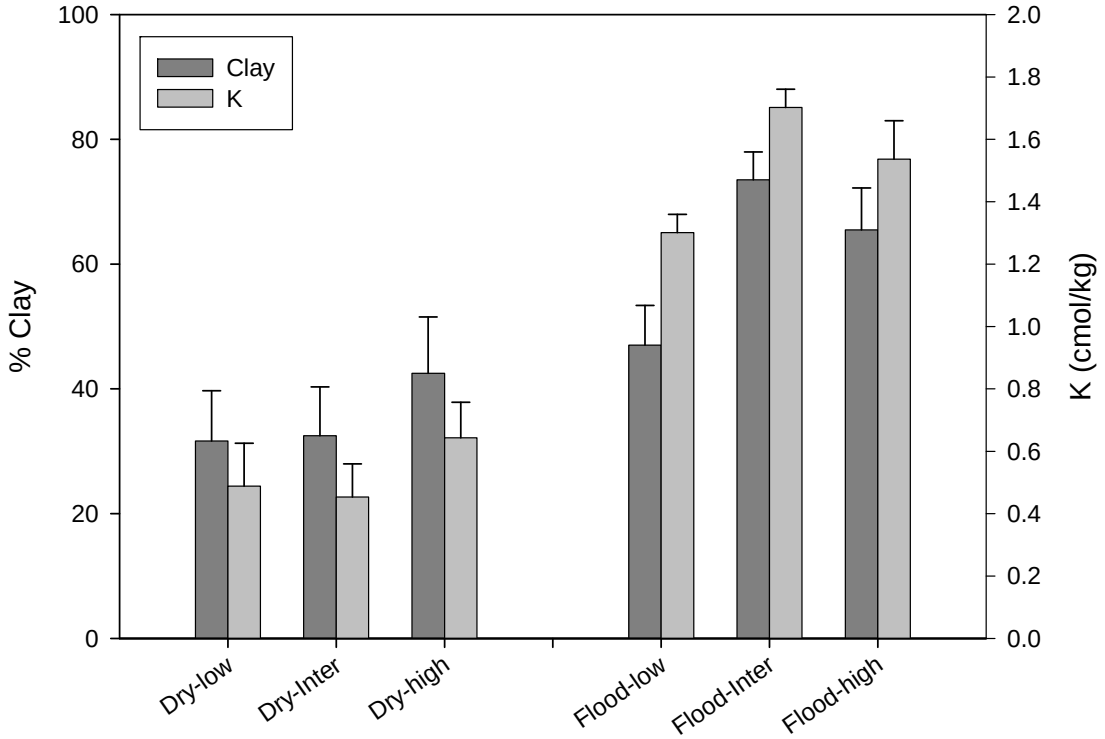


Figure 9. Clay content and K levels of soils at the low, intermediate and high EM locations within the Dryland and Flood irrigated vineyards

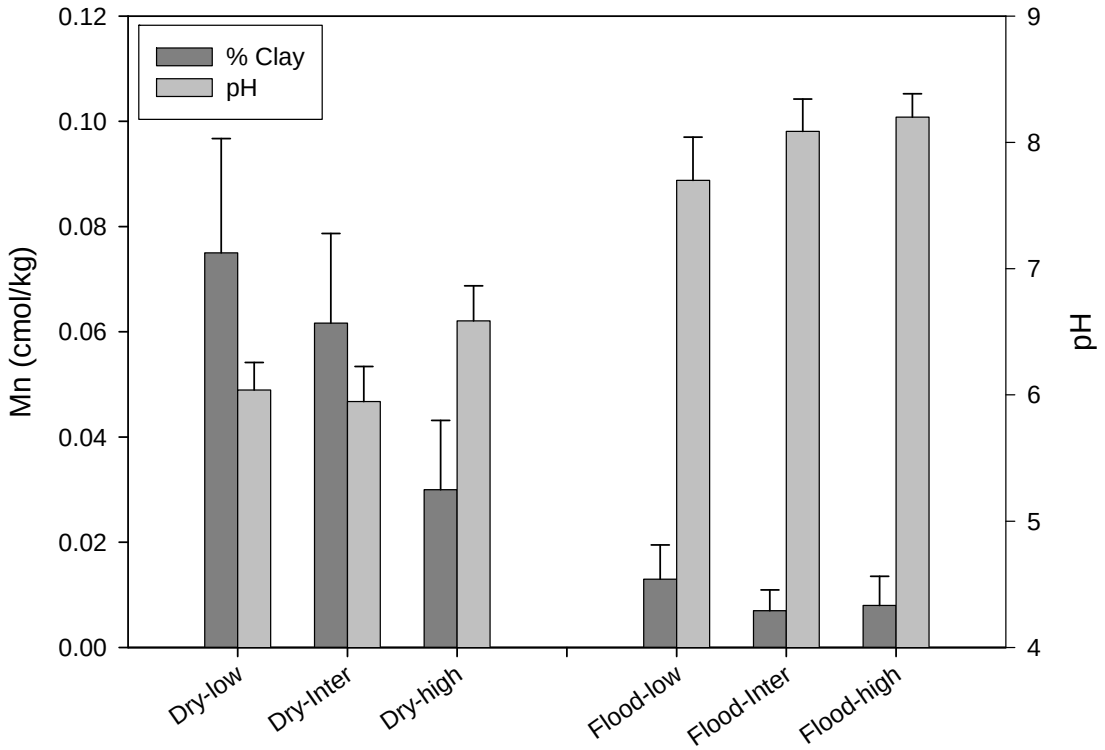


Figure 10. Mn and pH of soils at the low, intermediate and high EM locations within the Dryland and Flood irrigated vineyards.

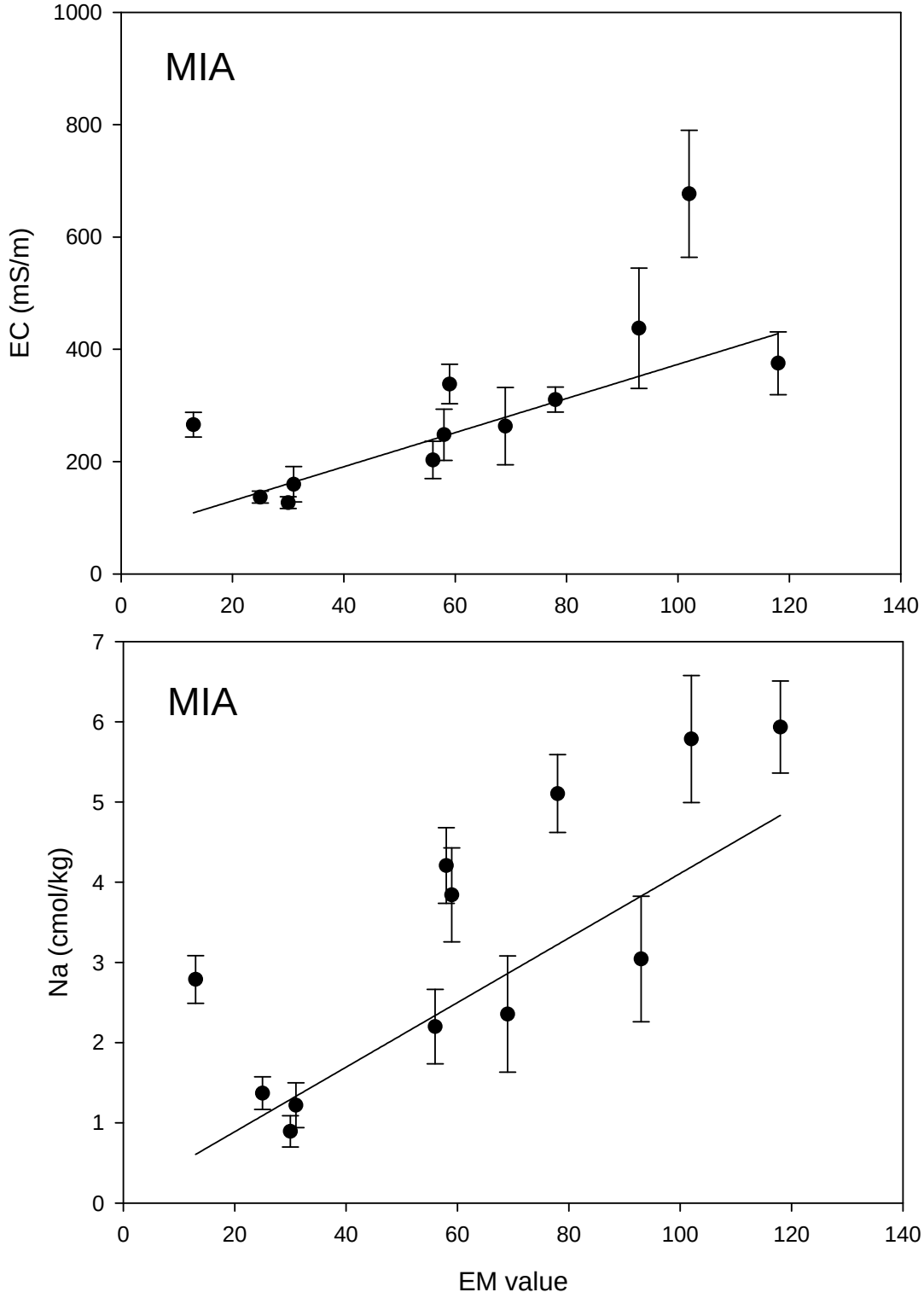


Figure 11. EC and Na levels correlated against EM38 values for vineyards in the MIA.

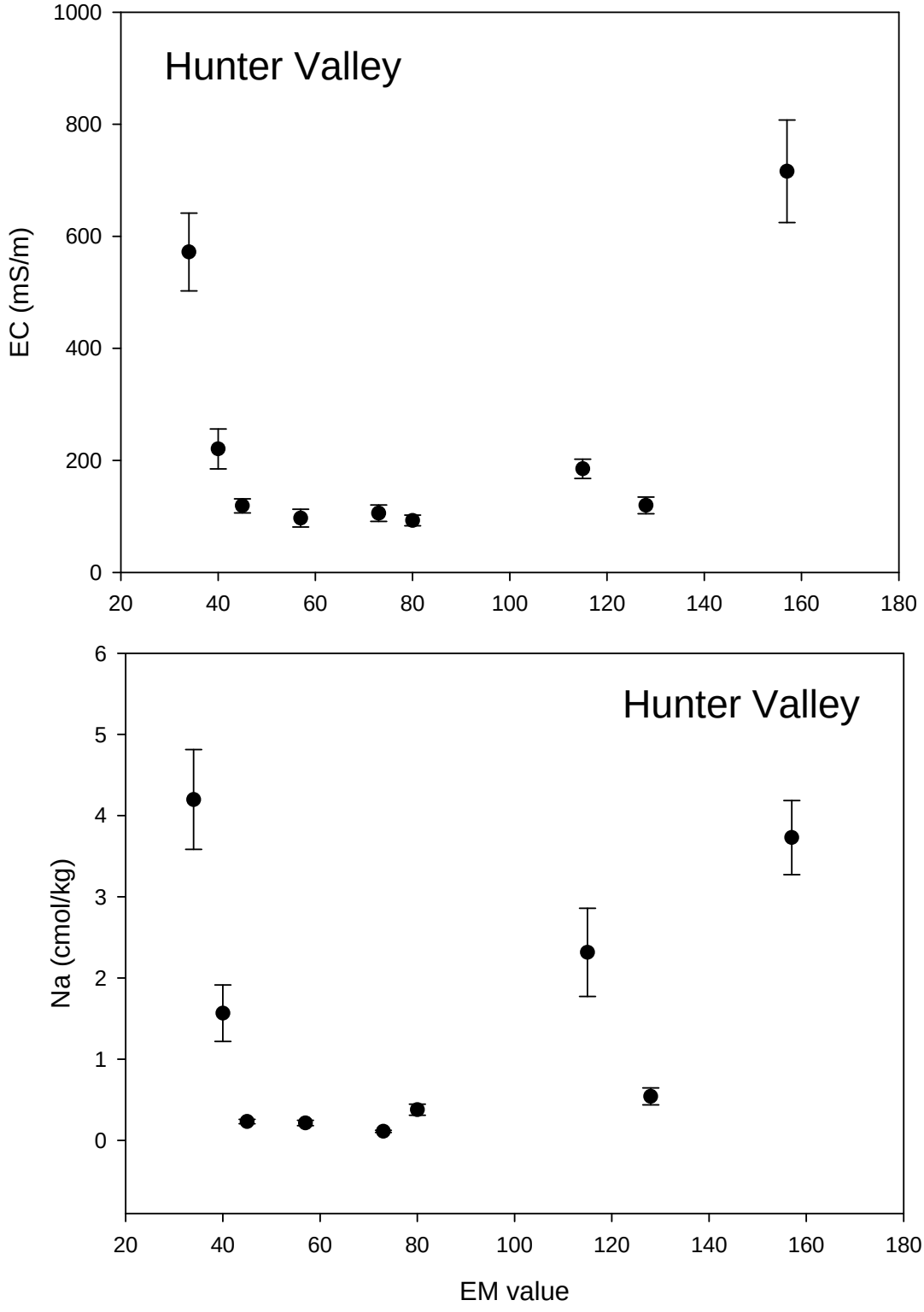


Figure 12. EC and Na levels correlated against EM38 values for vineyards in the Hunter Valley.

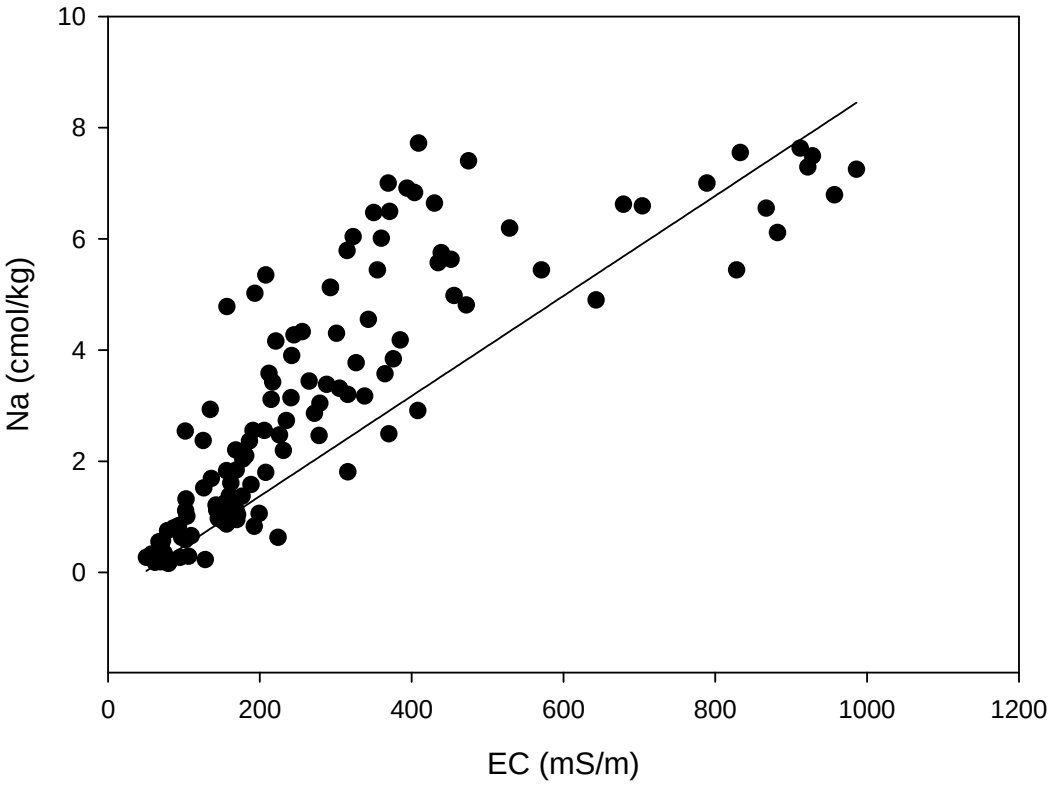


Figure 13A. Na correlated with EC of soils from the Hunter Valley and MIA.

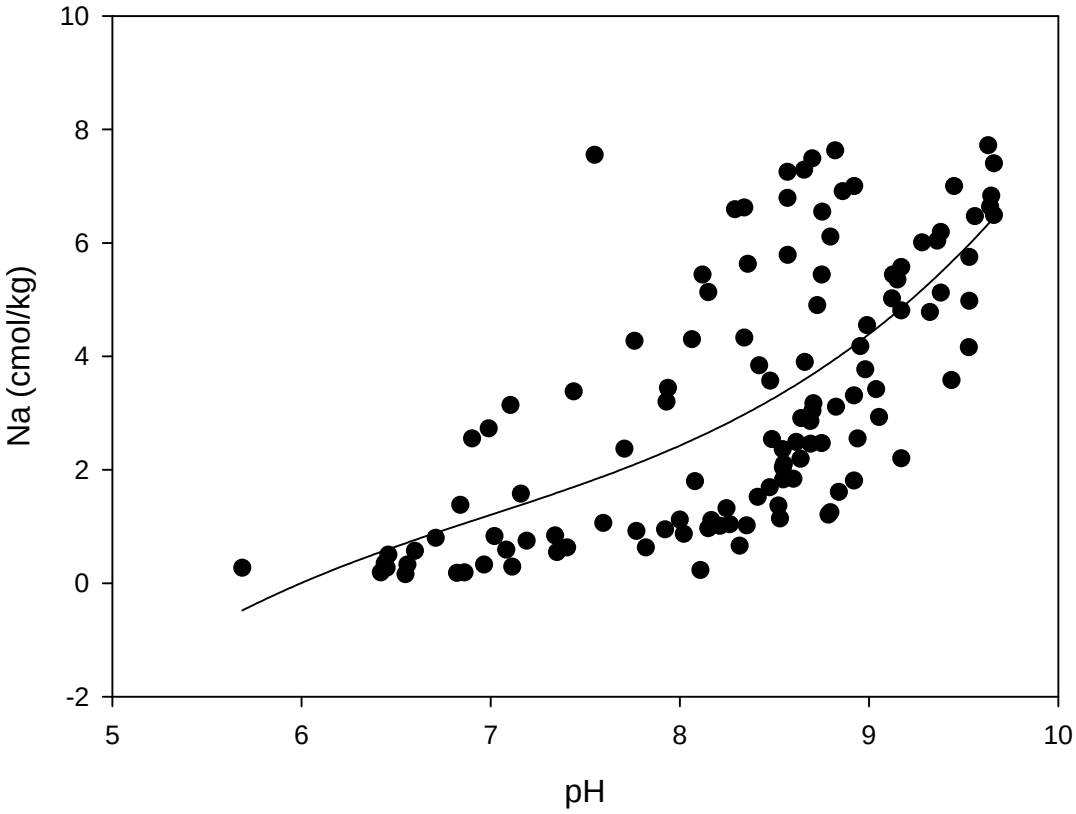


Figure 13B. Na correlated with pH of soils from the Hunter Valley and MIA.

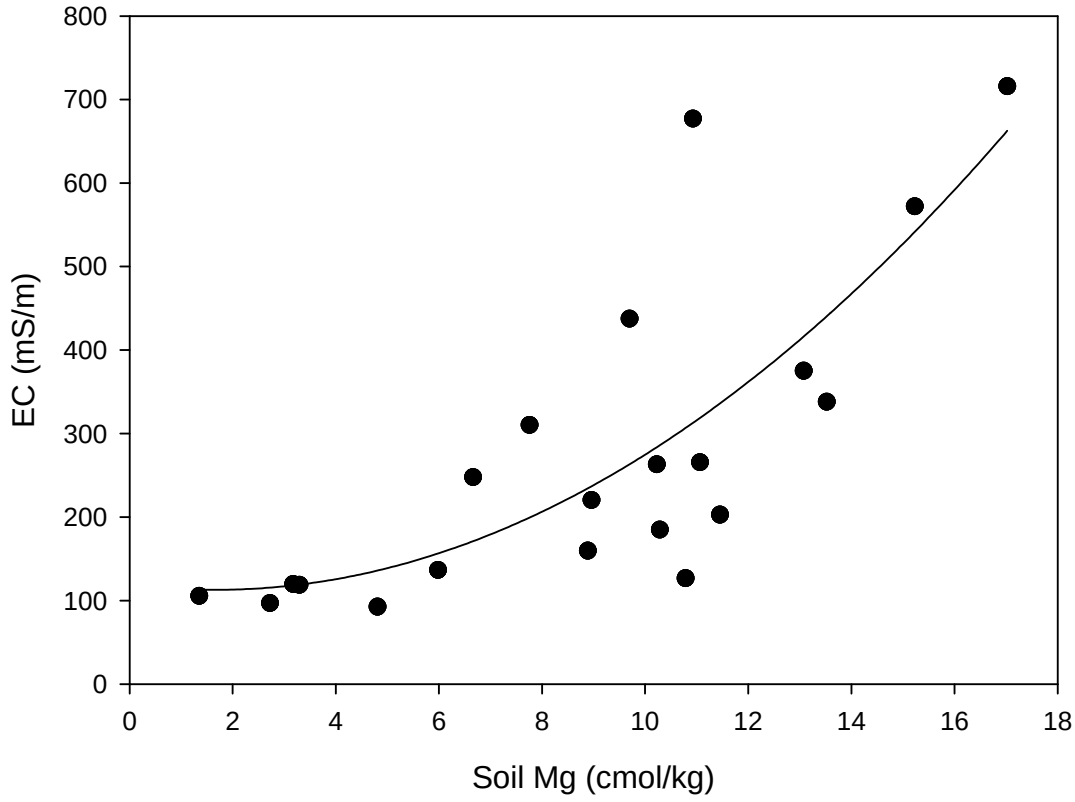


Figure 13C. EC related to Soil Mg levels in the MIA and Hunter Valley vineyards. Each data point represents the mean of 10 depths to 1m.

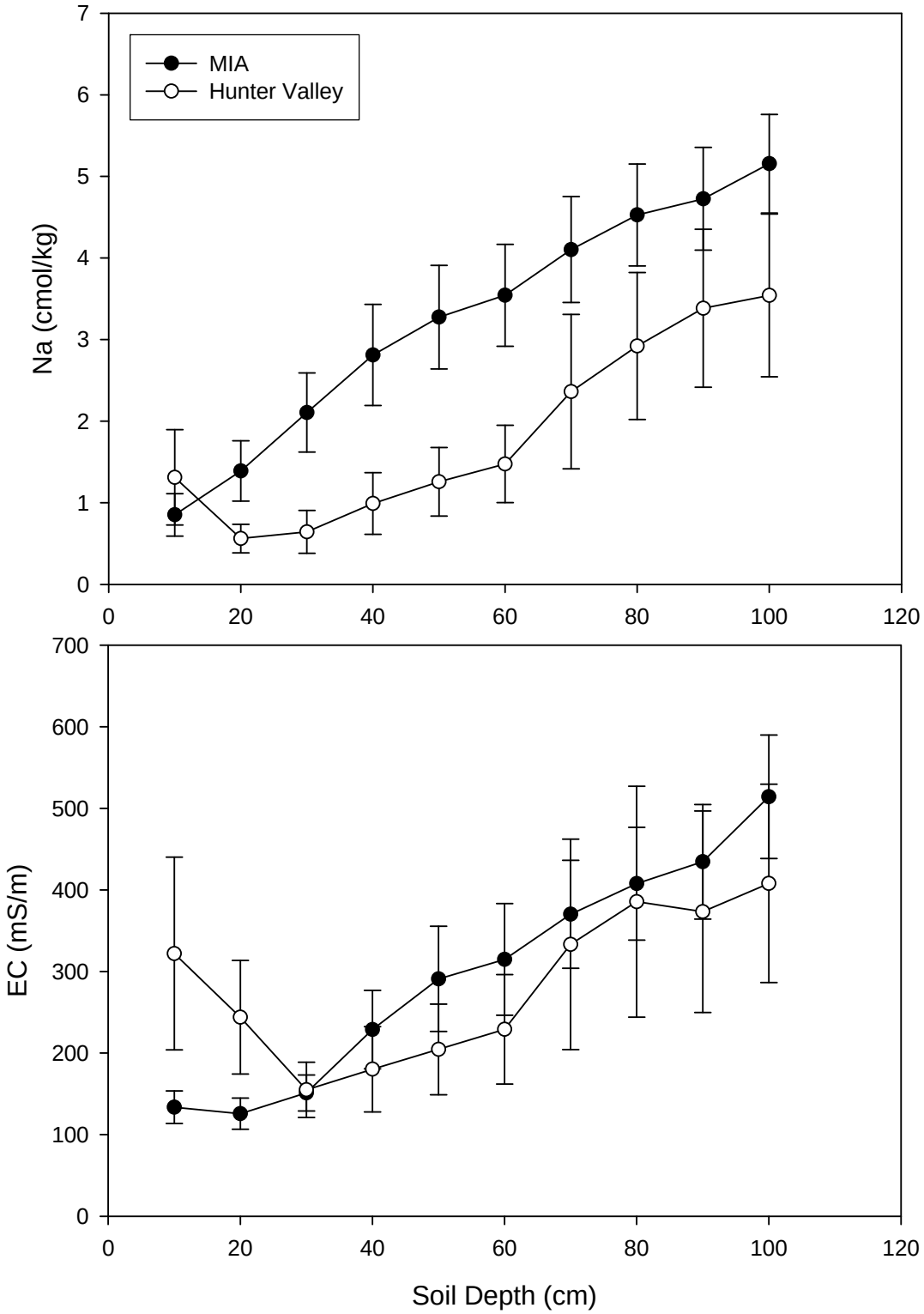


Figure 14. Na and EC changes with soil depth for vineyards of the MIA and the Hunter Valley.

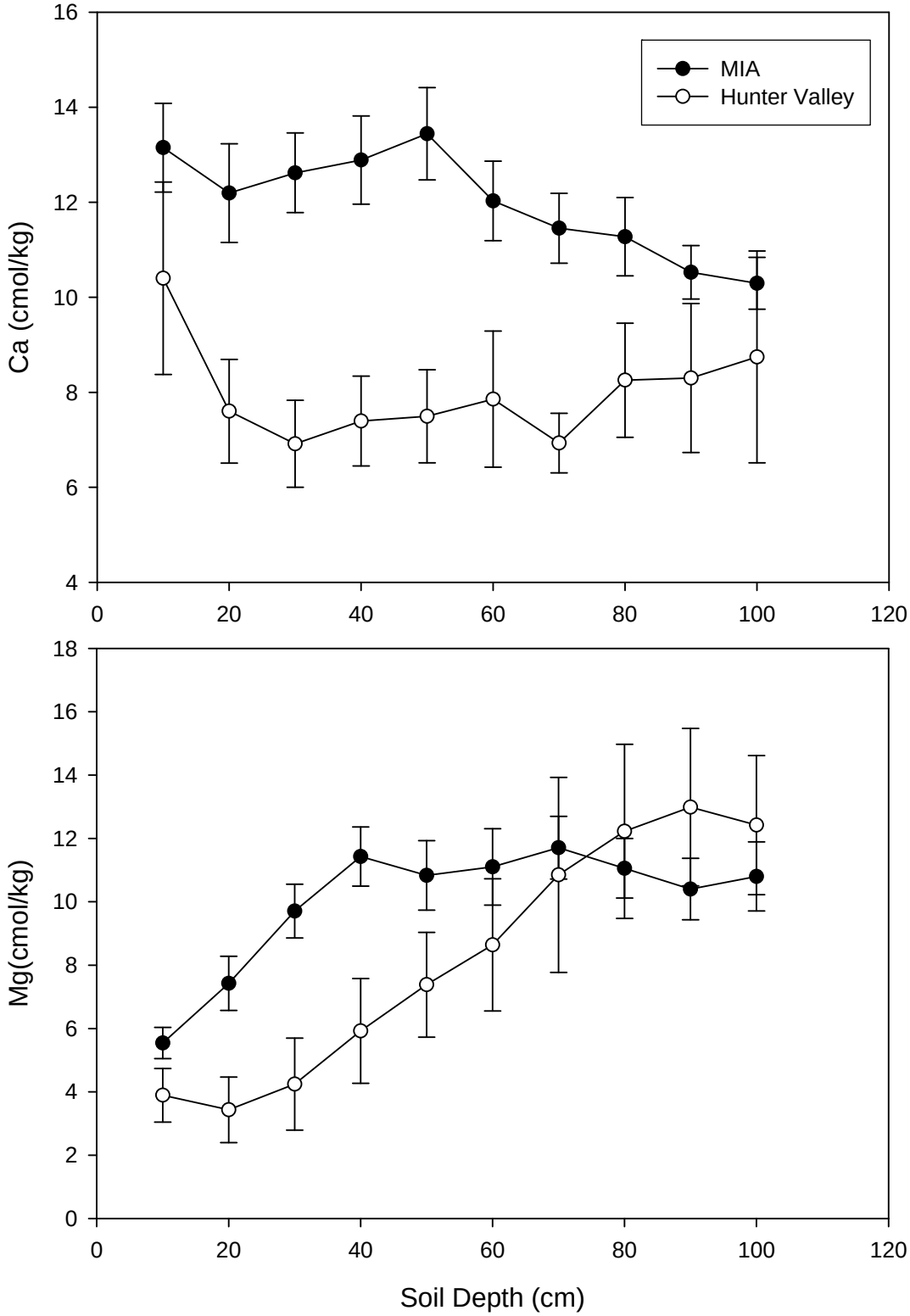


Figure 15. Ca and Mg changes with soil depth for vineyards of the MIA and the Hunter Valley.

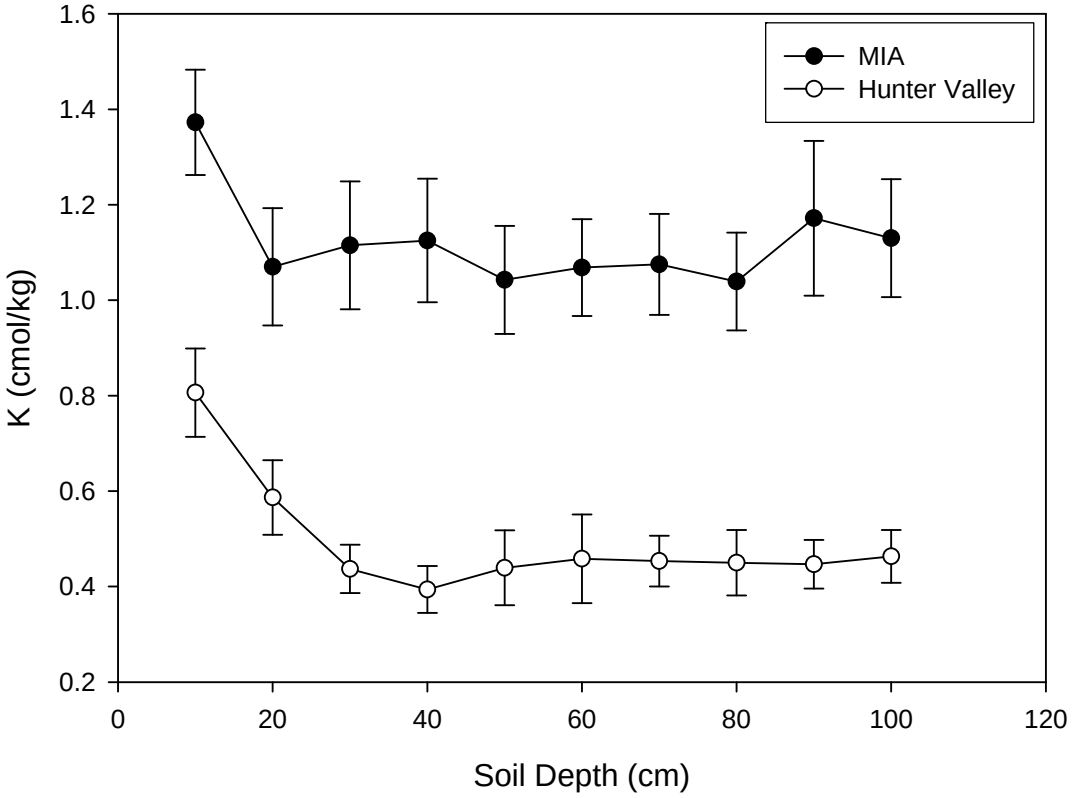


Figure 16. K concentrations with soil depth for vineyards of the MIA and the Hunter Valley.

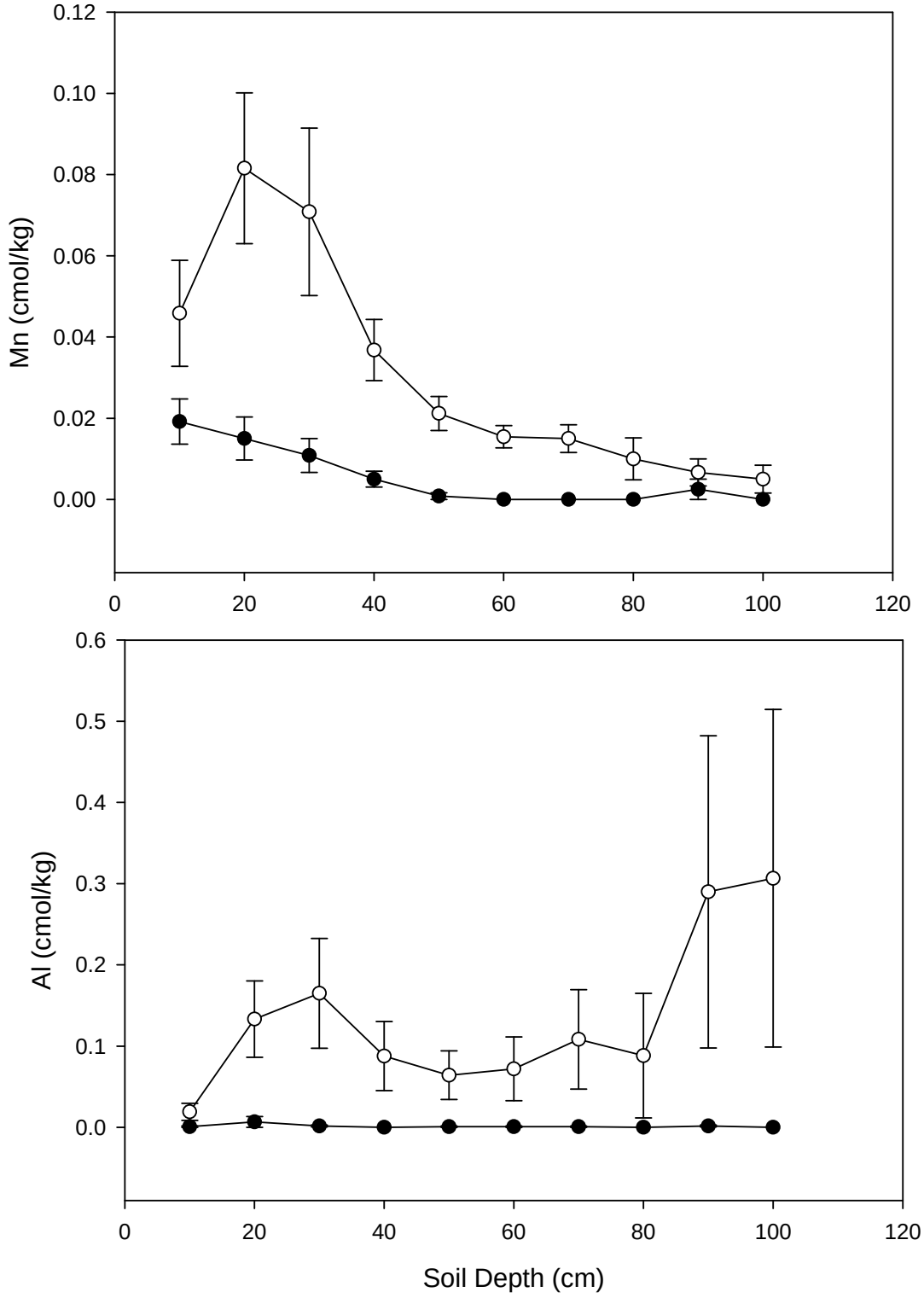


Figure 17. Mn and Al concentrations with soil depth for vineyards of the MIA and the Hunter Valley

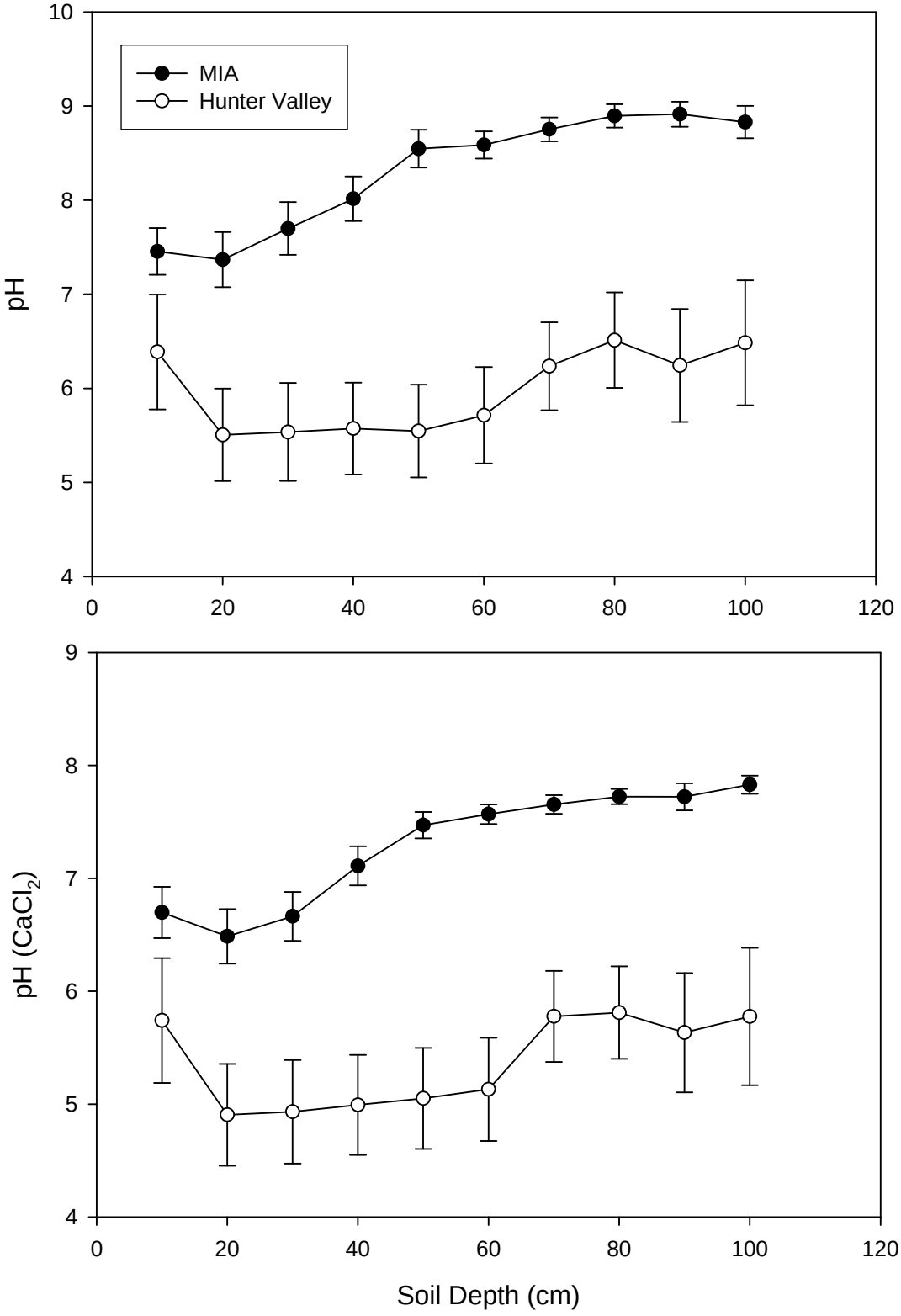


Figure 18. pH and pH ($CaCl_2$) changes with soil depth for vineyards of the MIA and the Hunter Valley

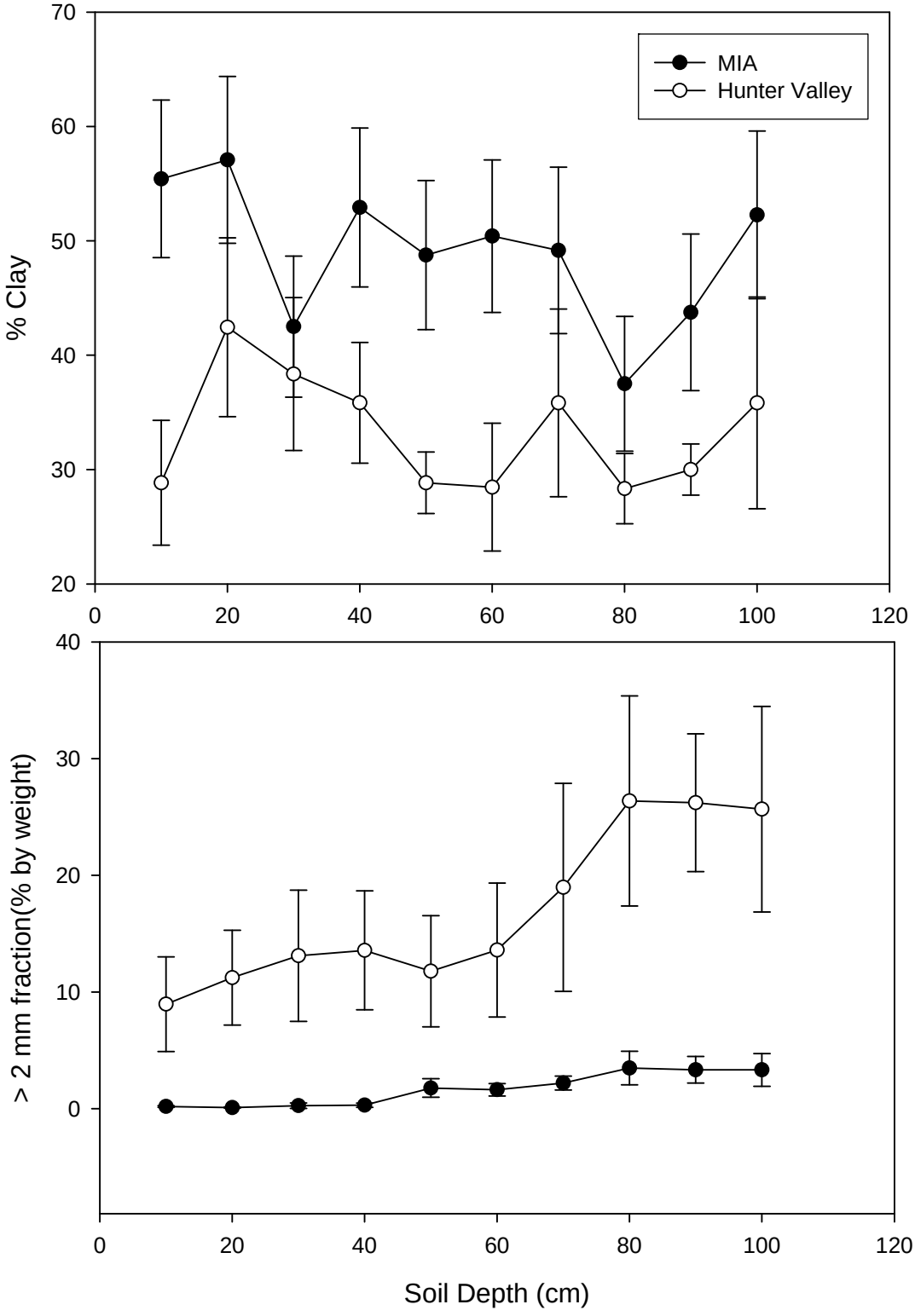


Figure 19. Clay content and changes in > 2 mm fraction of soil particles for vineyards of the MIA and the Hunter Valley

6. 1: Regional Study
C. Vineyard Soil Moisture

The availability of water to vines is dependent on a number of factors including rainfall patterns, type of irrigation, competing plant species and soil type. Soil properties including the water holding capacity of the soil determine the water availability to the plant. Grapevine root distribution also has an effect with hardpans and subsoil acidity limiting the depth to which roots grow. The type of irrigation applied will have an affect on the depth and horizontal spread of roots.

A characteristic soil moisture profile is provided for three sites below. The first site is the Hillslope-drip site in the Hunter Valley with frequent watering events throughout the season (Figure 1). Soil tension did not exceed 100 kPa at the 20 and 40 cm depths and 50 kPa at the 60 and 80 cm depths for most of the season. In the Dryland site, however, soil moisture continued to decline throughout the season reaching less than 500 kPa at the greater depths (Figure 2).

The readily available water (RAW) is shown for an MIA flood irrigated vineyard at the low, intermediate and high EM locations (Figure 3). The infrequent flooding events were not enough to keep the soil tensions from gradually increasing throughout the season. A comparison of the RAW of the 4 vineyards in the MIA and the three vineyards in the Hunter Valley indicated that the Dryland site had by far the least available RAW (Figure 4). There was extensive variability in soil moisture between the three points within a vineyard, however there was no correlation between soil moisture and the EM value (Figures 5A and 5B).

Soil moisture declined with depth in some vineyards such as the Dryland site (Figure 6). But in other vineyards the soil was fairly wet through the entire profile (Figure 7). As the season progressed the 25 and 50 cm portions dried out in the Dryland site (Figure 8), and in the Yenda-Flood site the inter-row area contained more moisture than underneath the vine (Figure 9).

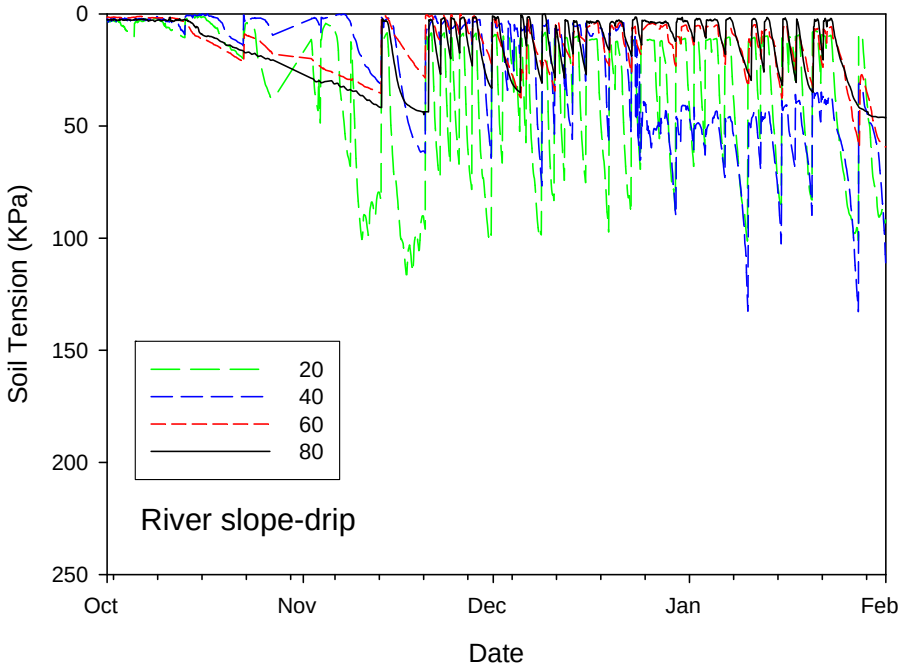


Figure 1. Soil tension at the Hillslope-drip site during the 06-07 season.

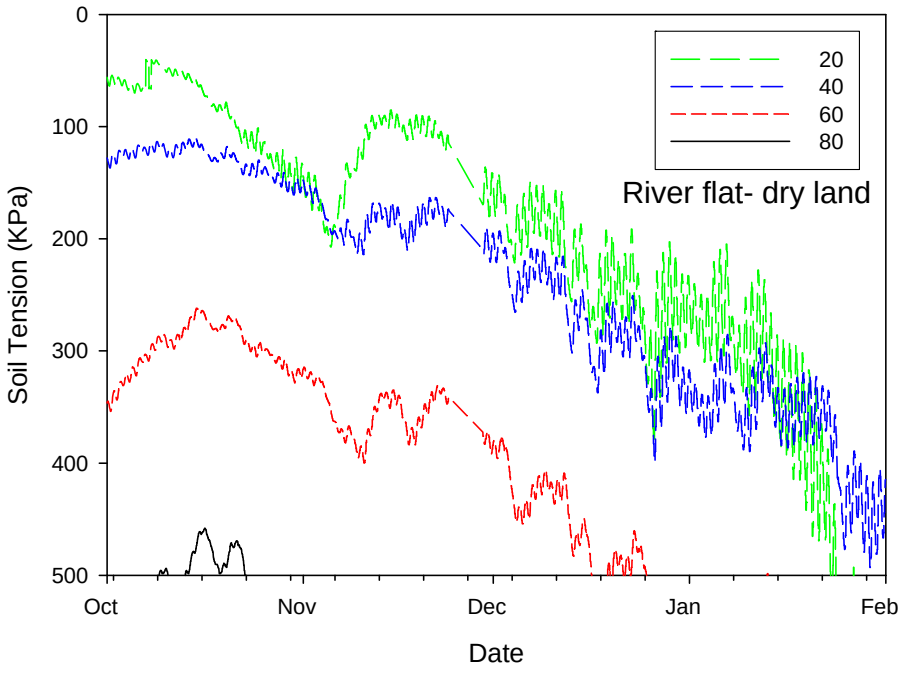


Figure 2. Soil tension at the Dryland site during the 2006-7 season

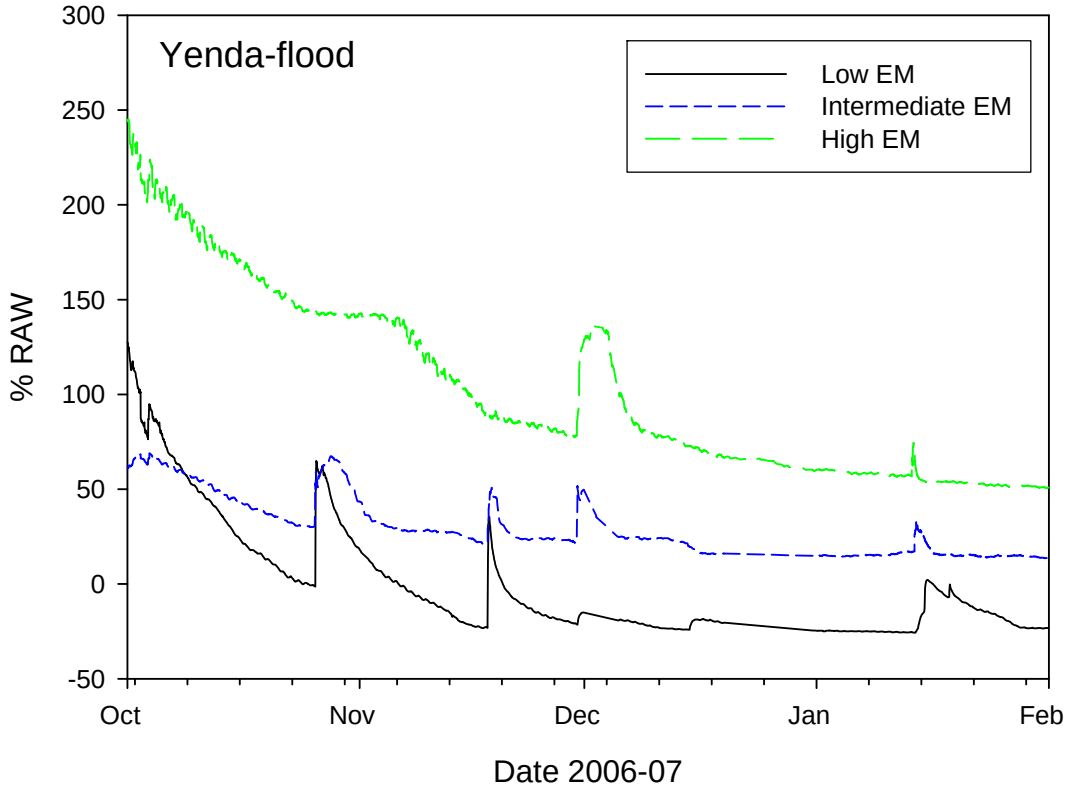


Figure 3. %Readily Available Water (RAW) of the low, intermediate and high EM locations over the 2006-07 season at the Flood irrigated vineyard.

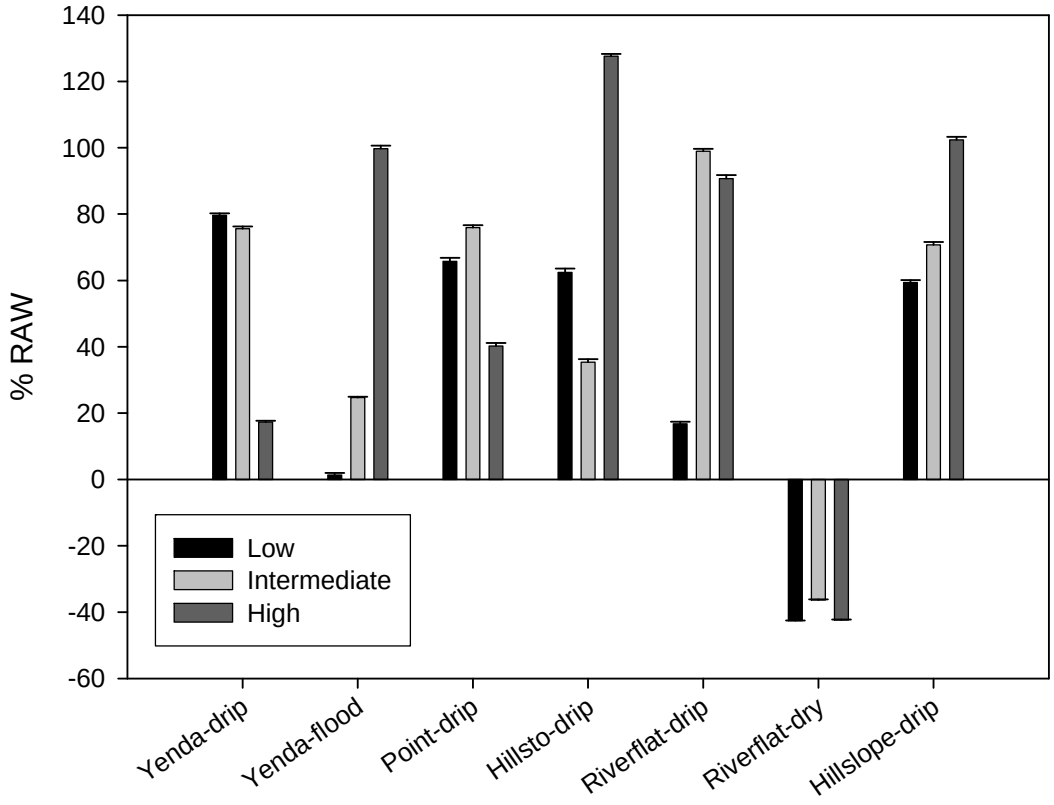


Figure 3. Readily available water (RAW) at the low, intermediate and high EM locations for the Hunter Valley and MIA vineyards during the 2006-07 season. Values were averaged for the period of October to February (budburst to harvest).

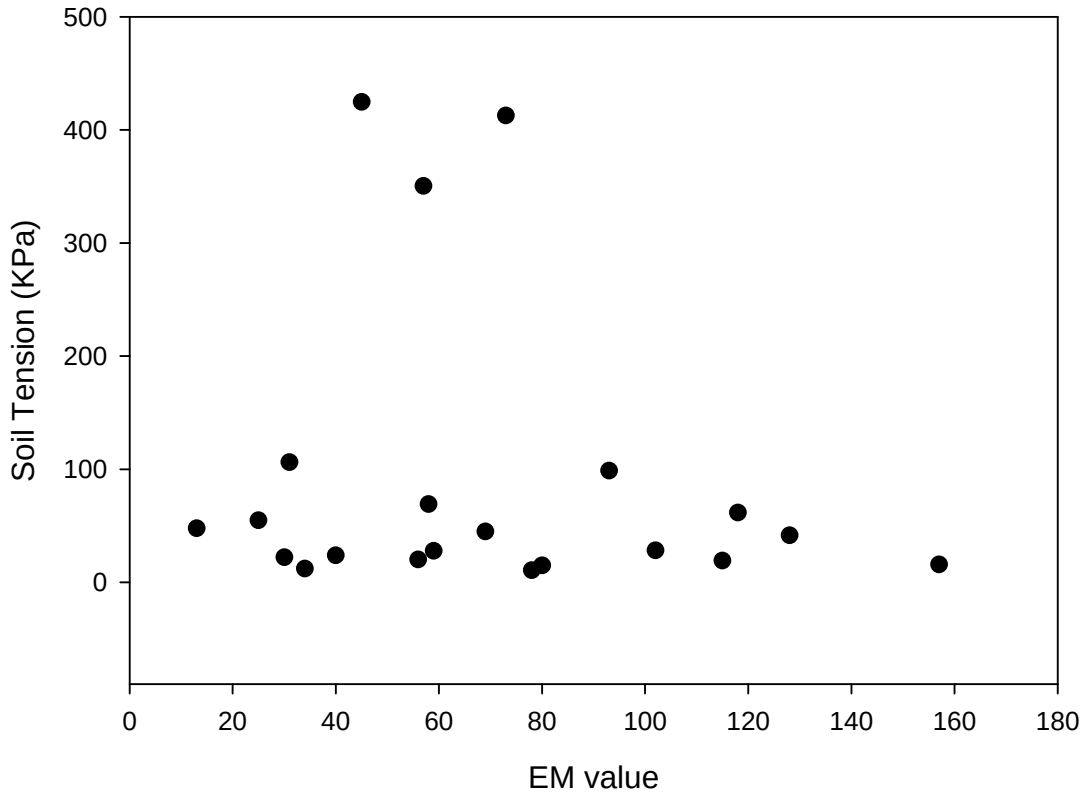


Figure 5A. Correlation between EM value and mean seasonal soil tension for all the sites.

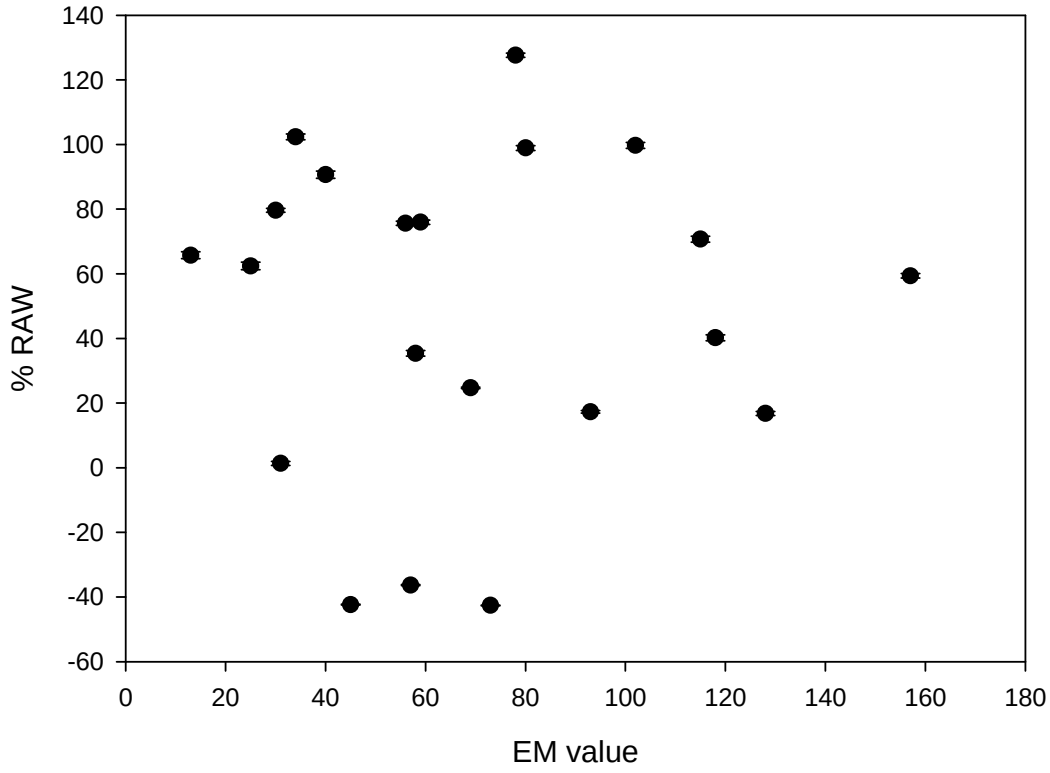


Figure 5B. Correlation between EM value and mean seasonal %RAW for all the sites.

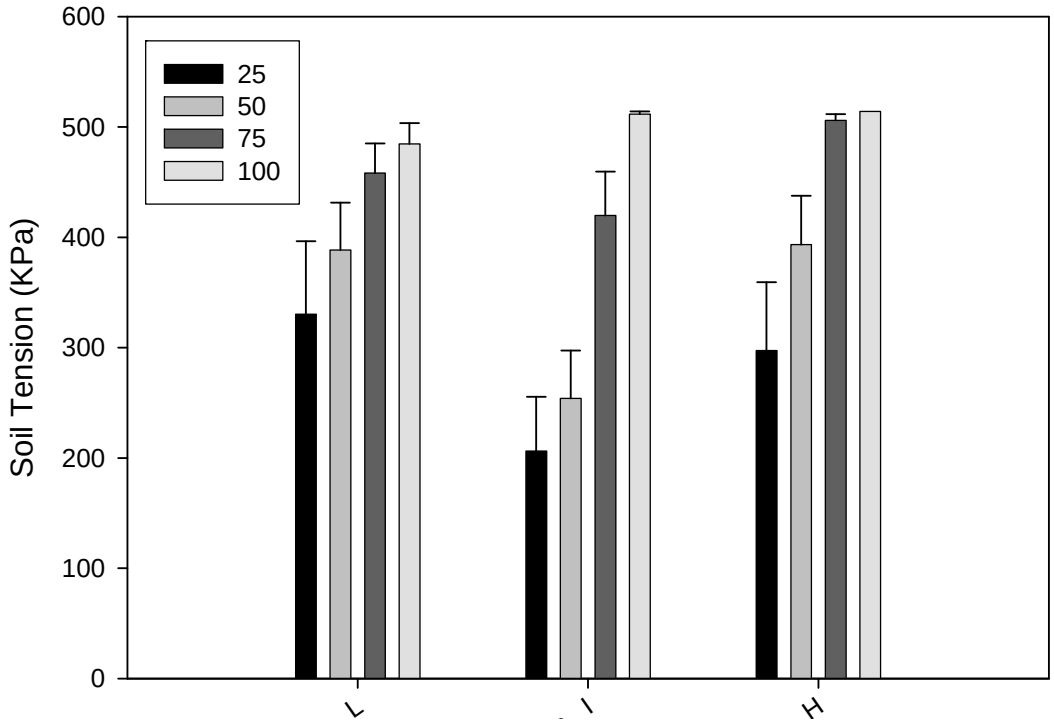


Figure 6. Soil tensions with increasing depths from 25 to 100 cm at the Dryland site in the low, intermediate and high EM locations.

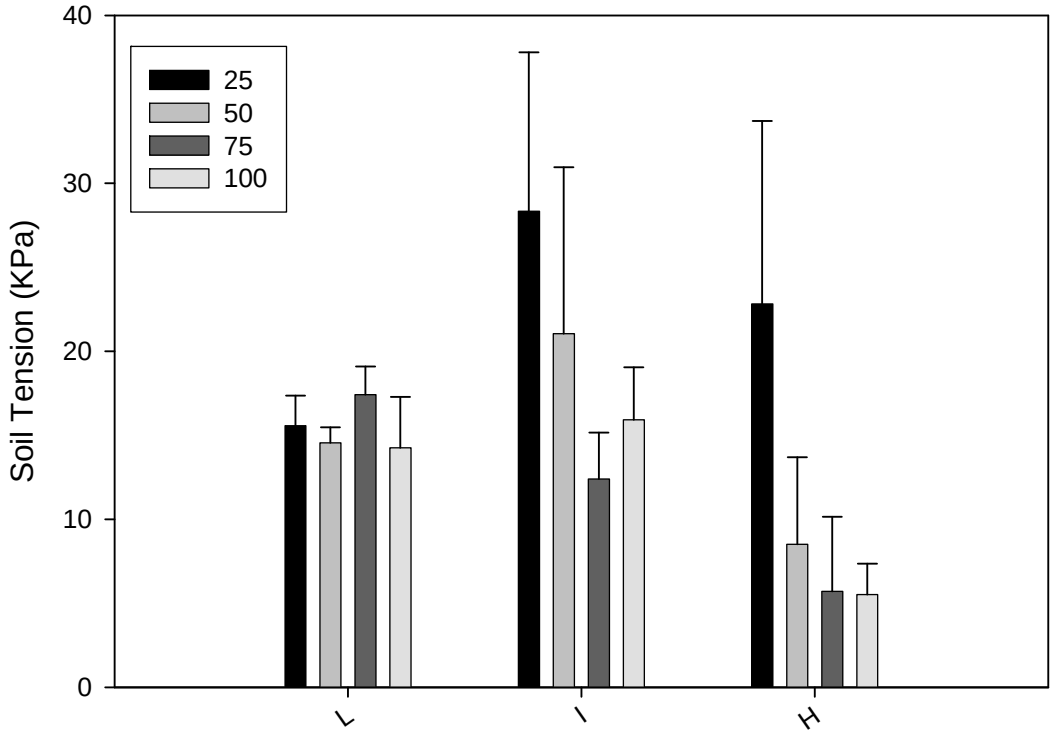


Figure 7. Soil tensions with increasing depths from 25 to 100 cm at the Hillslope-drip site in the low, intermediate and high EM locations. Values are averaged over the season.

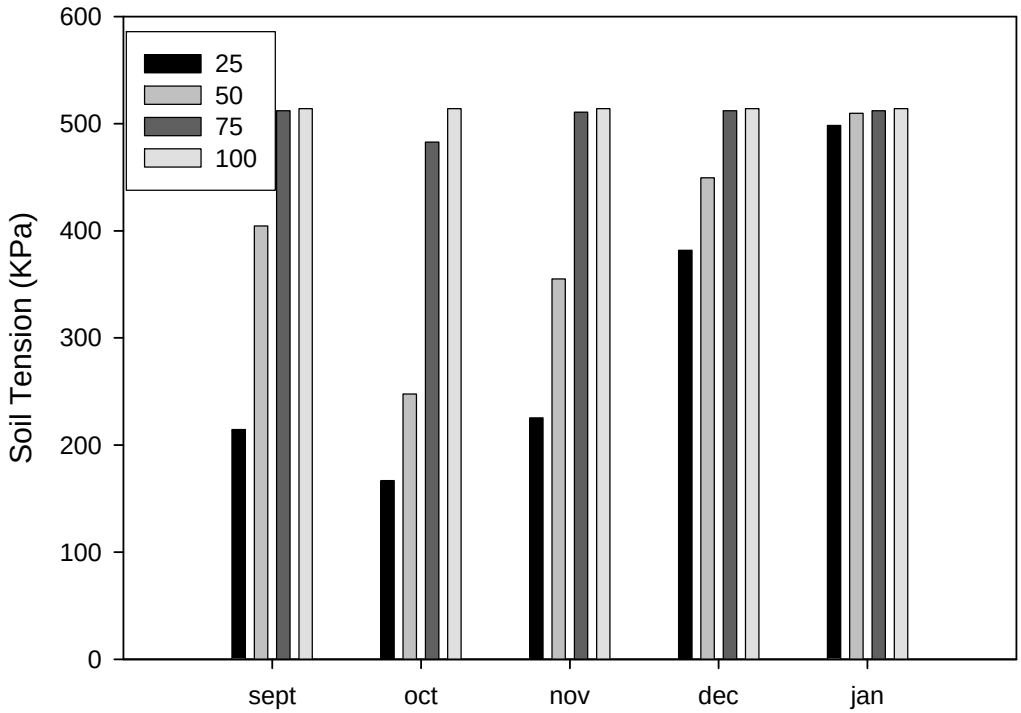


Figure 8. Soil tension over the season at the 4 depths at the riverflat Dryland vineyard at the Low EM location.

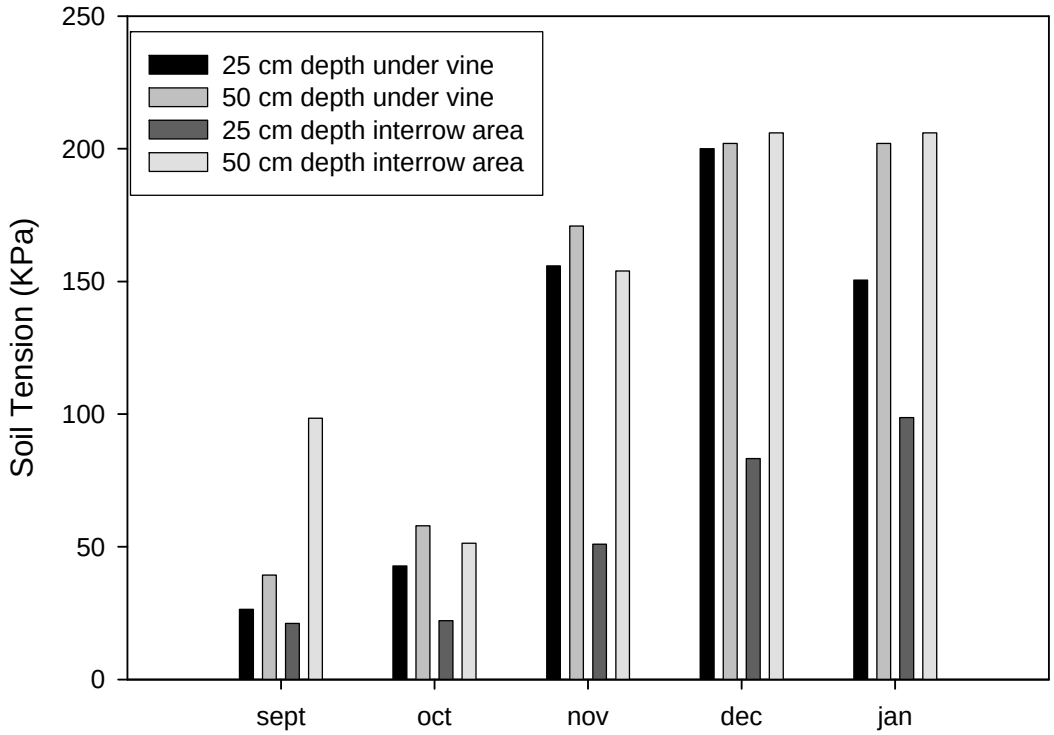


Figure 9. Soil tension over the season at the 2 depths beneath the vine and in the inter-row area in the Yenda-Flood site at the L location.

6.1: Regional Study
E. Canopy temperature and humidity

In order to better understand the impact of weather on the capability of Semillon vines to maintain healthy canopies and to ripen fruit to optimum composition, relative humidity and temperature were monitored at canopy height in each vineyard. There were only slight differences between the vineyards within Griffith or the Hunter Valley (with the exception of one vineyard in Hillston) so averages for the regions are shown. Maximum daily temperatures were not different between the two regions in the 2006-07 season, but in the 2007-08 season it was warmer in the spring in the Hunter Valley than in the MIA (Figure 2). As the season progressed, however, temperatures were higher in the MIA in November and January. Minimum temperatures tended to be lower in the spring in the MIA vineyards as well, but again later in the season they were slightly higher in the MIA. Mean maximum temperatures reached to 32°C in January in both regions in the 2006-07 season, but in the 2007-08 season they were not as extreme in the Hunter Valley (29°6C). Mean minimum temperatures ranged from 16 to 18°C in January.

The higher humidity in the Hunter Valley led to lower VPDs in this region, especially in the 2007-08 season (Figures 3 and 4). Mean daily relative humidity ranged from 60 to 75% in the Hunter Valley, while in the MIA they ranged from 40-50%. Mean monthly maximum VPDs were less than 2.0 kPa in September, but as the season progressed they reached to 4.1 kPa. Within January there were 10 days with VPDs greater than 5.0 kPa and 1 day greater than 6.0 kPa in the MIA (Figure 5).

Rain had a significant impact on soil moisture levels within the two regions. There was 4-fold more rain in the 2006-07 season as compared with the 2007-08 season in both regions (Figure 6). In both seasons there was twice as much rain in the Hunter Valley than in the MIA. Nearly 400 mm fell during from September to the end of January in the Hunter Valley in the second season. This officially ended the drought in this region.



Figure 1. Each vineyard was equipped with a weather station and a humidity and temperature probe. Note the hole next to the weather station where the soil core was taken for soil chemistry analyses.

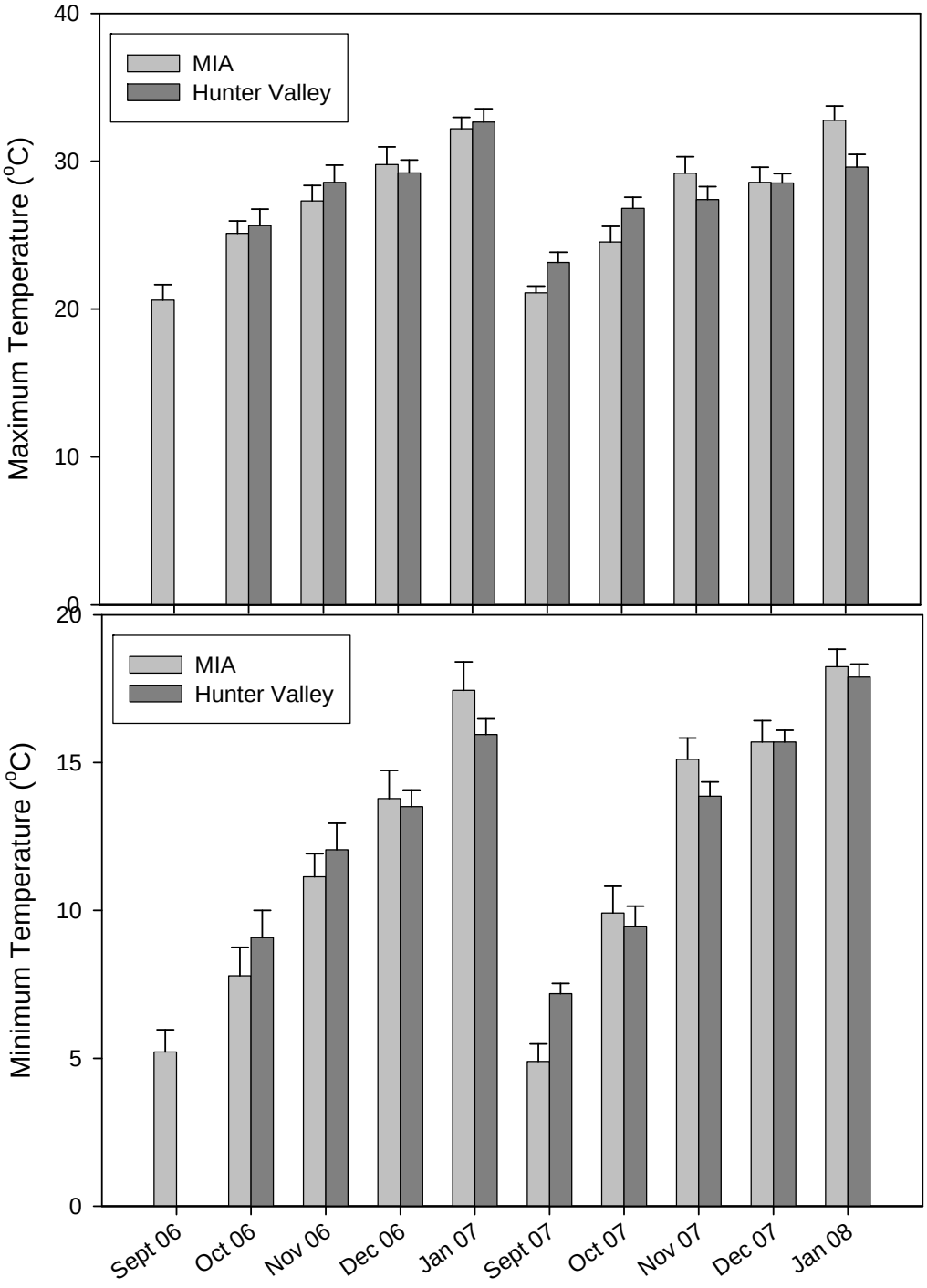


Figure 2. Maximum and minimum air temperatures in the MIA and the Hunter Valley vineyards during the 2006-07 and 2007-08 seasons.

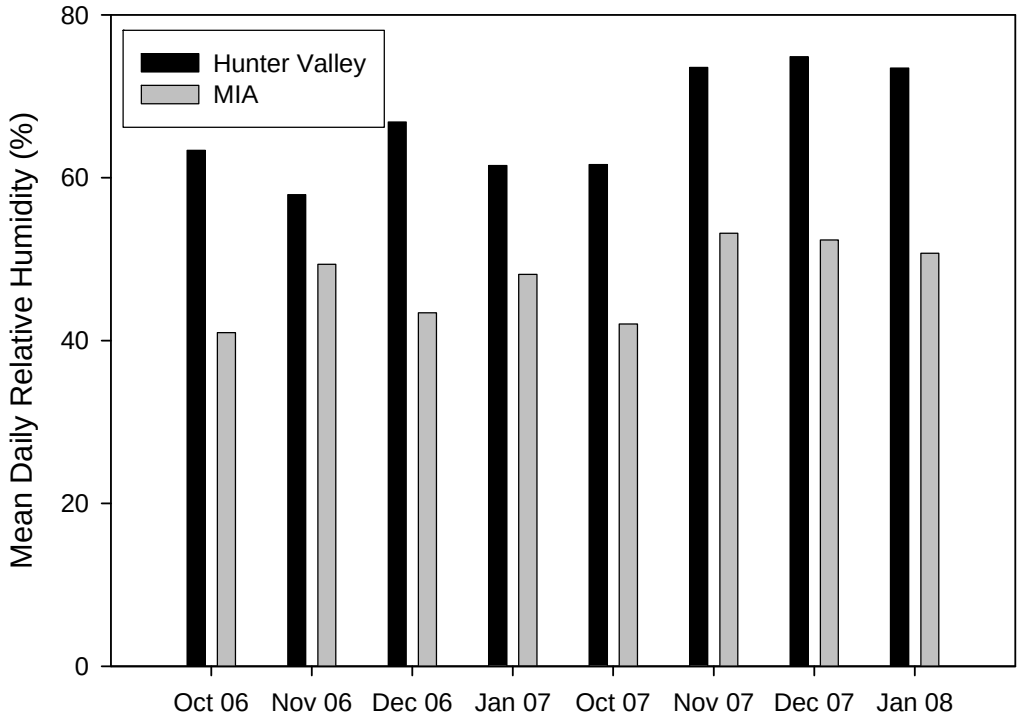


Figure 3. Mean daily RH in the MIA and the Hunter Valley vineyards during the 2006-07 and 2007-08 seasons.

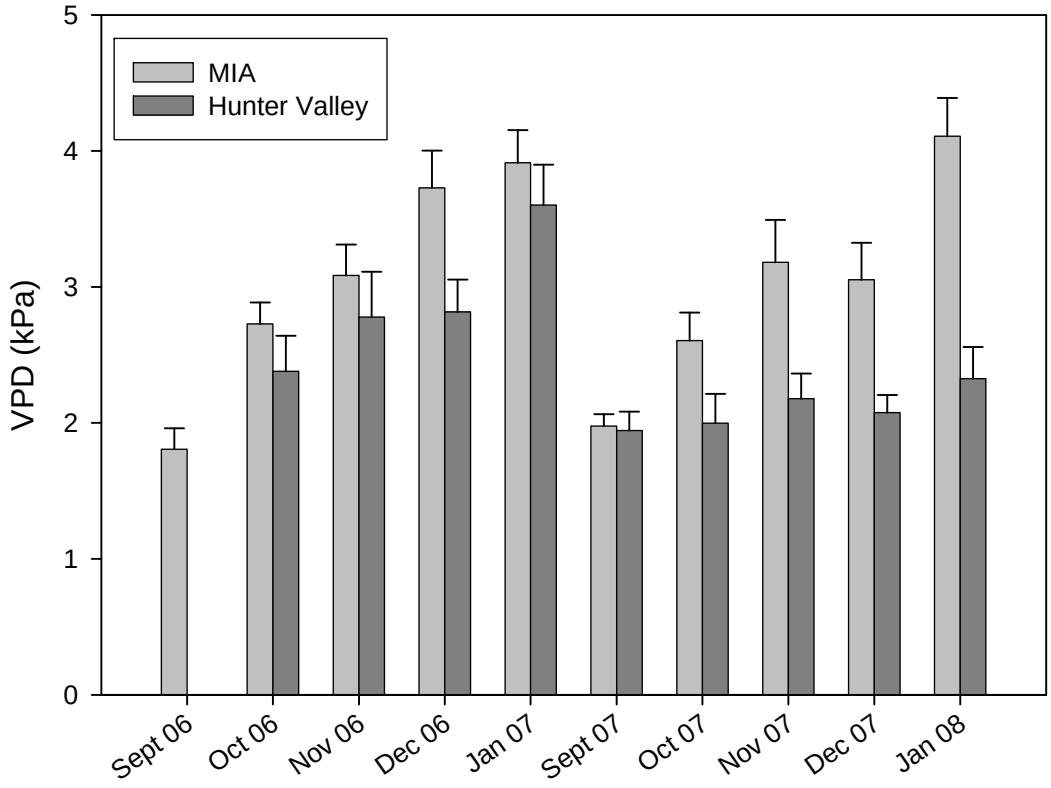


Figure 4. Monthly mean of the daily maximum VPD in the MIA and the Hunter Valley vineyards during the 2006-07 and 2007-08 seasons.

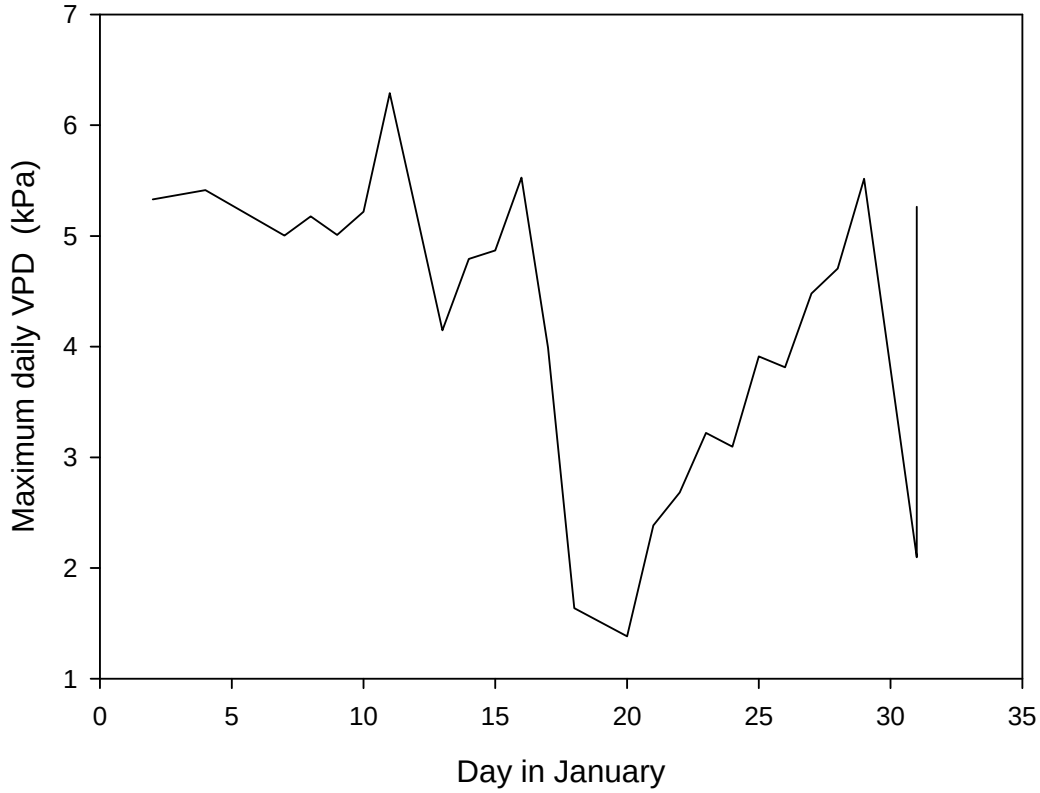


Figure 5. Maximum daily VPD in the MIA during the month of January 2008.

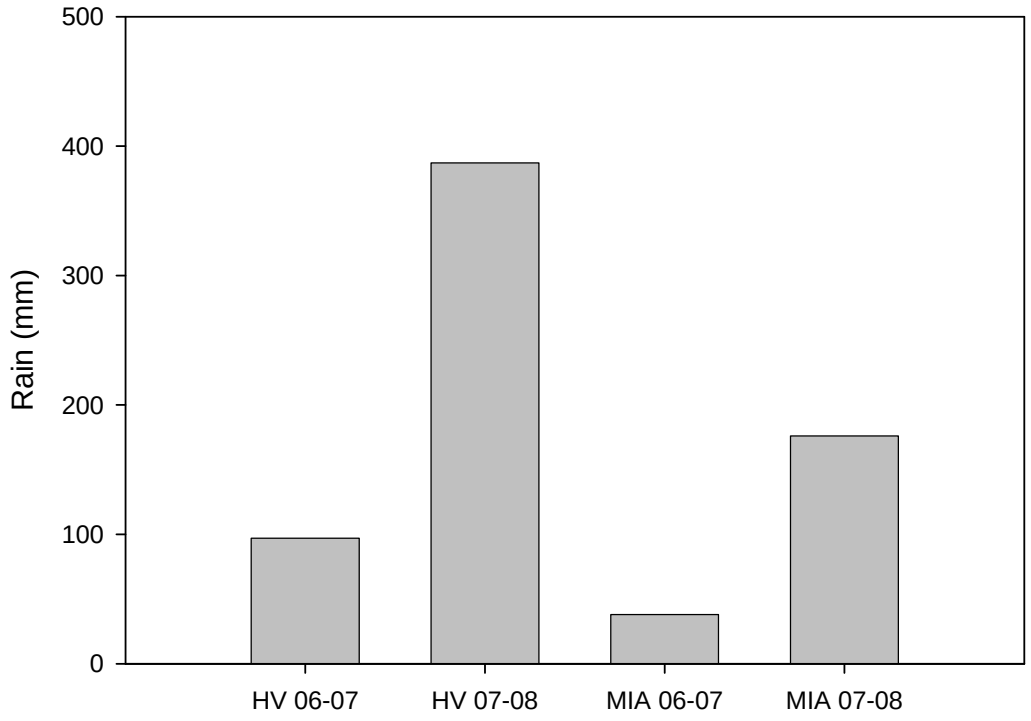


Figure 6. Rainfall from October to the end of January fallen in the Cessnock area (Hunter Valley) and the Griffith area (MIA) during the 2006-07 and 2007-08 seasons.

6. 1: Regional Study
F. Vineyard Canopy characteristics

Vine canopy size was assessed in the vineyards of the Hunter Valley and MIA. The canopies of vines from the MIA were larger than from the Hunter Valley. This was true for mean and total shoot length (Figure 1), and dry pruning weight and vine leaf area (Figure 2). Across all vineyards, there was a significant linear correlation between vine leaf area and vine pruning weight (Figure 3). There was also a positive correlation between vine shoot number and soil K levels (Figure 4).

The objective of this part of the study was to assess the impact of soil moisture and soil chemistry on canopy characteristics amongst the vineyards surveyed. Upon assessing the summarised data from all the vineyards there were no significant correlations of leaf area between soil moisture at any depth. Correlations of leaf area with soil moisture at 25 and 50 cm are shown in Figures 5 and 6. The Dryland site was at the extreme end in leaf area and soil tension but the other vineyards did not follow a similar trend. For instance, a leaf area of 4 m^2/ vine was produced by vines grown in soil tensions between 0 to 200 kPa. These differences are likely due to the different winter pruning and summer trimming practises between vineyards, leading to different shoot numbers and lengths. For this reason it was necessary to examine each vineyard separately and compare the soil moisture with canopy characteristics within that vineyard.

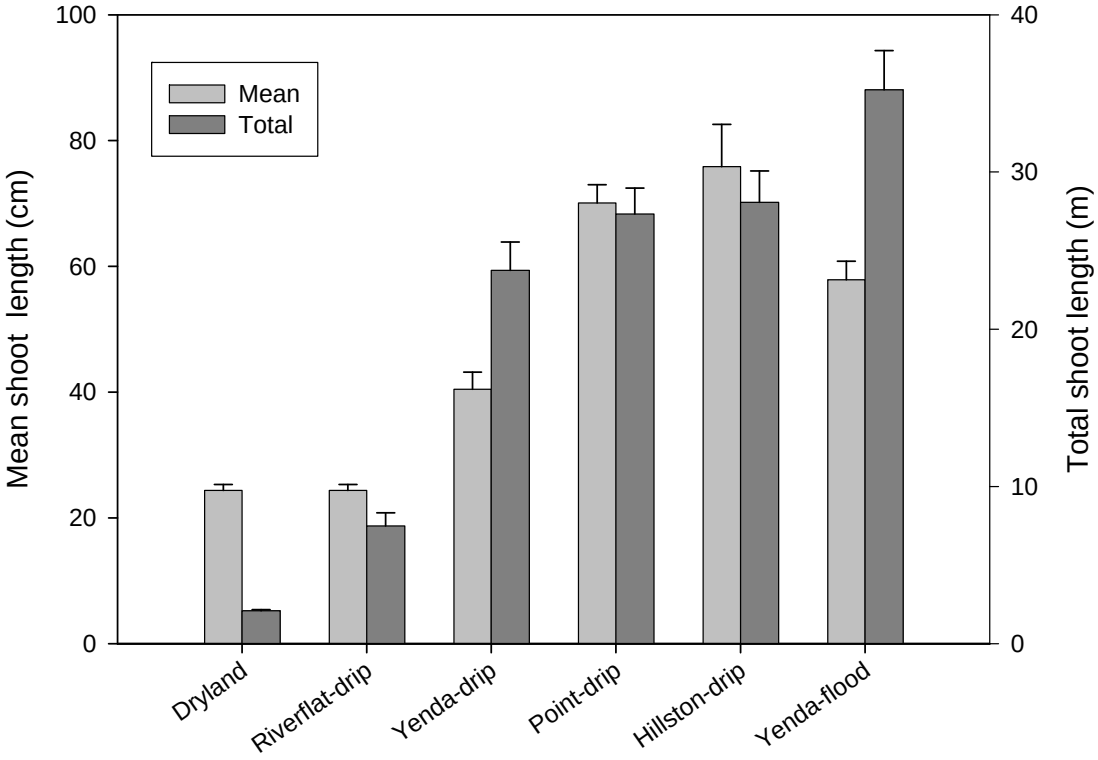


Figure 1. Mean and total shoot length of vines from the MIA and Hunter Valley vineyards in the 2006-07 season.

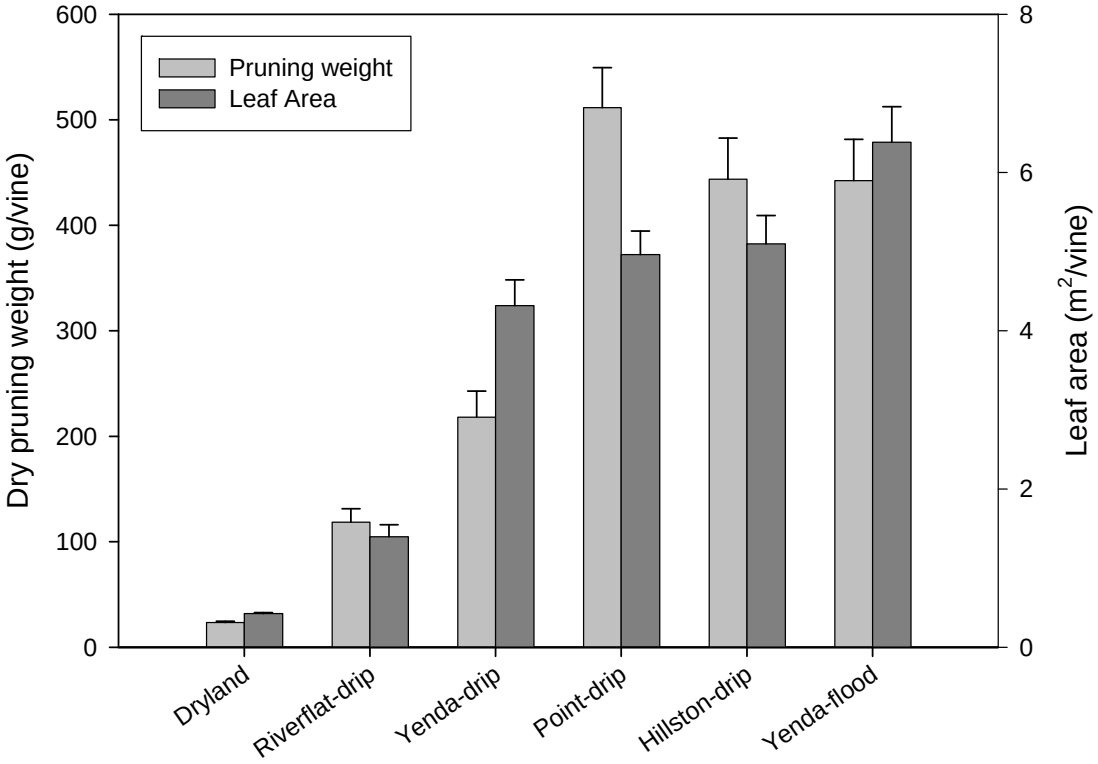


Figure 2. Dry pruning weights and leaf area of vines from the MIA and Hunter Valley vineyards in the 2006-07 season.

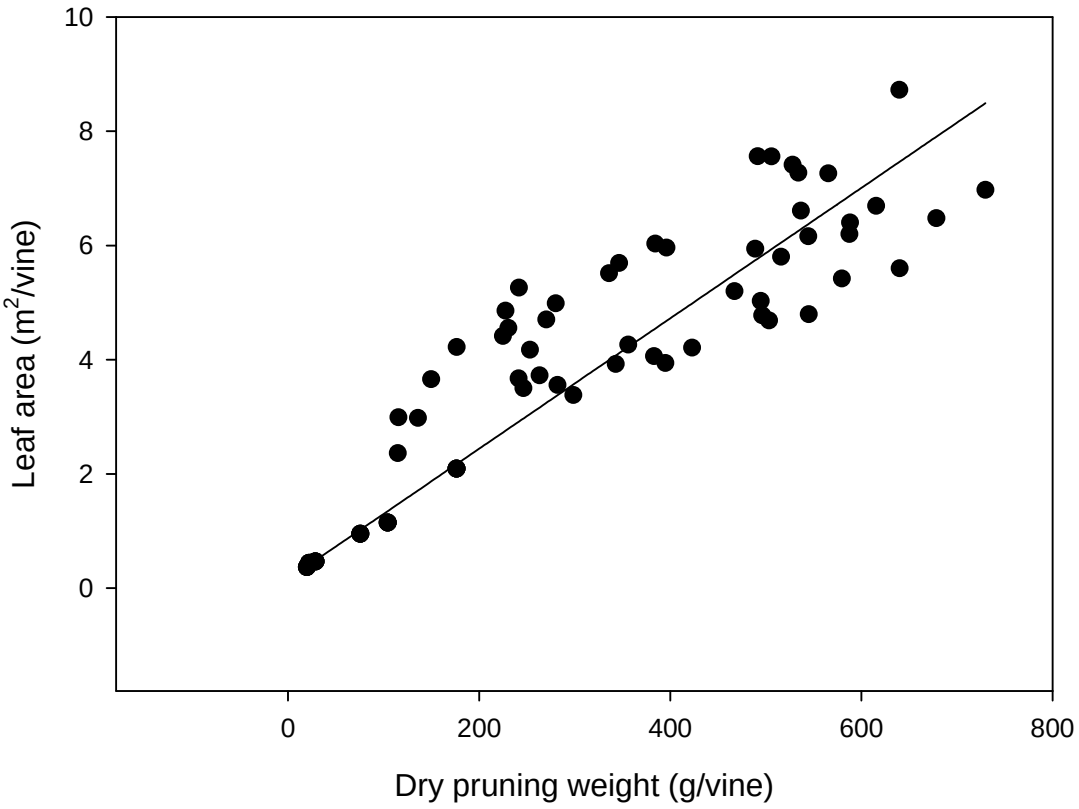


Figure 3. Correlation of leaf area with vine dry pruning weights.

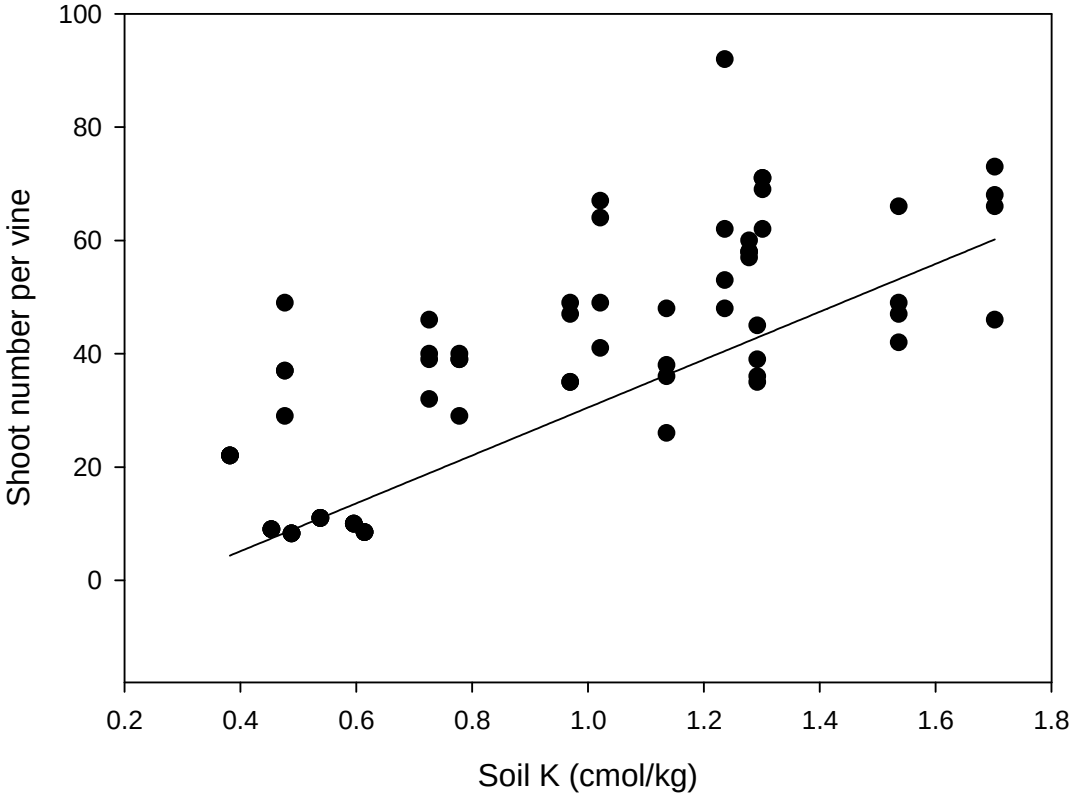


Figure 4. Correlation of shoot number per vine with soil K levels.

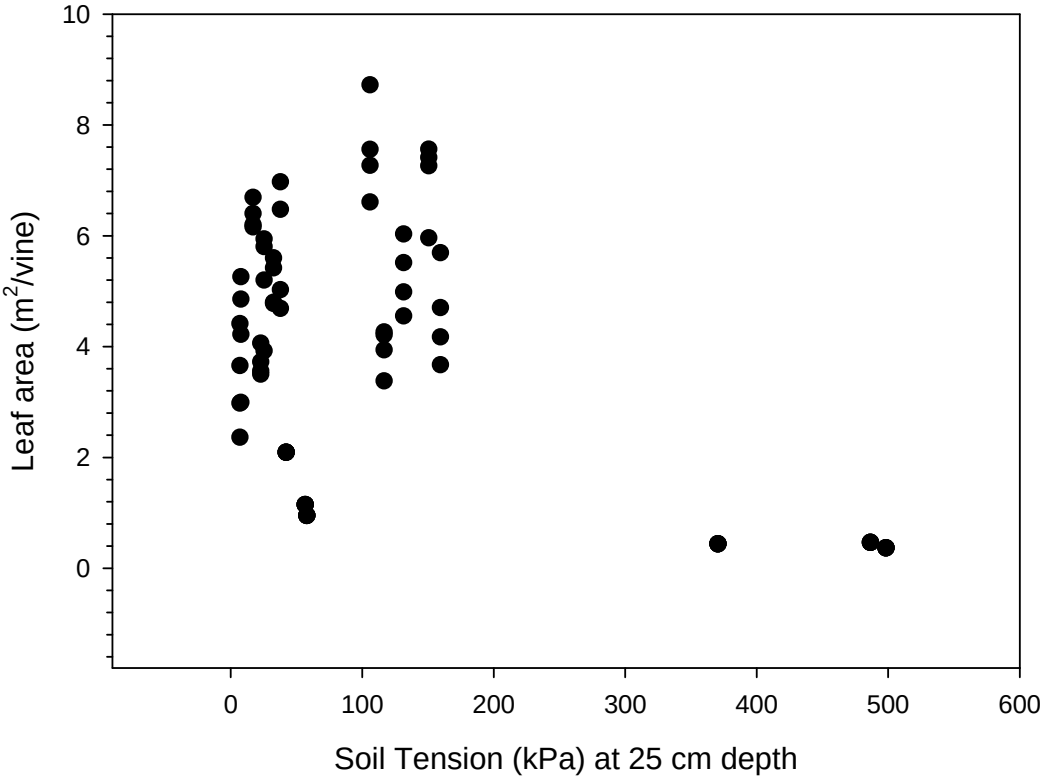


Figure 5. Leaf area compared to soil tension at 25 cm in January 2007. The extreme soil tension points represents the Dryland site in the Hunter Valley.

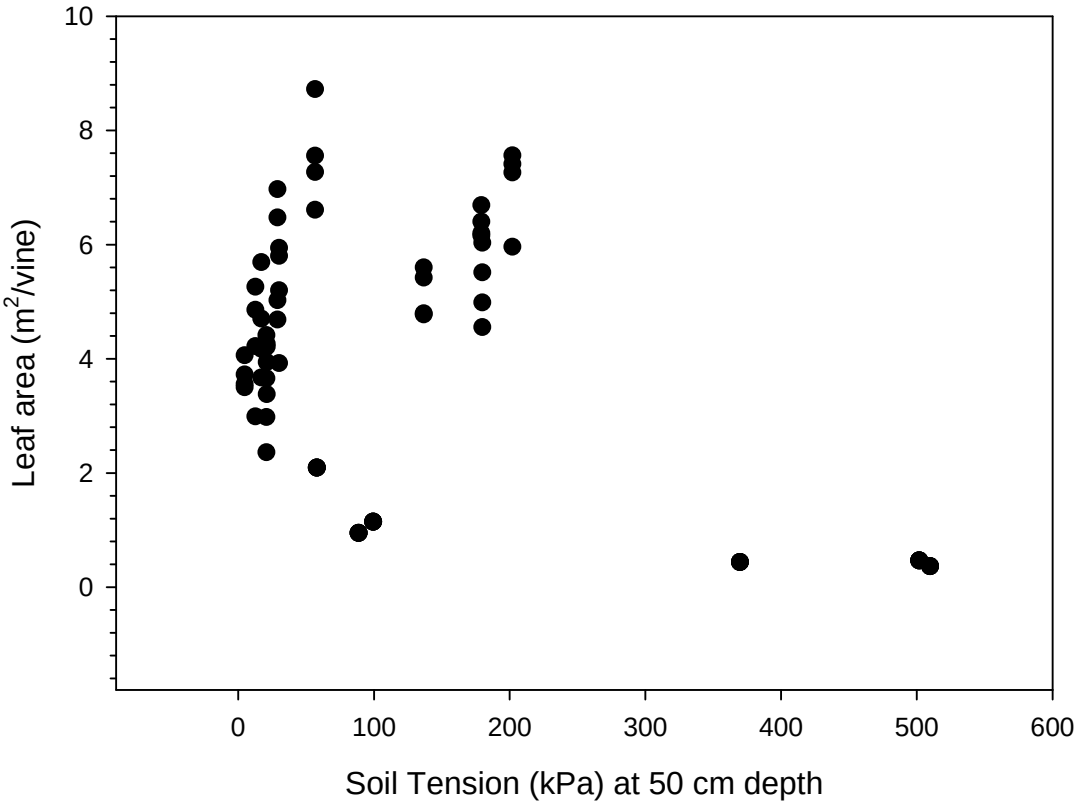


Figure 6. Leaf area compared to soil tension at 50 cm in January 2007. The extreme soil tension points represent the Dryland site in the Hunter Valley.

While there were no significant correlations between vine canopy size and soil moisture levels across the 7 sites, an analysis was carried out comparing canopy size and berry composition with soil moisture levels within each vineyard as averaged over each month of the season. It was found that within many of the vineyards soil tension had a negative correlation with leaf area. The following is a summary of each site studied over the 2006-07 season. Composition was assessed of berries sampled during January and in February at harvest.

Yenda-Flood site, MIA

At the Yenda-Flood site mean seasonal RAW ranged between 2 and 100% between the three EM locations as averaged over the season. Total vine shoot length was negatively correlated with seasonal soil tension a 50 cm. Ground area coverage per vine however was negatively correlated to seasonal soil tension at 25 and 75 cm depths. Leaf area and shoot length were also negatively correlated to soil Na and EC levels. Na and EC at this site were the highest of the 7 vineyards surveyed.

At the Yenda-Flood site, TSS of berries in January and February was negatively correlated with soil tension at 25, 50, 75, and 100 depths through December, January and February. pH and TA of January berries and bunch weight in January was negatively correlated to soil tension at 25 cm in January, and also mean seasonal soil tension at 25 cm.

Yenda-Drip site, MIA

At the Yenda-drip site mean seasonal RAW ranged between 16 and 80% between the three EM locations as averaged over the season. There were no correlations between canopy area, shoot length, or pruning weight with soil moisture levels (mean monthly or seasonal) at the three EM points. Ground area coverage per vine however was negatively correlated to seasonal soil tension at 50, 75 and 100 cm depths.

Crop load was negatively correlated to November, January, February and mean seasonal soil tensions at 25, 50 and 75 cm. January berry dry weight, TSS and pH and TA were negatively correlated mean seasonal soil tension at 100 cm. February pH was positively correlated and February TA was negatively correlated to mean season soil tension at 25, 50, 75 cm. February berry TSS was negatively correlated mean seasonal soil tension at a 100 cm depth. Berry fresh weight was not correlated to soil moisture.

Hillston-drip site, MIA

At the Hillston-drip site the RAW ranged from 20 to 100%. Dry pruning, shoot length and leaf area were negatively correlated with seasonal soil tension at 25 cm. Ground area of vine coverage was negatively correlated to Na and EC levels in the soil. Along with the Yenda-Flood site, Na and EC levels were very high in this vineyard.

pH and TA of the January berries were positively correlated with soil tension throughout the season at several depths at the Hillston-drip site.

Point-drip site, MIA

At the Point-drip site, mean seasonal RAW between the three EM locations ranged from 40 and 80% as averaged over the season. Ground area coverage per vine was negatively correlated to soil tensions in January and as meaned over the season at 25, 75 and 100 cm depths. Internode length was negatively correlated to mean season soil tensions at 25, 75 and 100 cm. Mean shoot length, total shoot length, dry pruning weights and leaf area were negatively correlated with mean seasonal soil tensions at 100 cm.

Yield was positively correlated to shoot number and canopy area. Yield and berry size were not affected by soil moisture differences between the three EM points (mean monthly or seasonal). Berry fresh weight was not correlated to soil moisture.

Riverflat-drip site, Hunter Valley

At the riverflat-drip site, %RAW ranged from 20 to 95%. The Low EM location had the lowest %RAW. The Intermediate location was in a depression and there was surface water accumulation at this point in the 2007-08 season due to the rain. Mean shoot length, total shoot length, vine leaf area, pruning weight negatively correlated with soil tension at 25 and 50 cm in January.

pH of berries was negatively correlated with seasonal soil tension at 25 and 50 cm. The pH (CaCl2) of the soil was negatively correlated with leaf area, shoot length and pruning weights. This may be because the pH was alkaline (up to 8.0) at some depths.

Hillslope-drip site, Hunter Valley

The Hillslope-drip site in the Hunter Valley had the least amount of water deficit of all the vineyards surveyed. RAW was between 60 and 100% as averaged over the season. Ground coverage per vine was negatively correlated to soil tension at 25cm in December and January. Unfortunately, there was a significant amount of canopy data missing for this vineyard.

TA of berries was negatively correlated to soil tension at 75 and 100 cm depth as averaged over the season.

Riverflat-dryland site, Hunter Valley

The RAW at the river-flat Dryland site was well below 0 throughout the entire season. Leaf area was negatively correlated with soil tension at 75 and 100 cm throughout the season. Pruning weight, total shoot length, mean shoot length and dry pruning weight was negatively correlated to soil tension at 100 cm as meaned at the end of the season. The Na, Mg and Ca levels in the soil was negatively correlated with leaf area, mean and total shoot length and dry pruning weight. This is interesting because the levels of these salts and the EC values were low compared to the other vineyards. There was not enough composition data to make any correlations with the other parameters in this vineyard during this season. pH was not a problem in this vineyard.

6. 1: Regional Study
F. Vine Water Status

The leaf burn symptomatic of Semillon vines may be the result of low soil moisture levels, high VPDs, or a combination of these two. Vine water status can be assessed using a Scholander pressure chamber (Figure 1) and the pressure required for sap to exude from the cut end of a petiole is recorded. Leaf water potential measurements can be made during the day to assess how current climatic and soil moisture conditions are affecting the vine's water status. Measuring leaf water potentials prior to dawn provides a measure of the vine's water status after a period of recovery during the night. Stomata are presumed to be closed during the night, limiting transpiration to the evaporative loss through the cuticle. Leaf water potentials taken at this time should be more closely related to soil moisture levels than midday measurements.

The objective of this study was to understand the relative contribution of soil moisture and VPD on Semillon vine water status. At each site, vines were sampled in three locations based on the EM survey. The leaf water potentials of these vines were assessed prior to sunrise and also midday. The water status of the vine was compared to leaf transpiration rates and stomatal conductance which was measured by a portable LiCor infrared gas analyser (Figure 2).



Figure 1. Pressure chamber used to measure leaf water potentials



Figure 2. A portable LiCor infrared gas analyser was used to measure leaf photosynthesis, transpiration and stomatal conductance.

There was a strong linear correlation of leaf water potential with VPD at the time the measurement was taken, across all vineyards and three seasons (Figure 3). Leaf water potentials reached -2.0 MPa when VPD extended to 5 kPa. There was no main effect, however, of leaf water potential with %RAW or soil tension at any of the depths (Figure 4). Assessing leaf water potential differences within each individual vineyard over the 3 seasons yielded similar results with a strong overriding effect of VPD but no main effect of soil moisture. At very high VPDs (> 3.0 kPa), however, leaf water potential was more negative with low %RAW (Figure 5).

Predawn leaf water potentials were generally only a fraction of midday leaf water potentials but some vines reached to -1.2 MPa, which is an indicator of substantive water stress. As expected, there was no relationship between predawn leaf water potentials and VPD (Figure 6A), however there was also no relationship to soil moisture, except for a very lose correlation with soil tension at 25 cm (Figure 6B). With VPDs greater than 0.5 kPa, however, there was a tendency for leaf water potential to be more negative with decreasing readily available water (Figure 6C).

Transpiration was linearly correlated to stomatal conductance while photosynthesis increased to a maximum and then remained constant with further increases in stomatal conductance (Figure 7). Over the three seasons and 7 vineyards surveyed, transpiration ranged from 0.5 to greater than 5 mmol H_20 m^{-2} s^{-1}. Stomatal conductance ranged from 0.05 to 0.7 mmol H_20 m^{-2} s^{-1}, and photosynthesis ranged from 3 to 15 μmol CO_2 m^{-2} s^{-1}.

Variability in transpiration rates of vines was greatest at leaf water potentials of -0.8 to -1.6 MPa (Figure 8). At leaf water potentials less negative or more negative than this range transpiration rates tended to be less variable. The absence of a tight correlation between transpiration and leaf water potential indicates that transpiration was not controlled by leaf water potential. Similar to leaf transpiration, stomatal conductance was also variable when leaf water potential ranged from -0.8 to -1.6 MPa

(Figure 9). The lowest stomatal conductance value, however, was smaller as leaf water potential became more negative. Again the absence of a tight relationship between stomatal conductance and leaf water potential indicates that these two parameters were not controlled by each other. In the Dryland site, however, there was a linear relationship between leaf water potential and stomatal conductance (Figure 10). In situations where water is extremely scarce, leaf water status may be able to send a signal to the stomata causing stomatal closure.

Vapour pressure deficit had no main effect on stomatal conductance (Figure 11). Stomatal conductance varied greatly at any particular VPD from 0.5 to 4.4 kPa. Readily available water also had no main effect on stomatal conductance (Figure 12), with large variation in conductance at any particular soil moisture level. The interactive effect of soil moisture and VPD on stomatal response was also assessed. There was a lack of response of stomatal conductance, however, to VPD at any particular range of soil moisture (Figure 13). Transpiration was, however, affected by VPD and %RAW (Figure 14). Transpiration was highest for those vines that were exposed to high VPD in combination with high soil moisture levels. As soil moisture declined, transpiration declined as well.

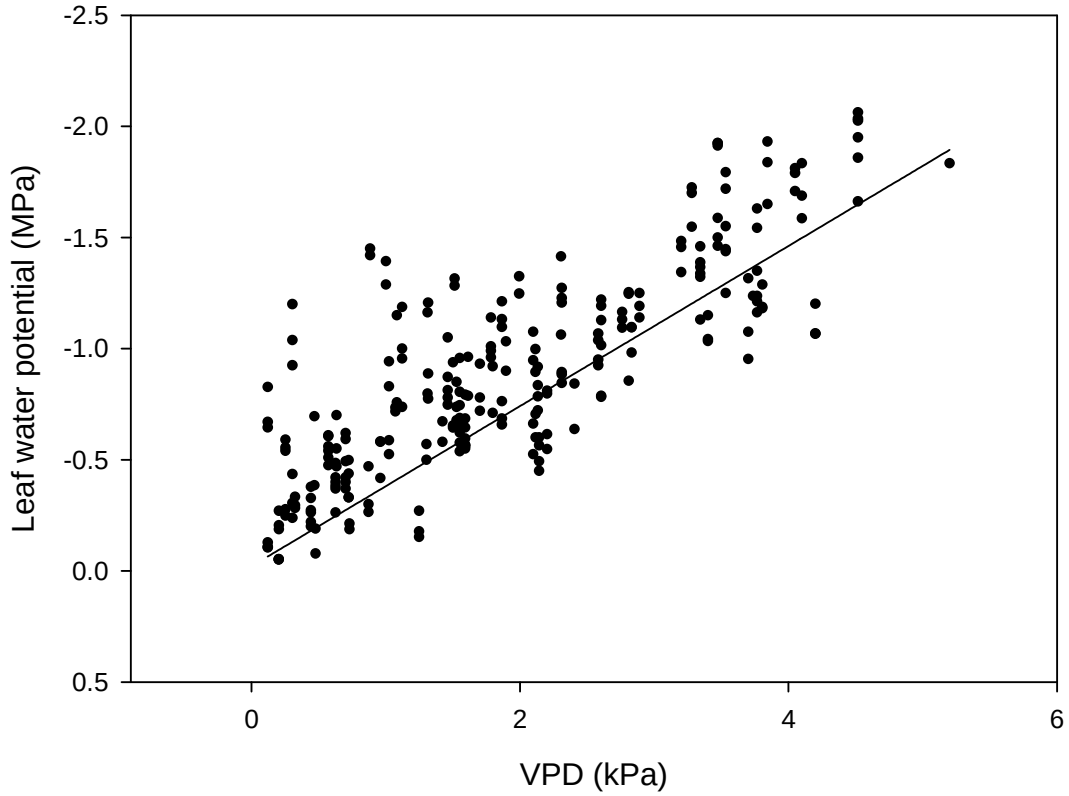


Figure 3. Leaf water potential correlated against VPD. Data are from the 05-06, 06-07 and 07-08 seasons. Each point represents the mean of 4 vines (R^2=0.72, $p<0.001$).

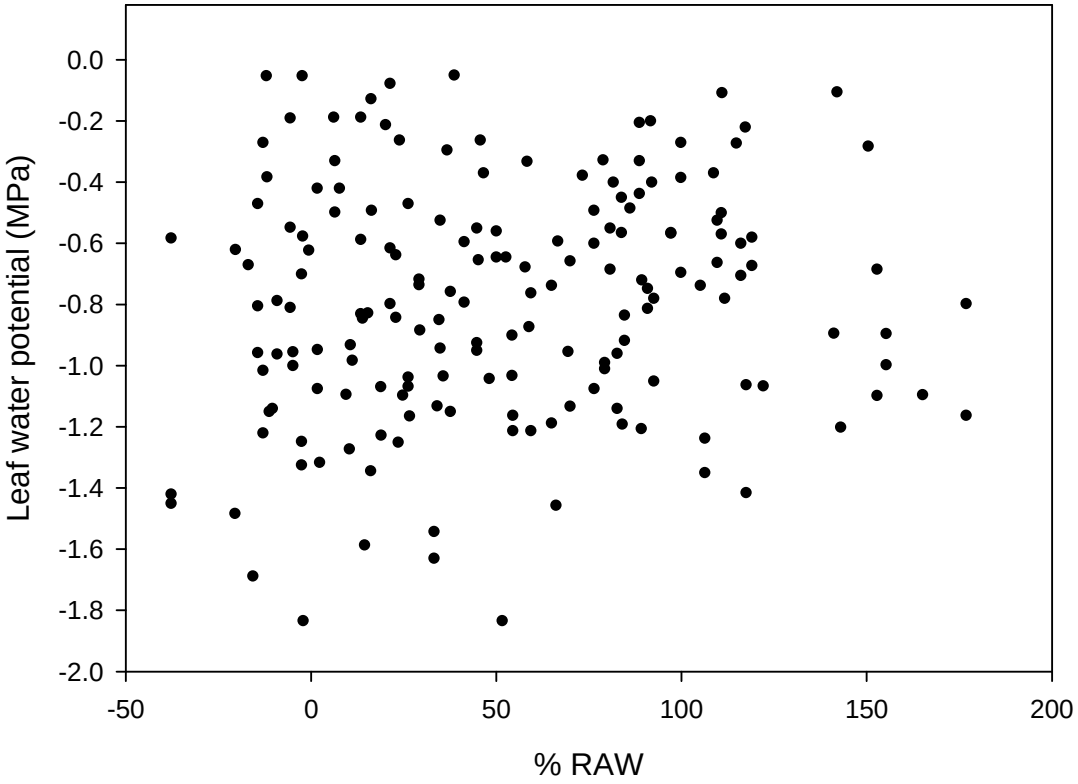


Figure 4. Leaf water potential correlated against %RAW. Data are from the 05-06, 06-07 and 07-08 seasons. Each point represents the mean of 4 vines.

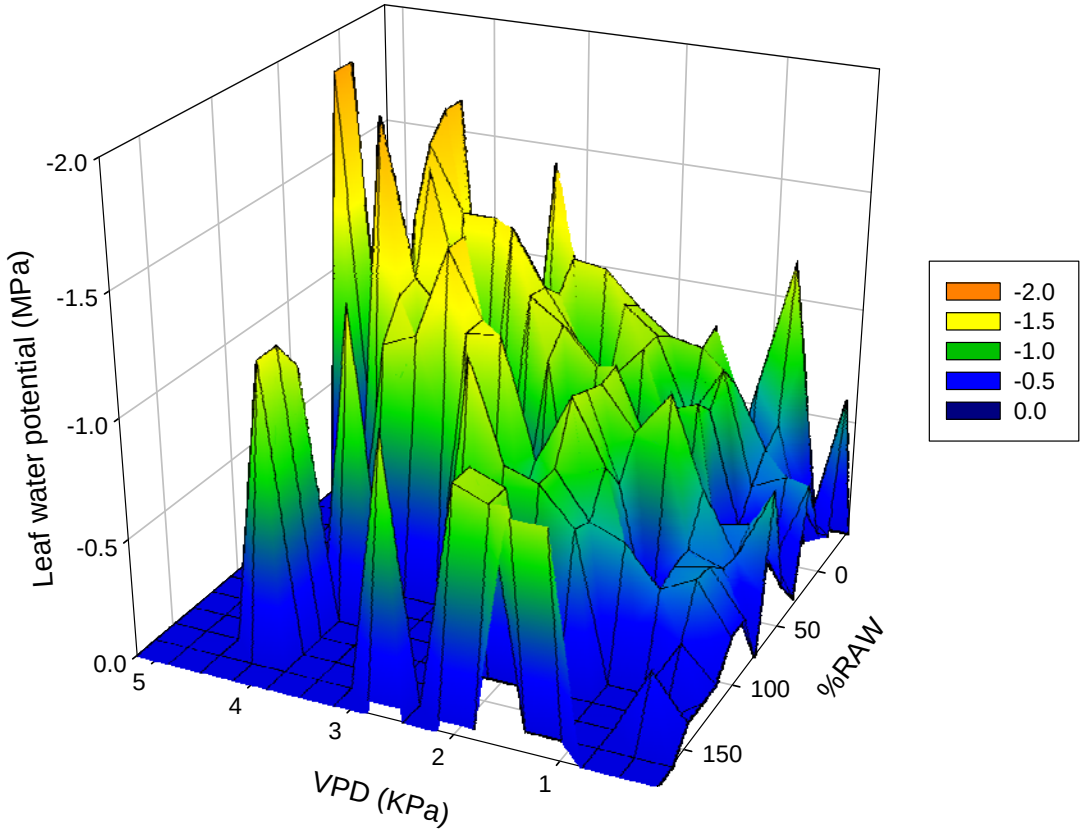


Figure 5. Leaf water potential correlated against %RAW and VPD. Data are from the 05-06, 06-07 and 07-08 seasons. Each point represents the mean of 4 vines.

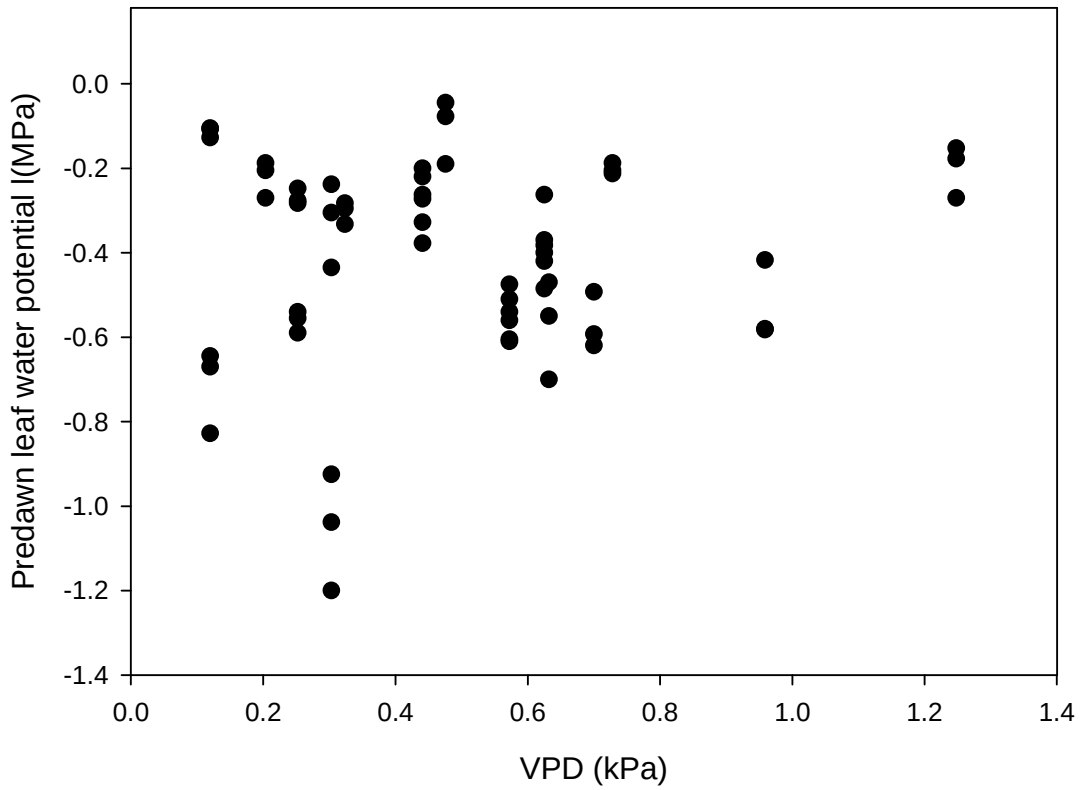


Figure 6A. Predawn leaf water potential correlated against VPD. Data are from the 05-06, 06-07 and 07-08 seasons. Each point represents the mean of 4 vines.

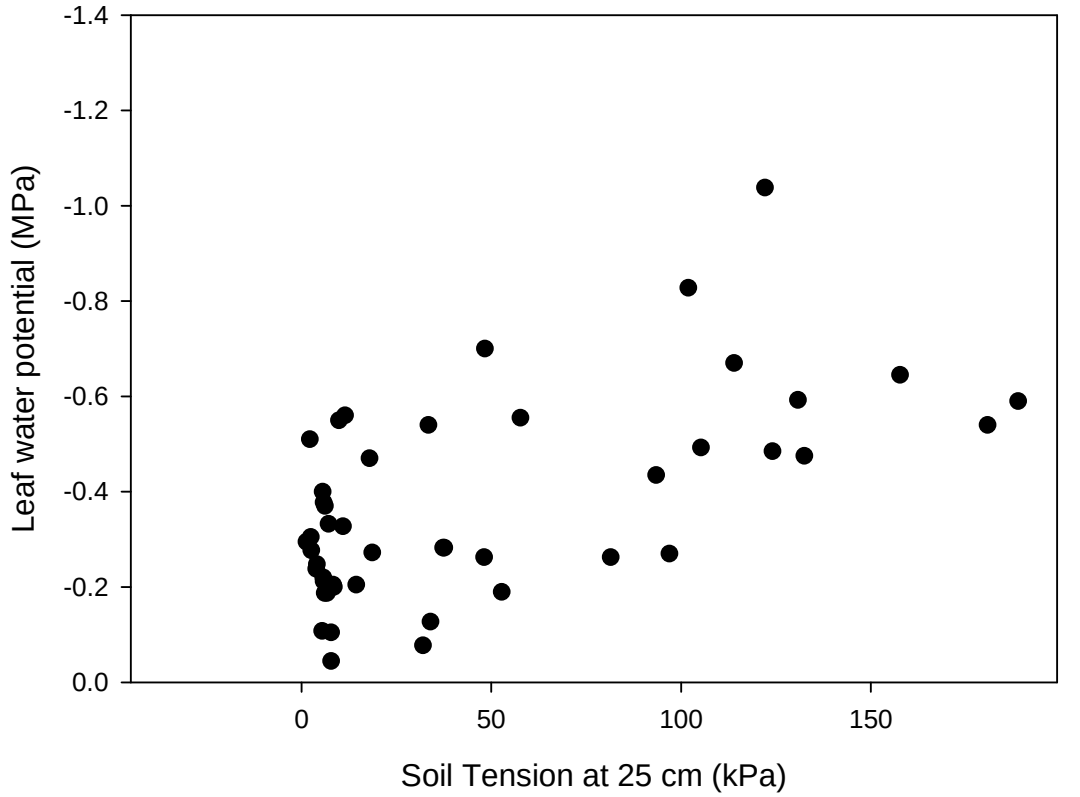


Figure 6B. Predawn leaf water potential correlated against soil tension at 25 cm depth. Data are from the 05-06, 06-07 and 07-08 seasons. Each point represents the mean of 4 vines.

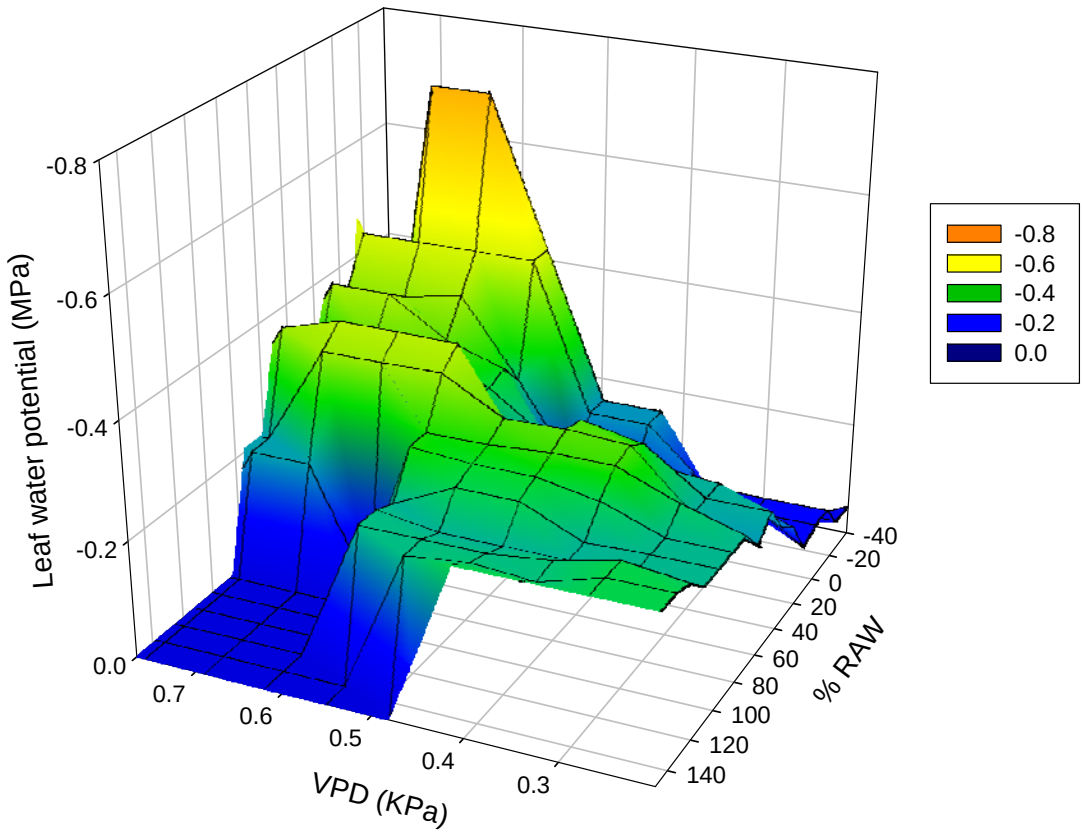


Figure 6C. Predawn leaf water potential correlated against %RAW and VPD. Data are from the 05-06, 06-07 and 07-08 seasons. Each point represents the mean of 4 vines.

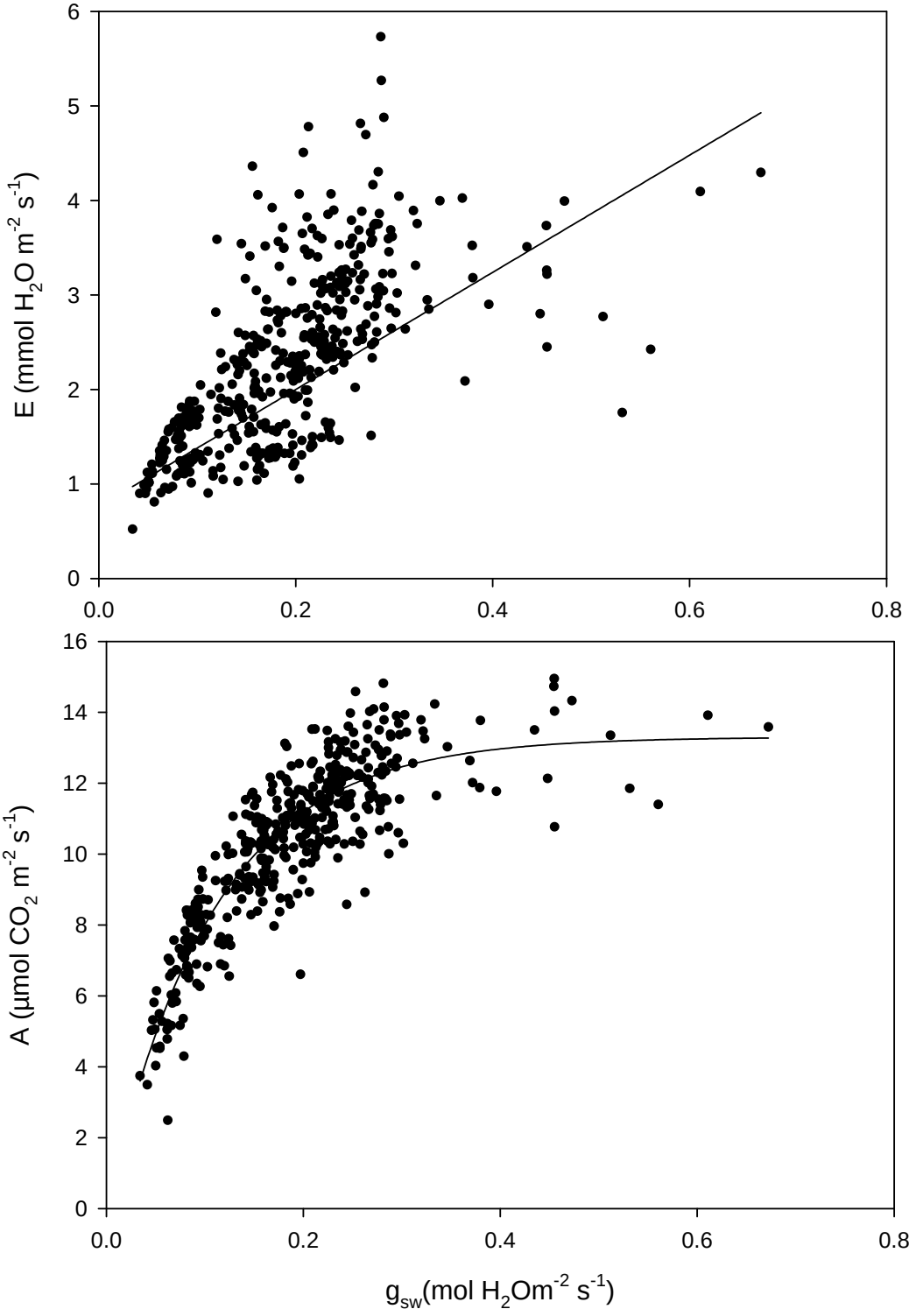


Figure 7. Photosynthesis and transpiration correlated against stomatal conductance. Data are from the 07-08 season.

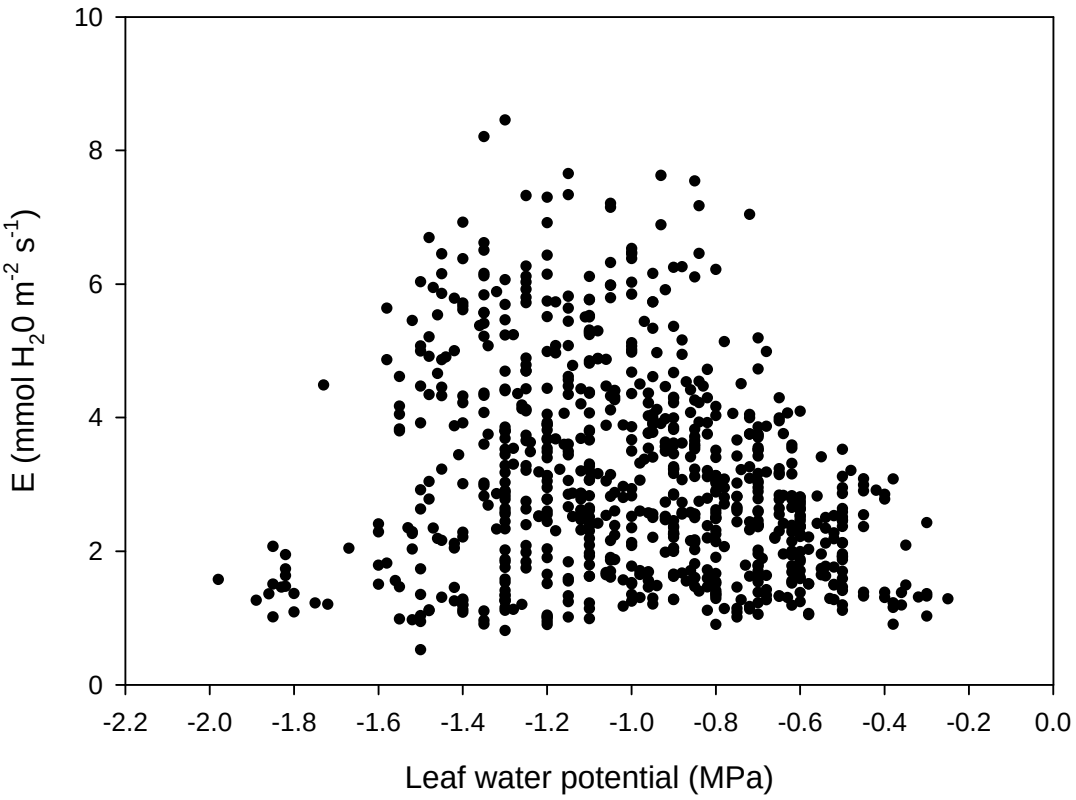


Figure 8. Transpiration correlated against leaf water potential. Data are for 3 seasons and 7 vineyards. Each data point represents one individual vine. Note the wide spread in E over the median leaf water potential range from -0.6 to -1.6 MPa.

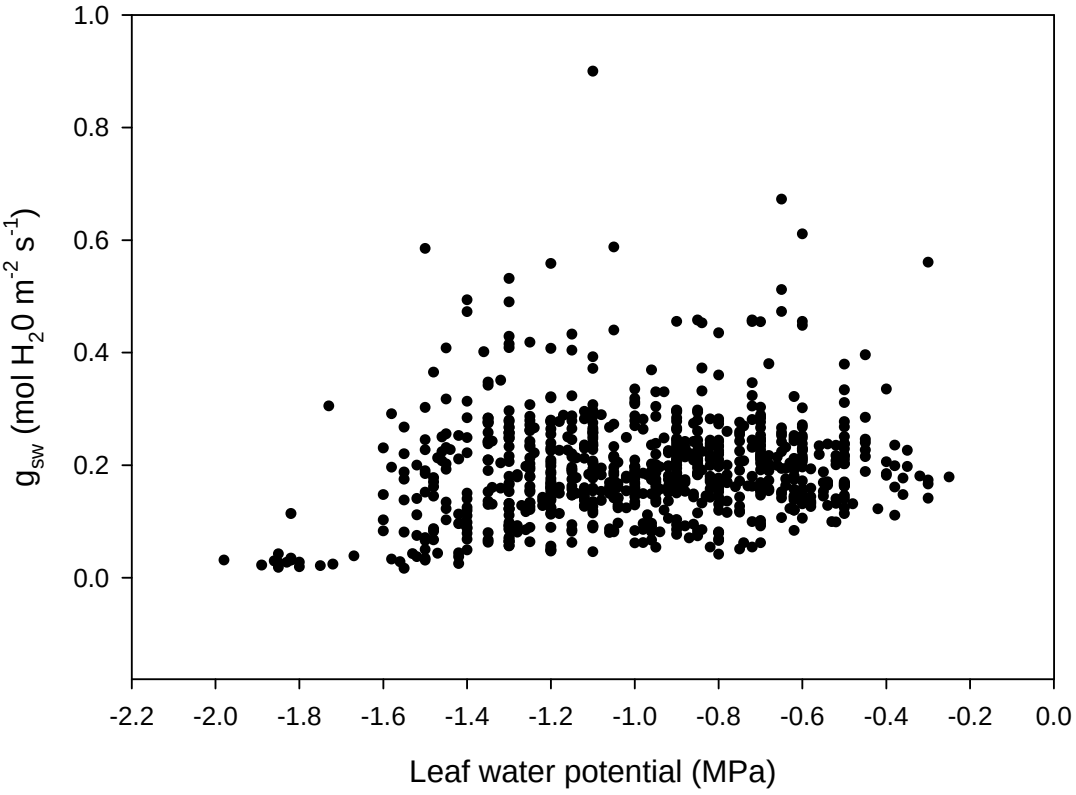


Figure 9. Stomatal conductance correlated against VPD. Data are for 3 seasons and 7 vineyards. Each data point represents one individual vine.

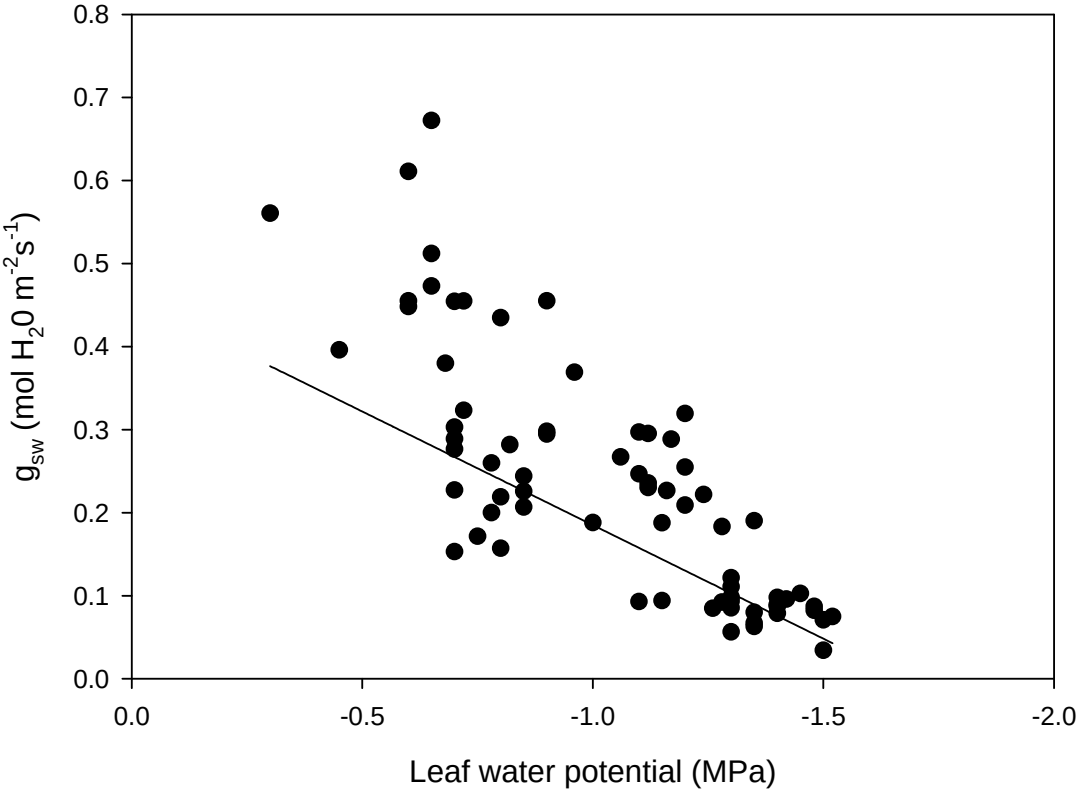


Figure 10. Stomatal conductance correlated against leaf water potential for the Dryland site in the 2007-08 season.

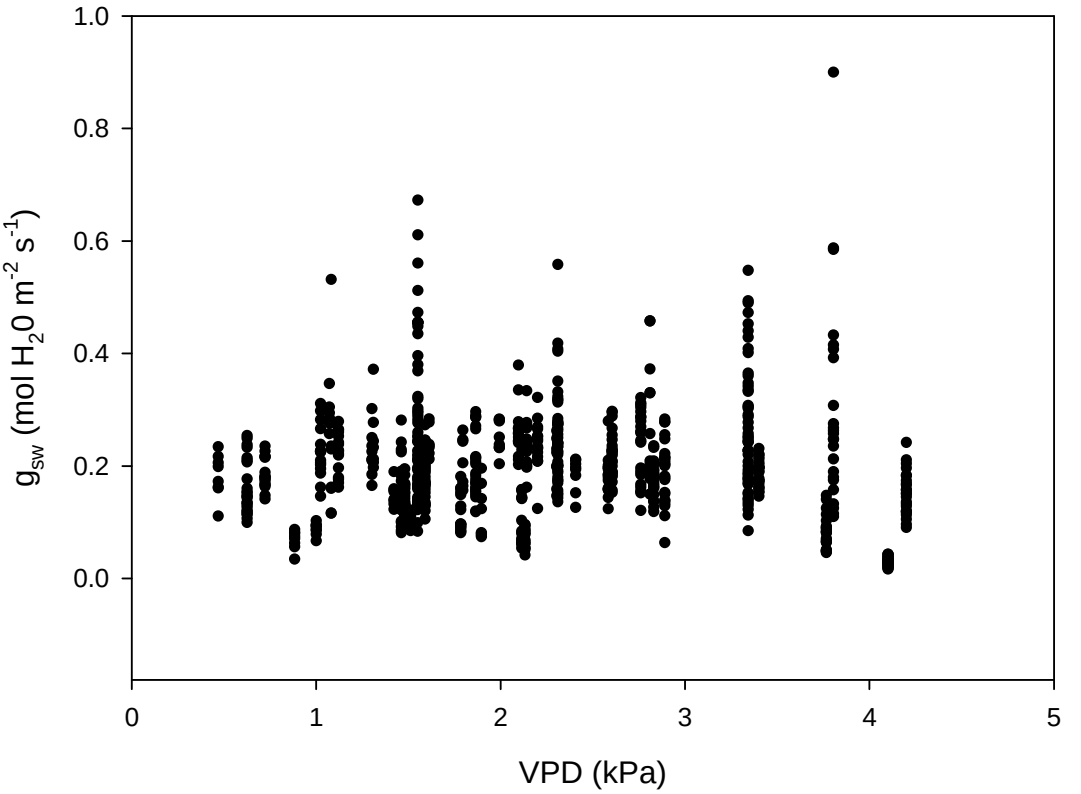


Figure 11. Stomatal conductance to water vapour correlated against VPD. Data are for 3 seasons and 7 vineyards. Each data point represents one individual vine.

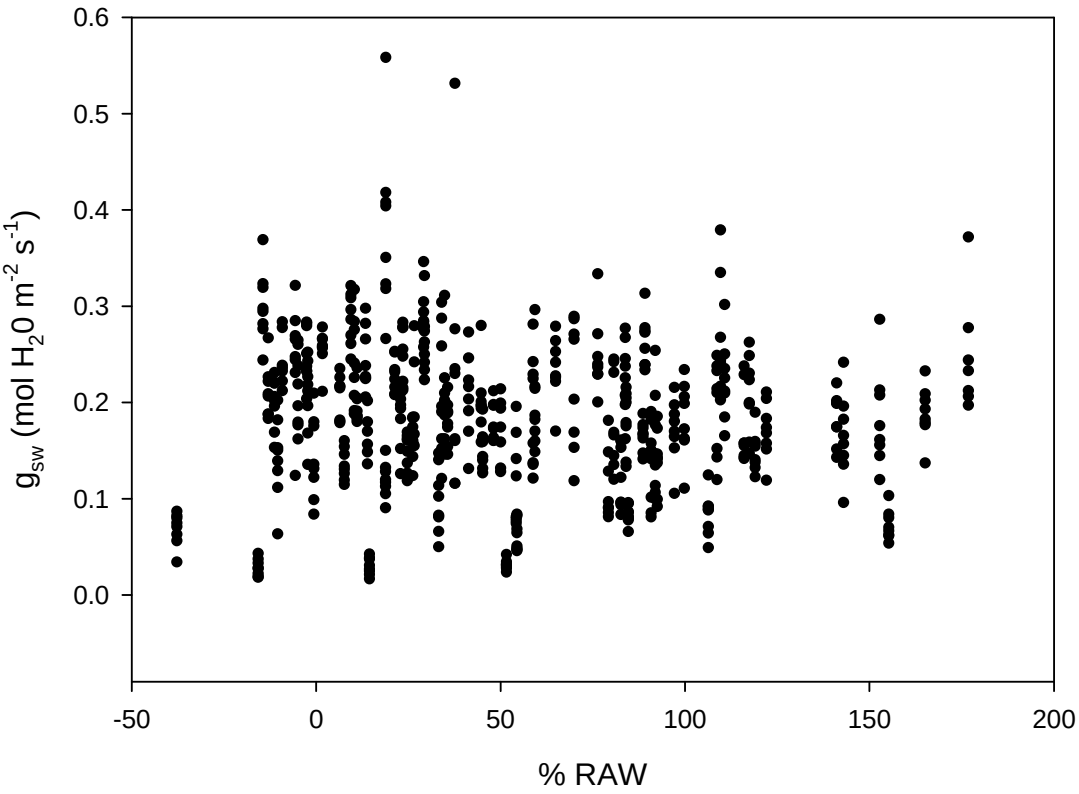


Figure 12. Stomatal conductance to water vapour correlated against %RAW. Data are for 3 seasons and 7 vineyards. Each data point represents one individual vine.

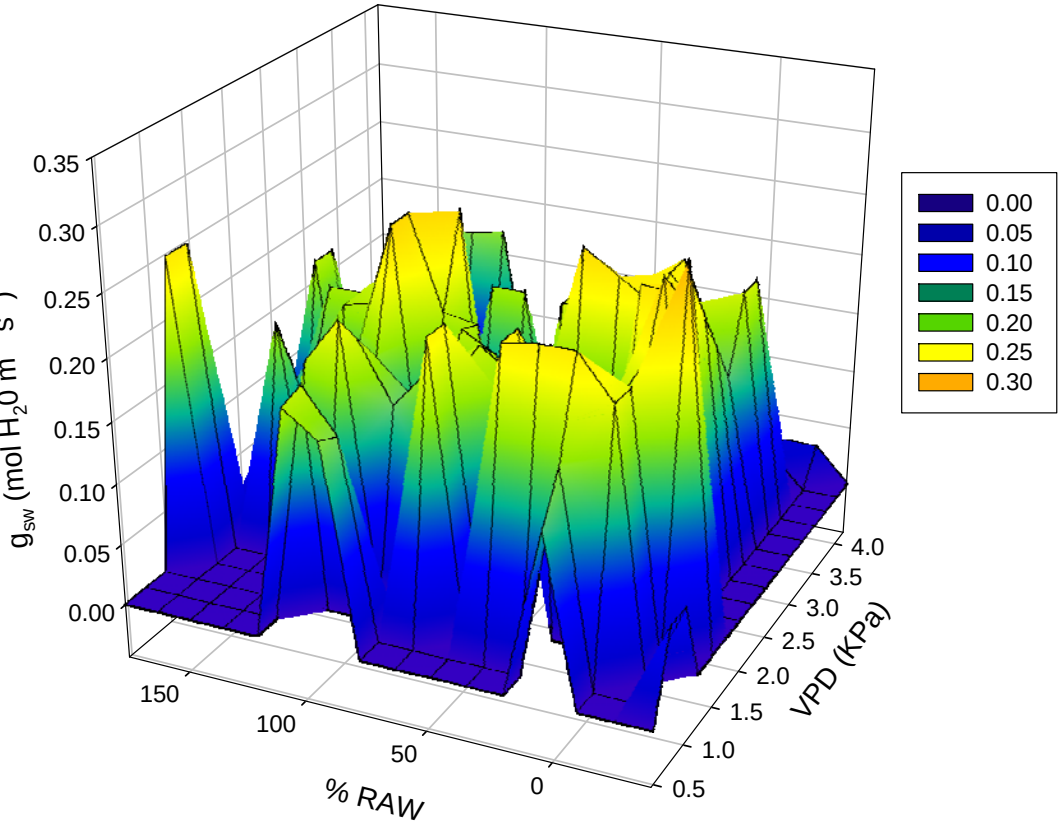


Figure 13. Stomatal conductance to water vapour correlated against %RAW and VPD. Data are for 3 seasons and 7 vineyards.

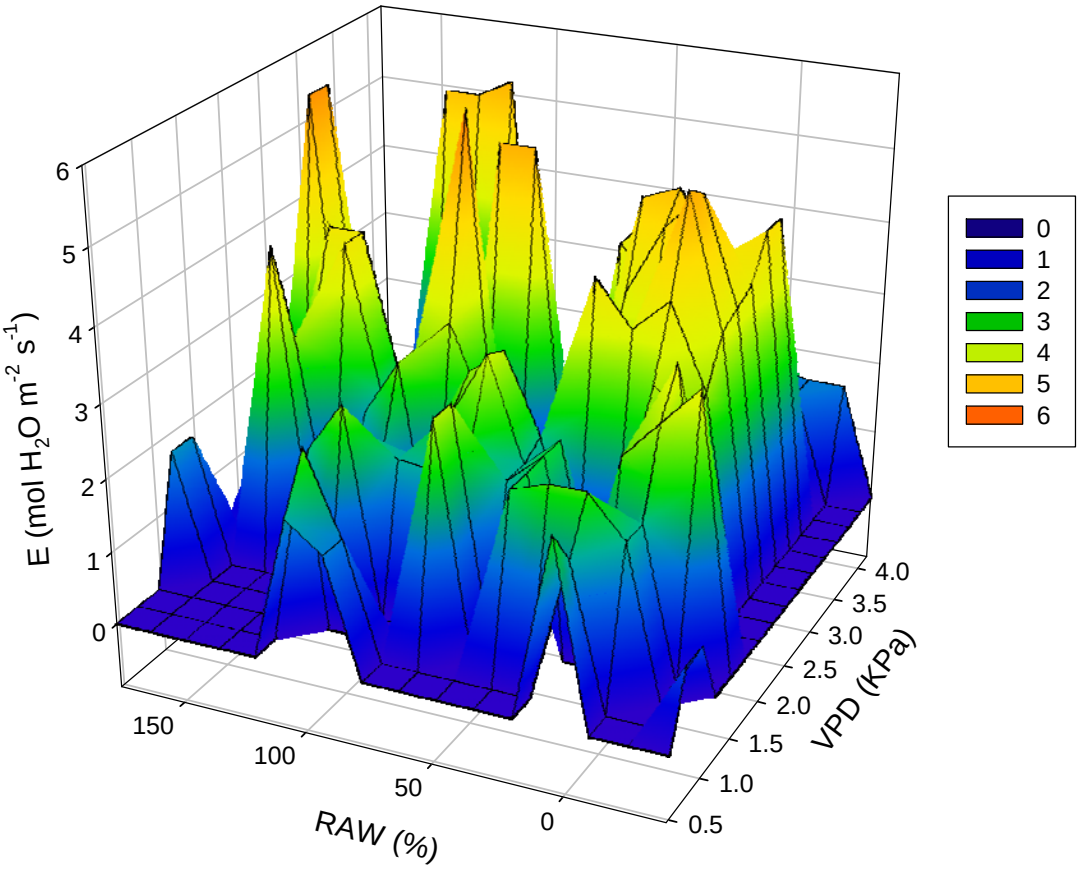


Figure 14 . Transpiration as a function of VPD and %RAW. Data presented cover 3 seasons and both regions (7 vineyards and 3 locations within the vineyard).

6. 1: Regional Study
G. Vine Sap flow

Sap flow through Semillon vines was monitored in the MIA and Hunter Valley vineyards in order to have an estimate of how much this variety transpires on a whole vine basis, and to understand the influence of soil moisture and daily fluctuations in evaporative demand on sap flow. Sap flow sensors were inserted into the water conducting pathway of the vine at about knee height (Figures 1 and 2). They were insulated from temperature fluctuations and logged at half hourly intervals throughout December and January of three seasons.

Flux through vines on an hourly and daily basis differed between vineyards (Figures 2 and 3). In the Hunter Valley, the Hillslope-drip site had the highest flux on both a vine and canopy area basis. The flux through the Riverflat-dry vines was limited as would be expected under the very negative soil tensions characteristic of this vineyard. It was surprising that the Riverflat-drip site with the reworked vines also had very limited rates of flux. It may be that transport through shoots brought up from the base of the vine is limited. The sectoriality of grapevines indicates that not all roots are readily connected to all shoots. If only a limited number of roots are providing readily accessible water to the shoots then sap flow through the trunk may be limited. PRD studies, however, indicate that water is transferred readily from one side of the vine to the other. The vines at this site were also the oldest in the survey and perhaps a considerable amount of dead wood had developed.

In the MIA, vine sap flow rates also varied with vineyard (Figures 4 and 5 and Tables 1 and 2). The highest rates were in the Yenda-drip site on both a vine and leaf area basis, while the lowest rates were in the adjacent block at the Yenda-Flood site. The Yenda drip irrigated block was on a sandy clay-loam soil, and in the 2005-06 season was watered every second day. Therefore, the soil tensions did not reach more than 20 kPa at 25 to 100 cm depths and the readily available water (RAW) was near to 100% through these two months. The second block of Semillon vines was on a clay-loam soil and was flood irrigated every 10-15 days. Average soil tensions in the root zone were 90 to 200 kPa and the RAW was less than 10% during most of the ripening period. Daytime vine sap flow was less than half of vines from the drip irrigated block despite larger canopies. Leaf margins were burnt and, prior to irrigation, predawn leaf water potential indicated that vine water status did not recover during the night. At harvest, berries were shrivelled, and had lower fresh weights than berries of the drip irrigated block.

In the 2007-08 season, sap-flow rates were up to 3-fold greater in the Hunter Valley vineyards and up to 2-fold greater in the MIA vineyards as compared to the 2006-07 season. This is likely because of the lower soil tensions experienced in the 2007-08 season. The Hunter Valley in particular received 4-fold more rain (387 mm) during this season and the Dryland site responded with the greatest increase in sap flow rates (Table 1 and Figure 7). The conversion of the flood vineyard in the MIA to a drip irrigated vineyard in the 2007-08 also likely contributed to the far less negative soil tensions.

VPD and soil tension were correlated against Flux to understand how these two parameters interacted on Flux rates. Flux was predominantly driven by VPD since the

correlation was much tighter (Figure 9) than with % RAW (Figure 10). When VPD was high, however the amount of moisture in the soil was a limiting factor on flux rates. When VPD was low, the soil moisture levels were not critical (Figure 11). This pattern was seen in all the vineyards surveyed, including the Dryland site. The large differences in sap flow between the seasons also indicate that soil moisture levels had an influence. These differences were not due to VPD because they were generally lower in the second season as compared with the first. The response to VPD that we observed in Semillon does not occur in all vines. In Merlot, for instance, sap flow did not respond to VPD (Loveys, 2005).

How do these flux rates compare to other vines in similar situations? Estimates of water flux through grapevines can be at 4 L/h in Concord vines (Tarara and Ferguson, 2001) during the middle of the day. Substantially less than this, in Merlot vines daily water use only reached 3L per vine (Loveys, 2005). Estimates from the literature indicate that daily vine water use is somewhere between 3 and 15 L. In our study there was a 4-fold variation in vine water use between vineyards. Vine canopy size also has a large impact on vine water use. Our Semillon vines transpired at 0.2 L/day in very dry conditions up to 3.2 L/day in moist conditions, as averaged over the ripening period. It would be expected that these rates are higher in spring when leaves are younger and not yet fully developed. The large number of variables influencing sap flow rates make comparisons across varieties difficult.

It would be expected that damage occurs at the margins of leaves due to lower water status in this area. Limited water at the margins is the result of delivery rates not keeping up with evaporation rates from the leaf's surface. This may indicate that water flow through the vines is too slow compared with what is required to maintain leaves in a hydrated state. The conducting pathway may contain large resistances impeding flow. Hydraulic conductance was not successfully measured for Semillon vines but this may be an exercise well worth doing to confirm these results.



Figure 1. Sap flow sensors in the Hunter Valley Dryland site.



Figure 2. Insertion of sap flow sensors into vine trunk.

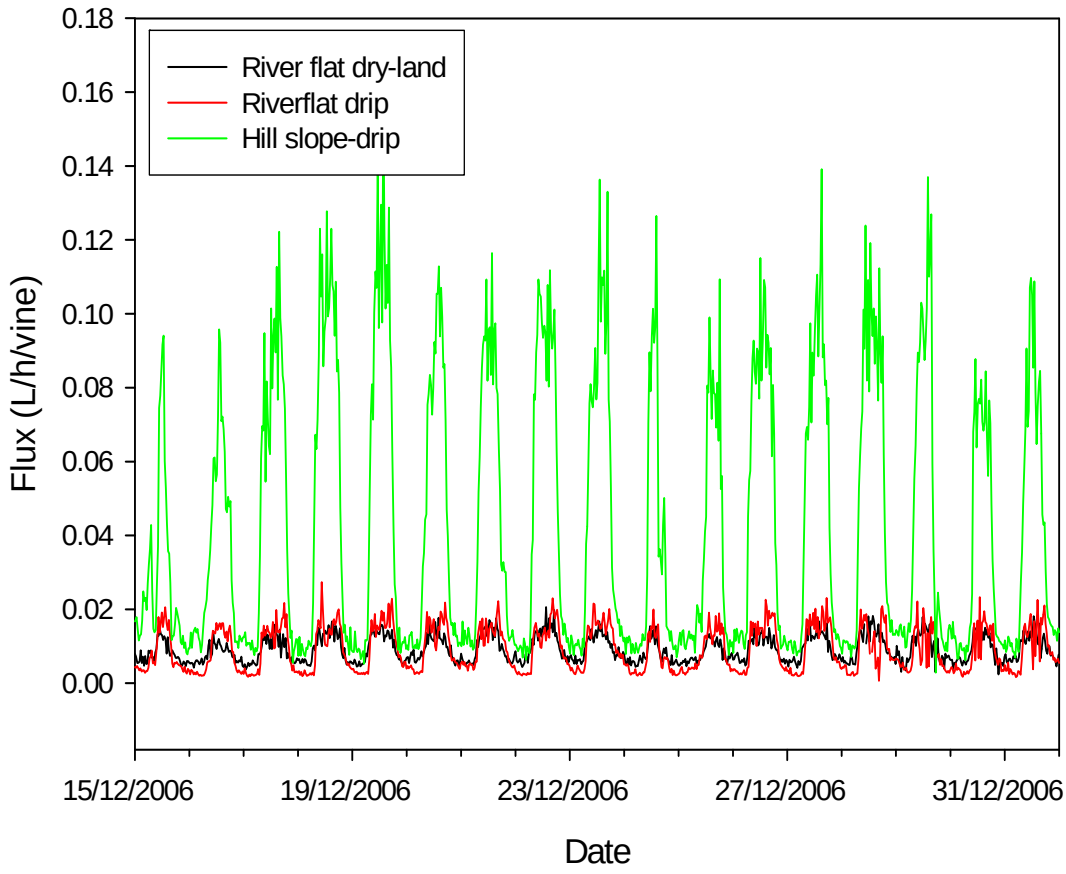


Figure 3. Flux through vines on an hourly basis in the Hunter Valley sites.

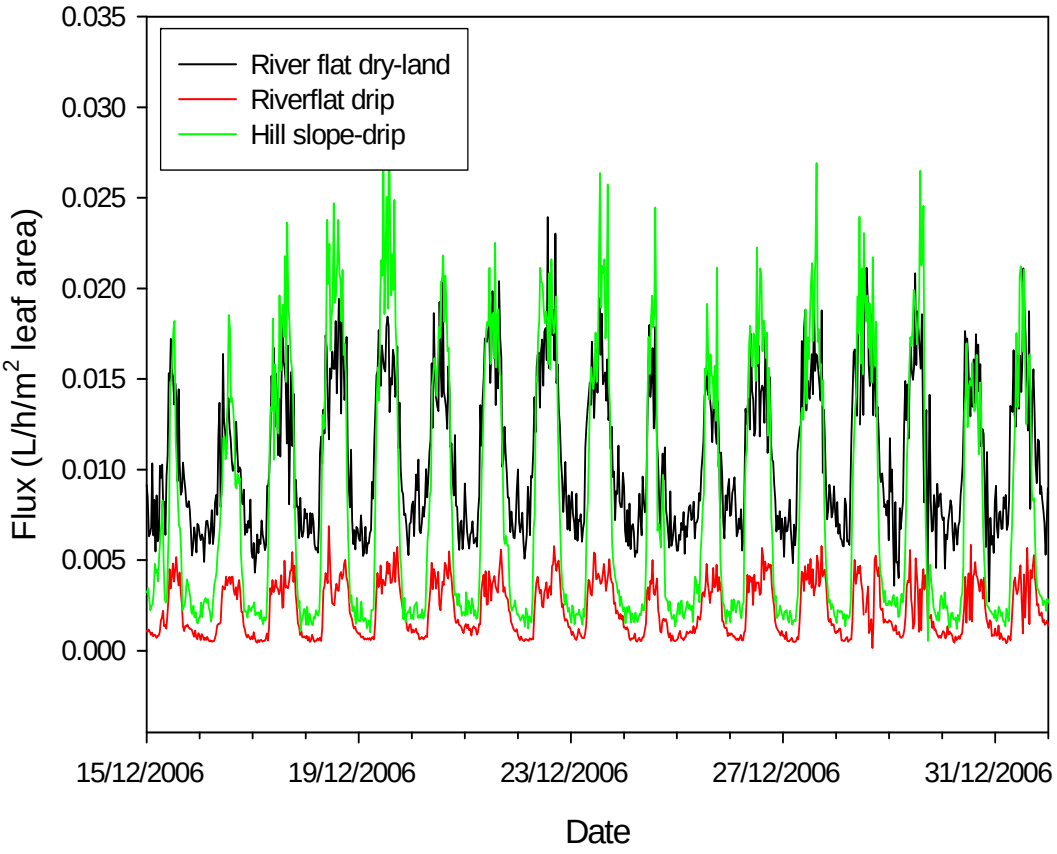


Figure 4. Flux through vines on an hourly and leaf area basis in the Hunter Valley sites.

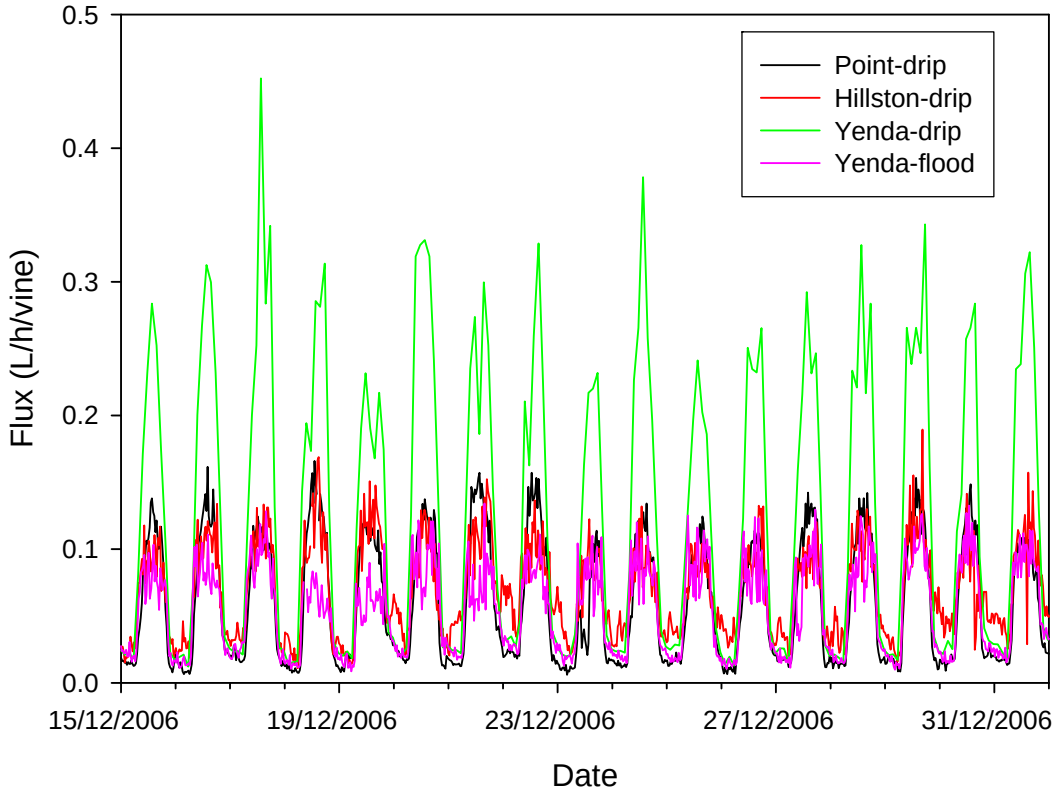


Figure 5. Flux through vines on an hourly basis in the MIA sites.

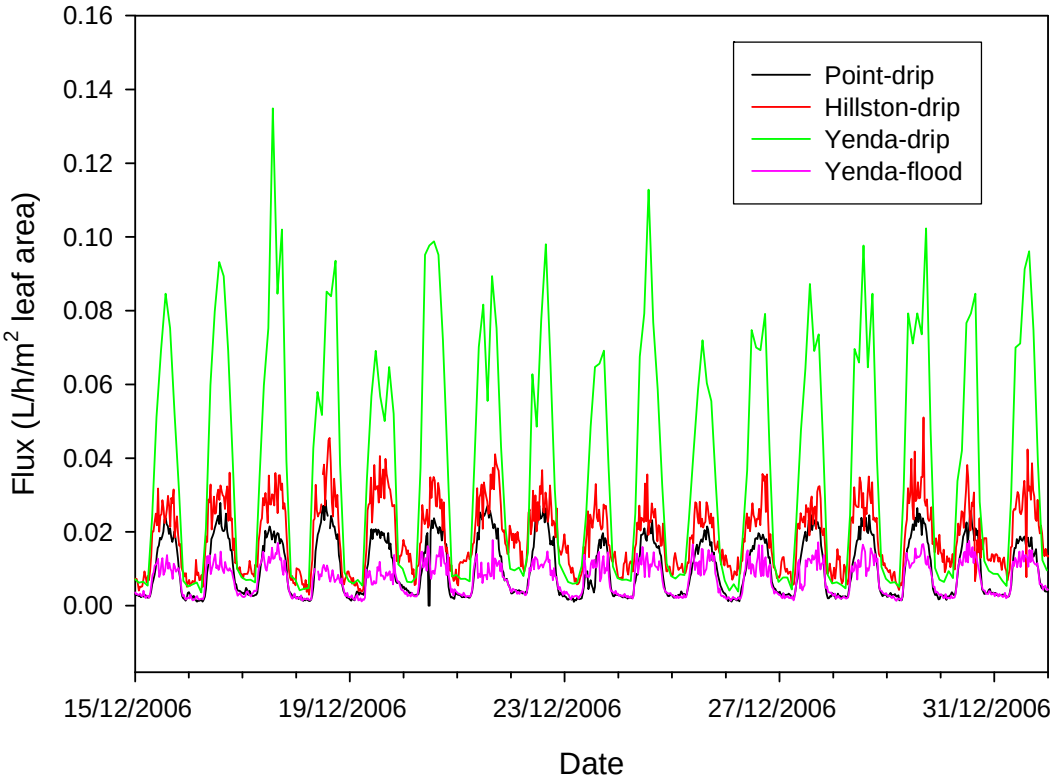


Figure 6. Flux through vines on an hourly and leaf area basis in the MIA sites.

Table 1. Mean daily sap flow of vines from the MIA and Hunter Valley as compared over the 2006-07 and 2007-08 seasons. Despite the higher rain in the second season in the Hunter Valley, RAW was lower because less water was applied through irrigation.

Region	Vineyard	2006-07		2007-08		
		Sap flow ($L\ d^{-1}$)	% RAW	Sap flow ($L\ d^{-1}$)	% RAW	
Hunter Valley	Riverflat dry	0.220±0.003	-43.7±0.08	0.64±0.02	-27.7±0.6	
	Riverflat drip	0.219±0.005	59.9±1.3	0.403±0.014	19.1±0.9	
	Hillslope drip	0.97±0.03	69.8±1.0	1.21±0.06	12.9±0.8	
MIA	Yenda-Flood	1.21±0.02	16.1±0.1	0.93±0.02	49.6±0.5	
	Yenda-drip	3.03±0.05	100.1±0.8	1.97±0.06	102.5±0.6	
	Point-drip	1.50±0.03	47.1±0.4	0.73±0.013	56.4±0.7	

Table 2. A comparison of soil and vine water status at the Yenda Drip and Flood sites in the 2005-06 season. The average daily maximum temperature during January and early February was 36.1°C, while the average VPD at 3 pm was 4.8 kPa.

	Yenda-Drip	Yenda-Flood
Soil tension (kPa)	<20	90-200
Readily Available Water (%)	100	<10
Vine sap flow (L day^{-1})	3.50 ± 0.06	0.90 ± 0.01
Cane fresh weight (kg)	0.56 ± 0.04	1.13 ± 0.08
Leaf transpiration (mmol m^{-2} s^{-1})	5.3 ± 0.1	3.4 ± 1.2
Predawn ψ (MPa)	-0.30 ± 0.1	-1.0 ± 0.1
Berry fresh weight (g)	1.44 ± 0.08	0.99 ± 0.07

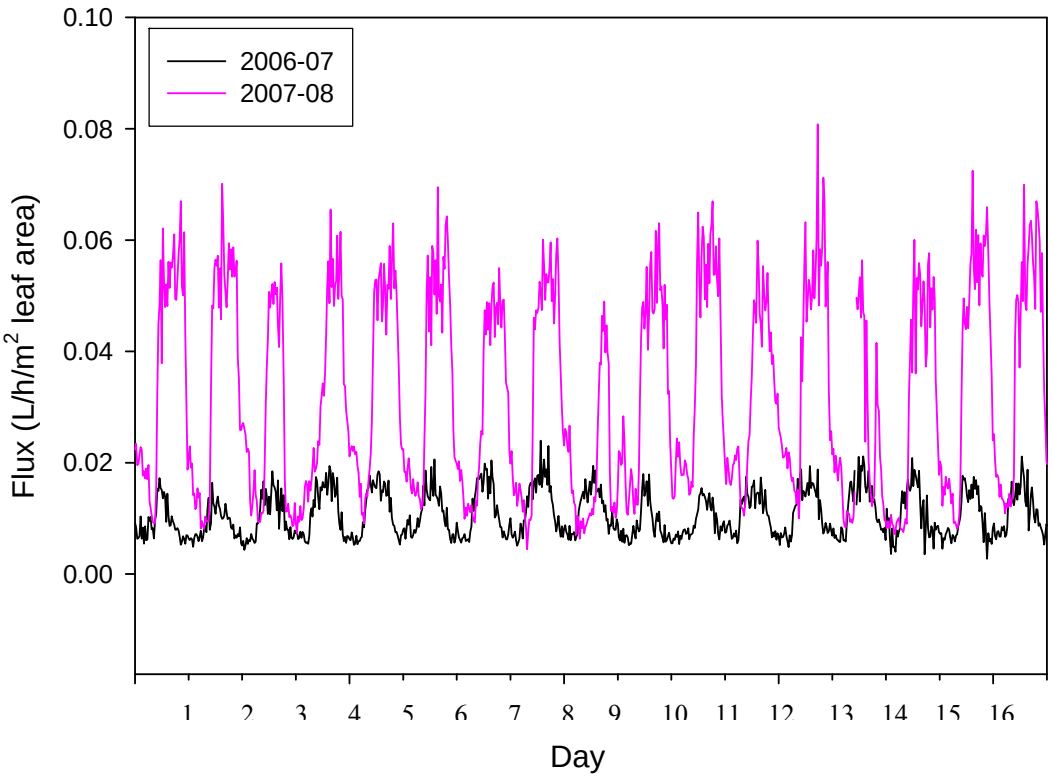


Figure 7. Flux through vines of the Riverflat Dryland site in the 2006-07 and 2007-08 seasons. Rainfall was 97 mm in 2006-07 and 387 mm in 2007-08 from November to the end of January.

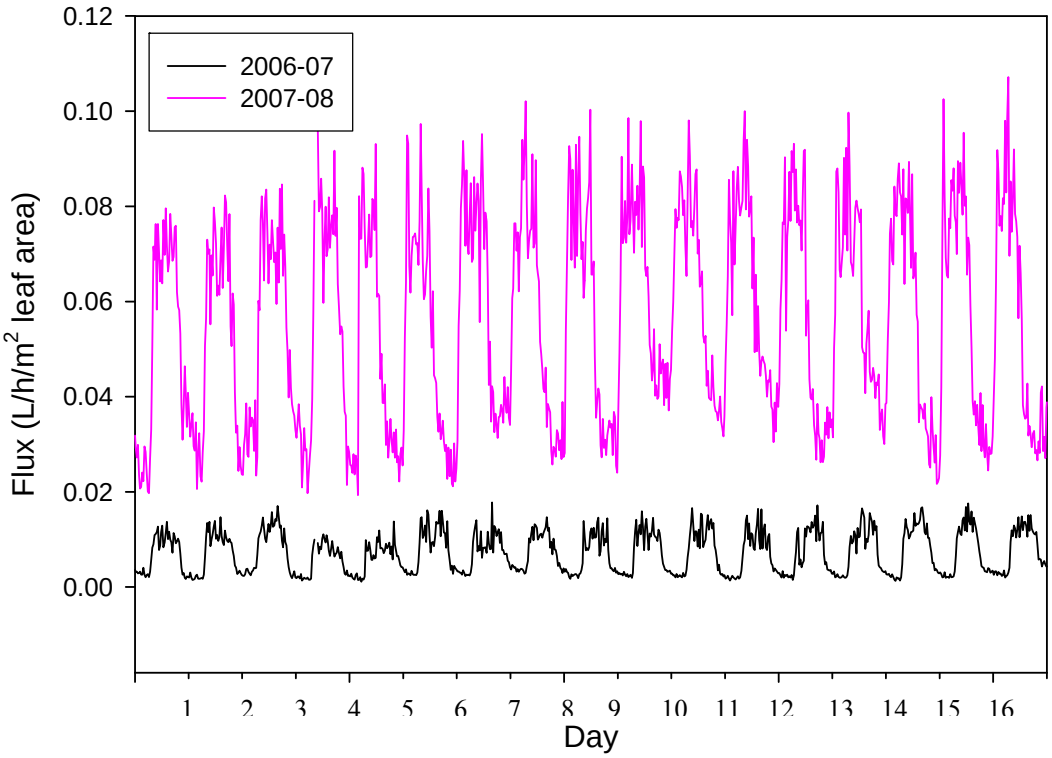


Figure 8. Flux through vines of the Flood vineyard in the 2006-07 as compared with the 2007-08 season when it had been converted to drip irrigation. Mean readily available water (RAW) was 16.1 ± 0.2% in 2006-07 and 49.6 kPa in 2007-08. Rainfall was 38 mm in 2006-07 and 176 mm in 2007-08 season.

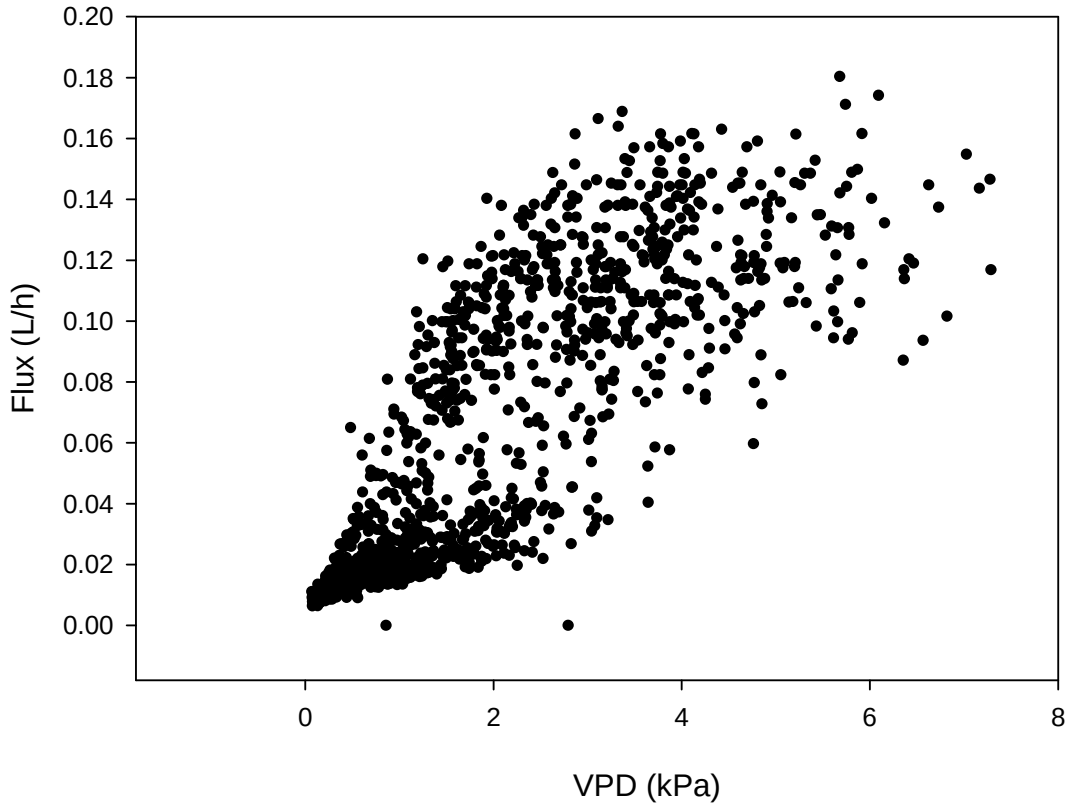


Figure 9. Flux correlated to VPD in the 2006-07 season for the Point-drip site.

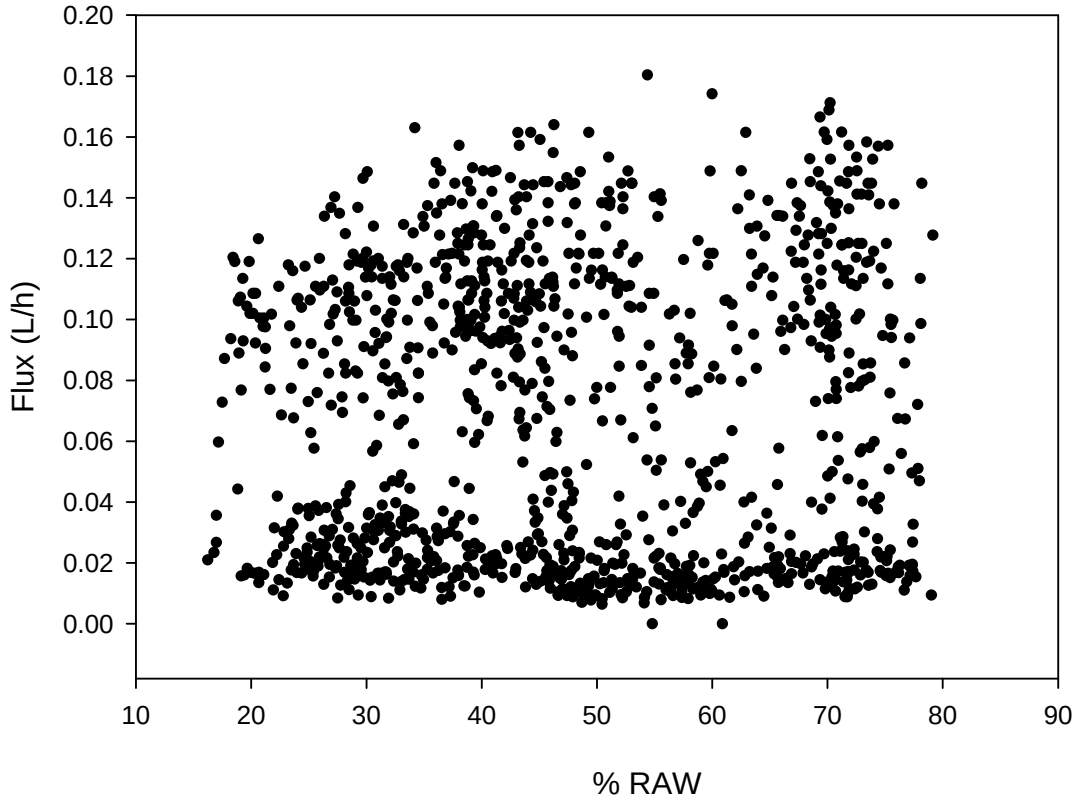


Figure 10. Flux correlated to % readily available water in the 2006-07 season for the Point-drip site.

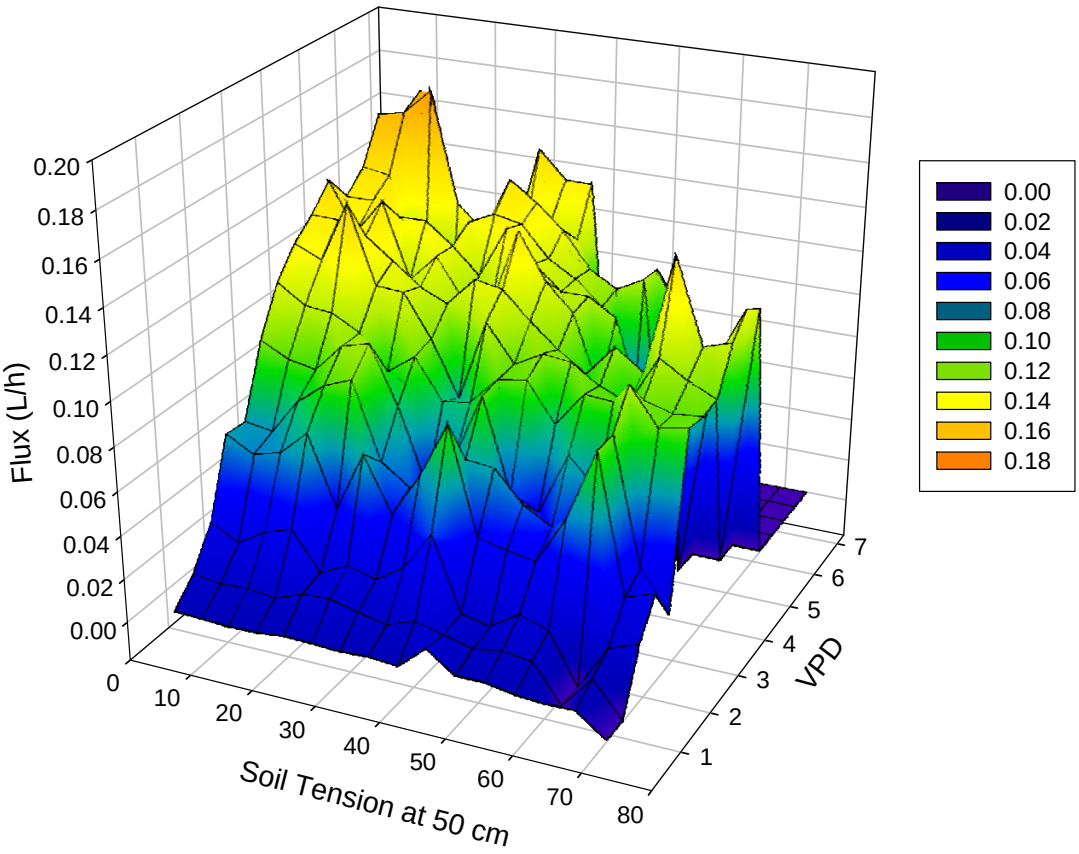


Figure 11. Flux correlated with soil tension and VPD for the Point-drip site in the 2006-07 season.

6. 1: Regional Study
H. Yield and berry composition

Anecdotal evidence indicates that Semillon berry development is slowed during water stress. Berries become less juicy and more viscous as vines experience water deficits during the ripening period. In some instances the berries attain undesirable flavours and stop accumulating sugars. The objective was to characterise berry composition, size and yield of Semillon vines from the Hunter Valley and MIA, and to determine how vine water status had an impact on these parameters.

In the 2007-08 season, the Hunter Valley received 200 mm more rain than in the MIA. In this season, the Yenda-flood site had been converted to drip irrigation. The greater rainfall in the Hunter Valley may explain the greater average bunch weight (Figure 1). While berry number/bunch was not different between the vineyards (Figure 2), berry fresh weight was lower for vines from the MIA. There were no differences in berry fresh weight of vines in the site that had been converted from flood to drip irrigation (Figure 3), likely because of adequate soil moisture for these vines. Berry dry weight, however, was lowest for the Low EM location which had the lowest soil moisture (Figure 4A). Berry water content was lowest for vines from the Yenda-drip site (Figure 4B). Berry total soluble solids were highest for the Point-Drip vineyard (Figure 5).

The most striking difference between the regions was berry pH and TA. The Hunter Valley fruit had lower pH (3.4 as compared to 3.8) and higher TA (4 g/L as compared to 8 g/L) (Figures 6 and 7). Regional soil differences may explain this. In the Hunter Valley, lower soil pH, and lower levels of K prevail (See section 6.B Soil Characteristics). The lower VPD in the Hunter Valley (See section 6.E Canopy temperature Characteristics) may also have influenced these berry parameters through slowed ripening, however berry TSS were not substantially less in the fruit from the Hunter Valley (Figure 5).

Yield was greater for vines in the MIA than in the Hunter Valley (Figure 8) and this was due to greater number of bunches/vine (Figure 9). At the Yenda-drip and Yenda-flood sites there were approximately 150 bunches/vine, but in the Hunter Valley sites there were less than 70 bunches/vine. The Dryland site had the fewest bunches/vine at less than 25. Crop load, however, was not substantially different between regions (Figure 10) and ranged from 0.1 to 0.6 kg of fruit/vine.

The field survey did not highlight overall effects of vine water status on berry composition. This is likely because clone, vine age, fertilisation, soil type, pruning and summer trimming were confounding any interactions. In the Dryland site, however, berries on vines with more negative leaf water potentials were lower in TSS, dry weight, pH and higher in TA (Table 1).

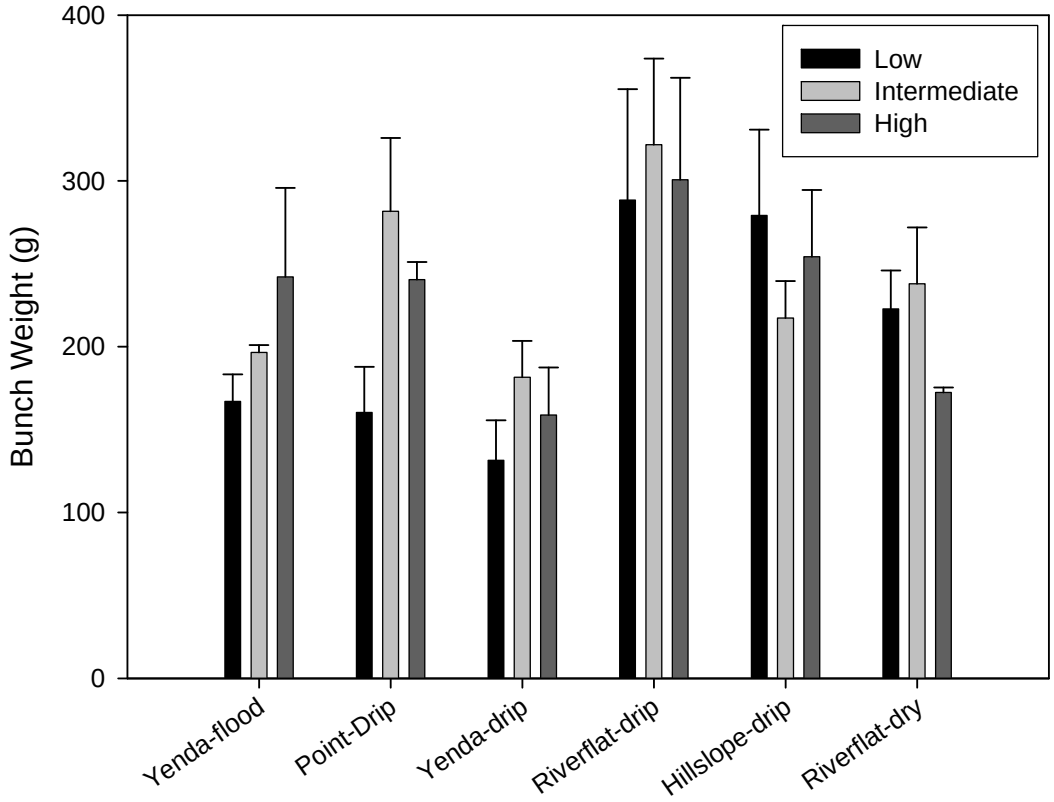


Figure 1. Average bunch weight of vines grown in the MIA and the Hunter Valley at Low, Intermediate and High EM locations in the 2007-08 season.

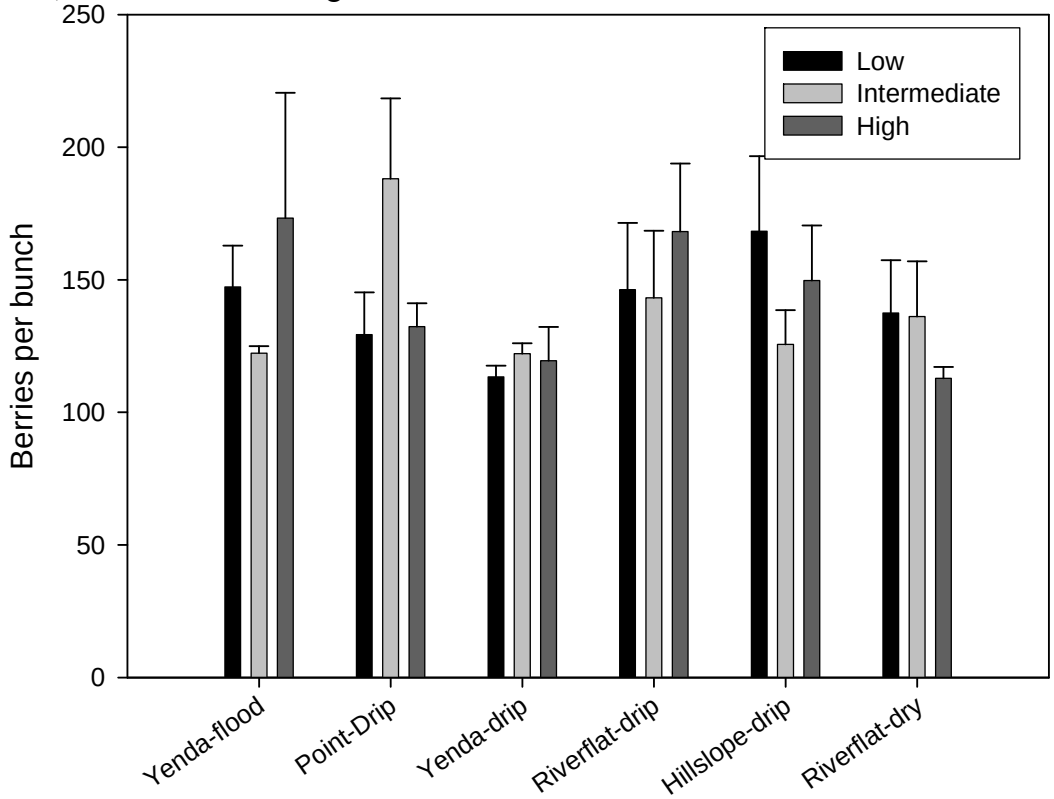


Figure 2. Average number of berries/bunch of vines grown in the MIA and the Hunter Valley at Low, Intermediate and High EM locations in the 2007-08 season.

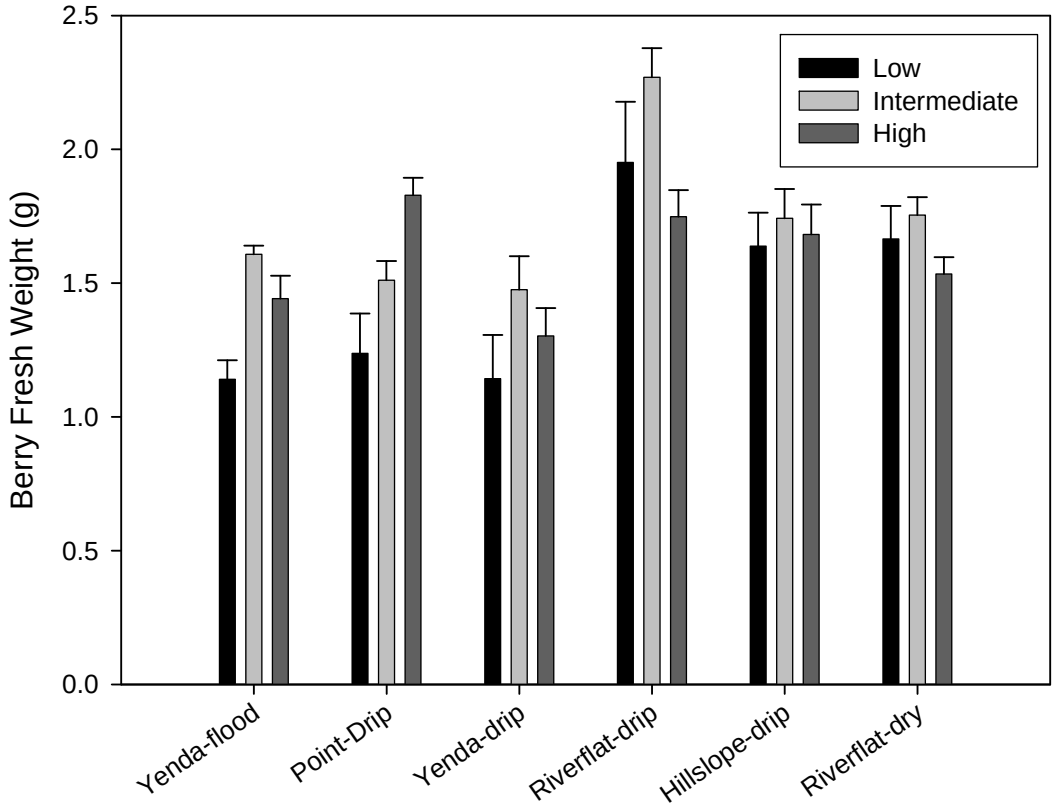


Figure 3. Average berry fresh weight of vines grown in the MIA and the Hunter Valley at Low, Intermediate and High EM locations in the 2007-08 season.

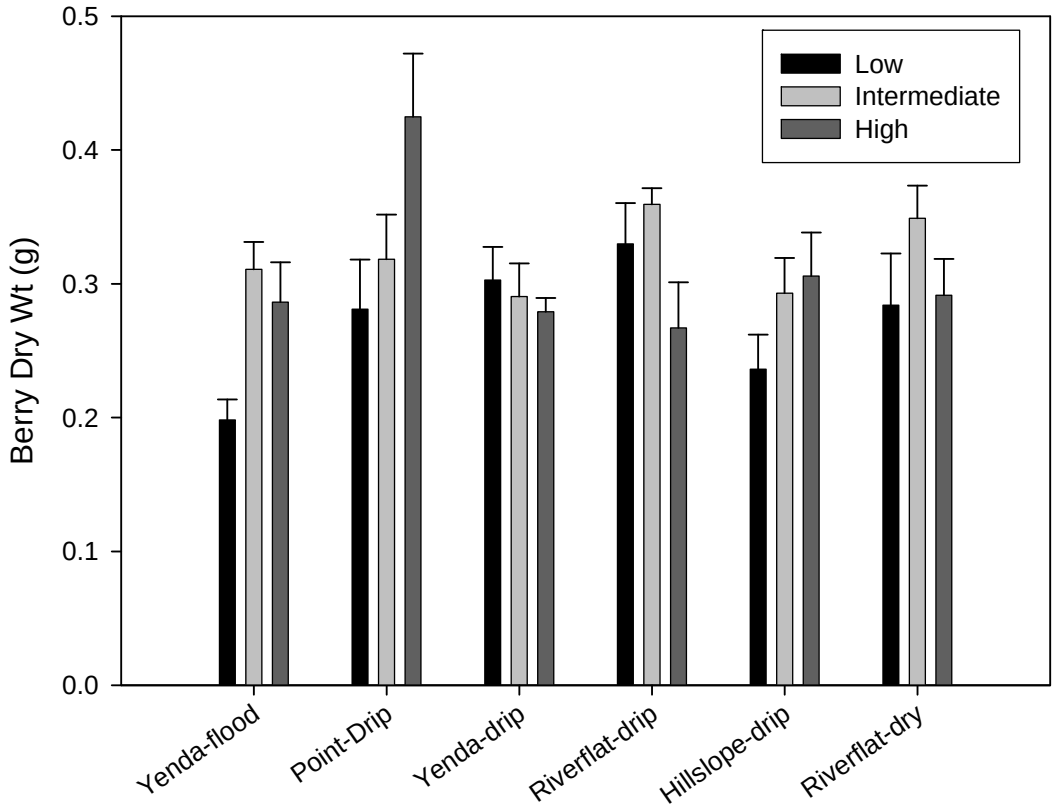


Figure 4A. Average berry dry weight of vines grown in the MIA and the Hunter Valley at Low, Intermediate and High EM locations in the 2007-08 season.

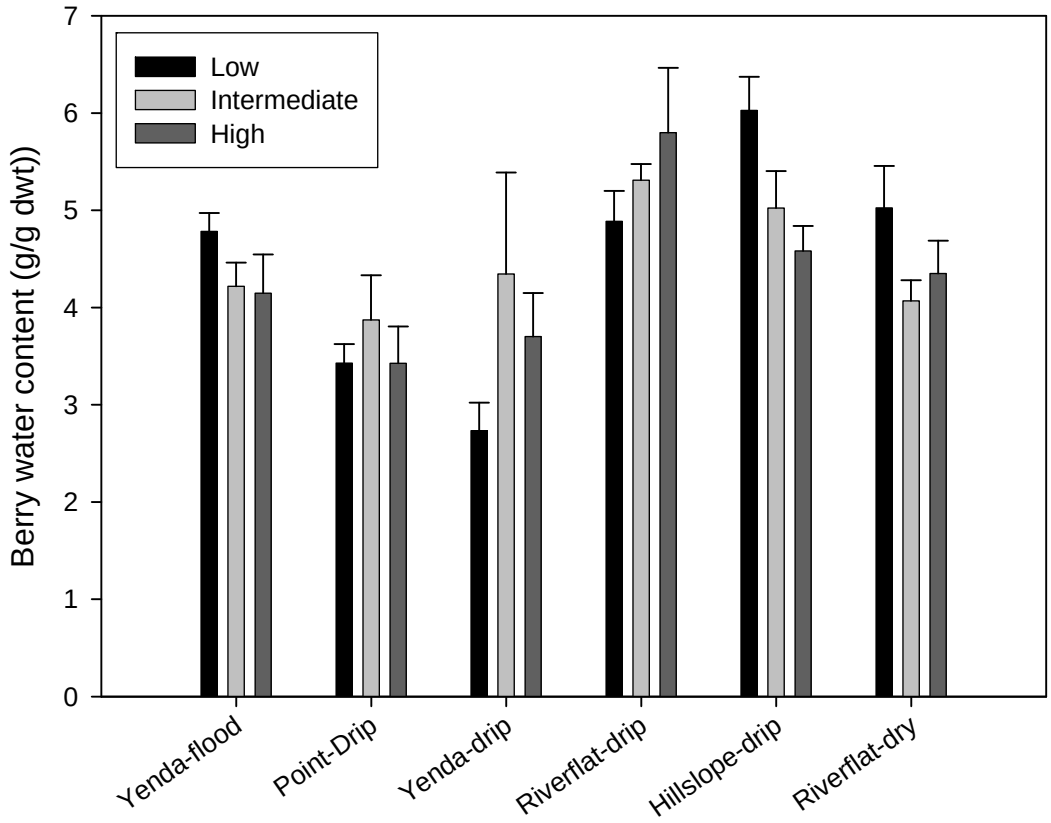


Figure 4B. Berry water content of vines grown in the MIA and the Hunter Valley at Low, Intermediate and High EM locations in the 2007-08 season.

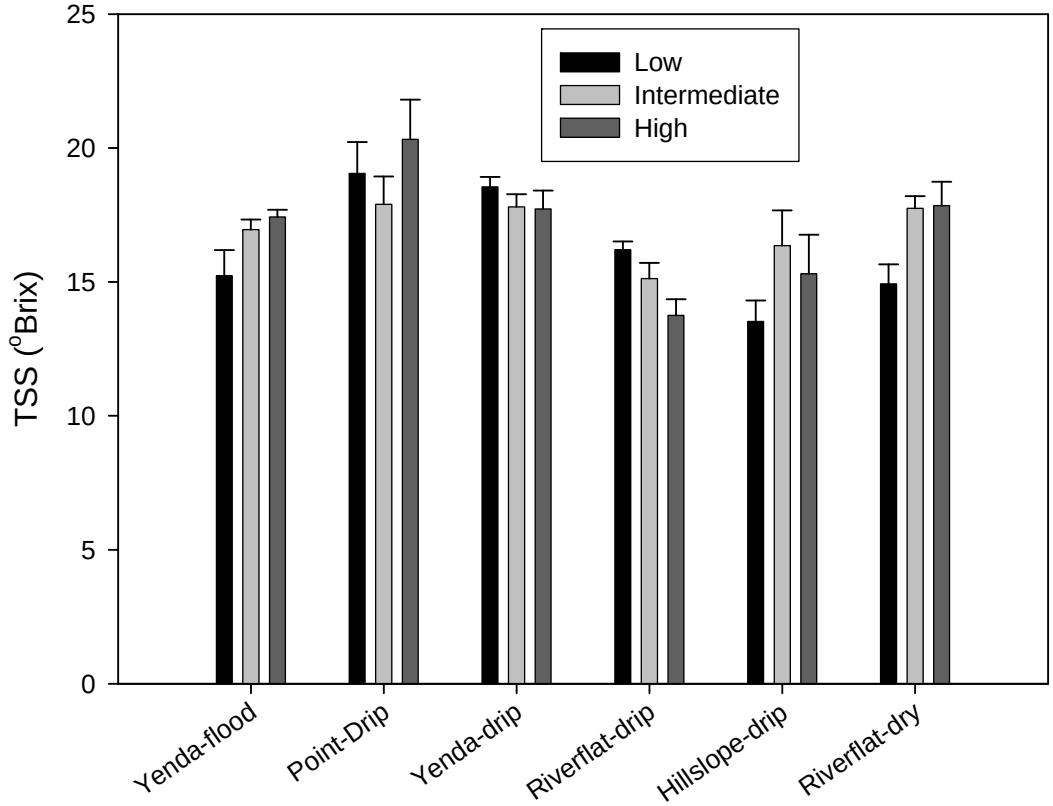


Figure 5. Berry total soluble solids of vines grown in the MIA and the Hunter Valley at Low, Intermediate and High EM locations in the 2007-08 season.

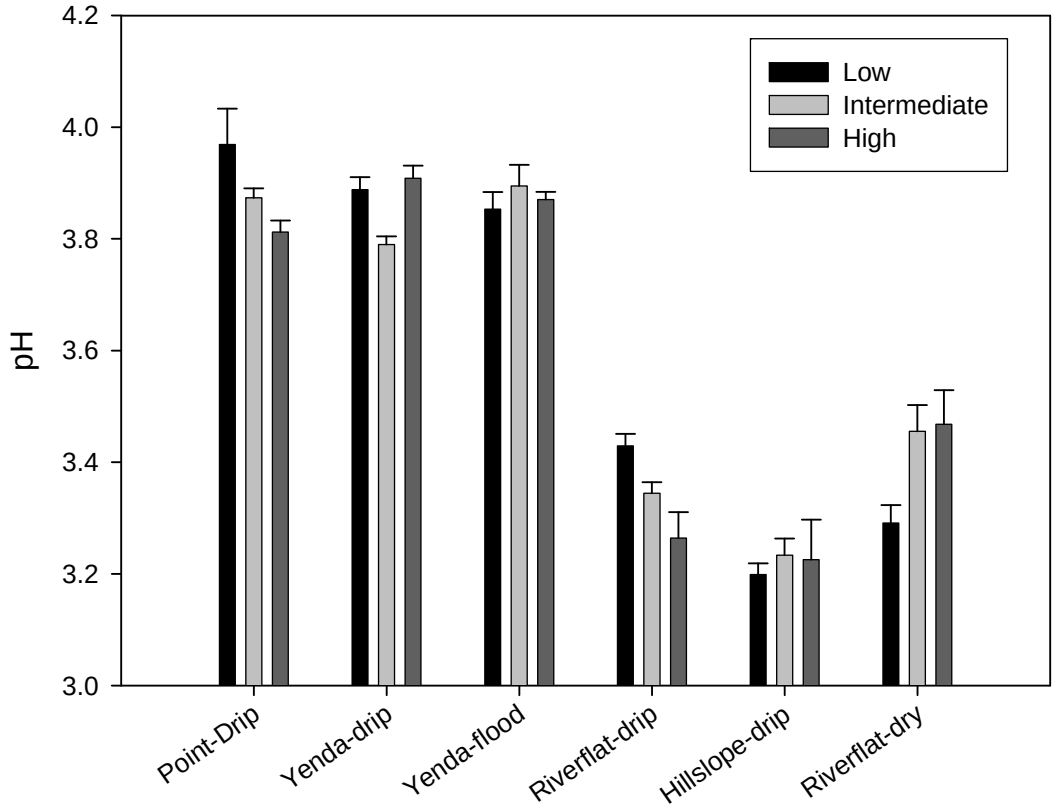


Figure 6. Berry pH of vines grown in the MIA and the Hunter Valley at Low, Intermediate and High EM locations in the 2007-08 season.

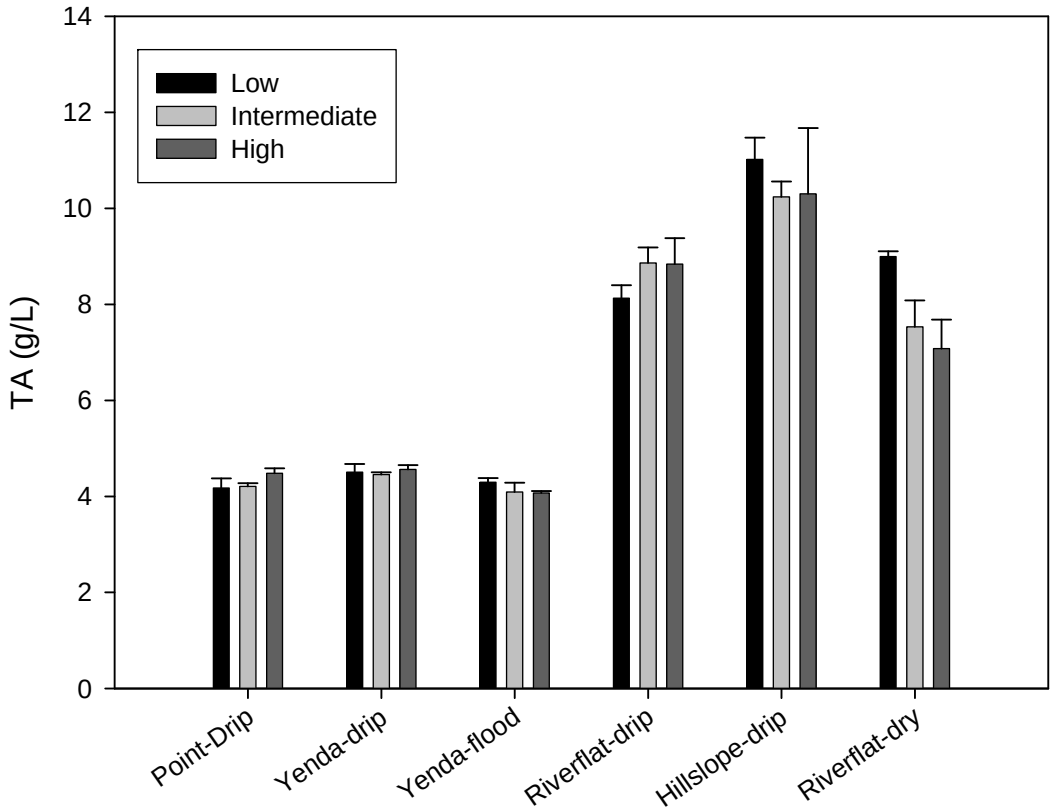


Figure 7. Berry titratable acidity of vines grown in the MIA and the Hunter Valley at Low, Intermediate and High EM locations in the 2007-08 season.

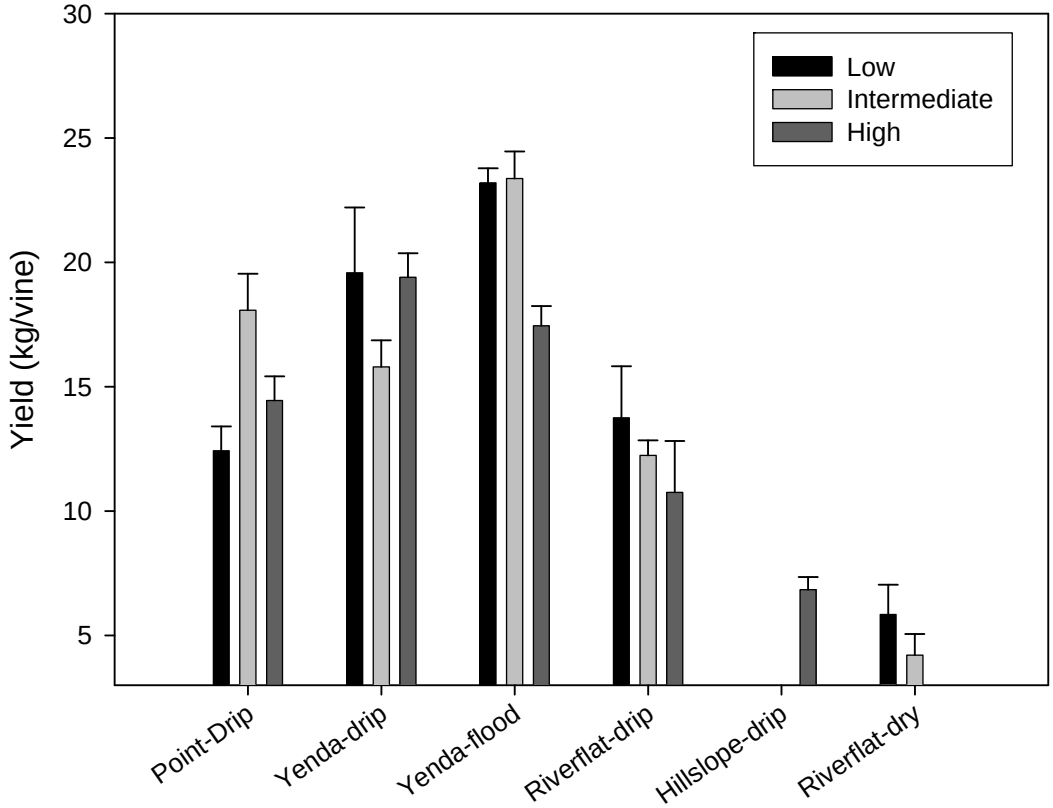


Figure 8. Yield of vines grown in the MIA and the Hunter Valley at Low, Intermediate and High EM locations in the 2007-08 season.

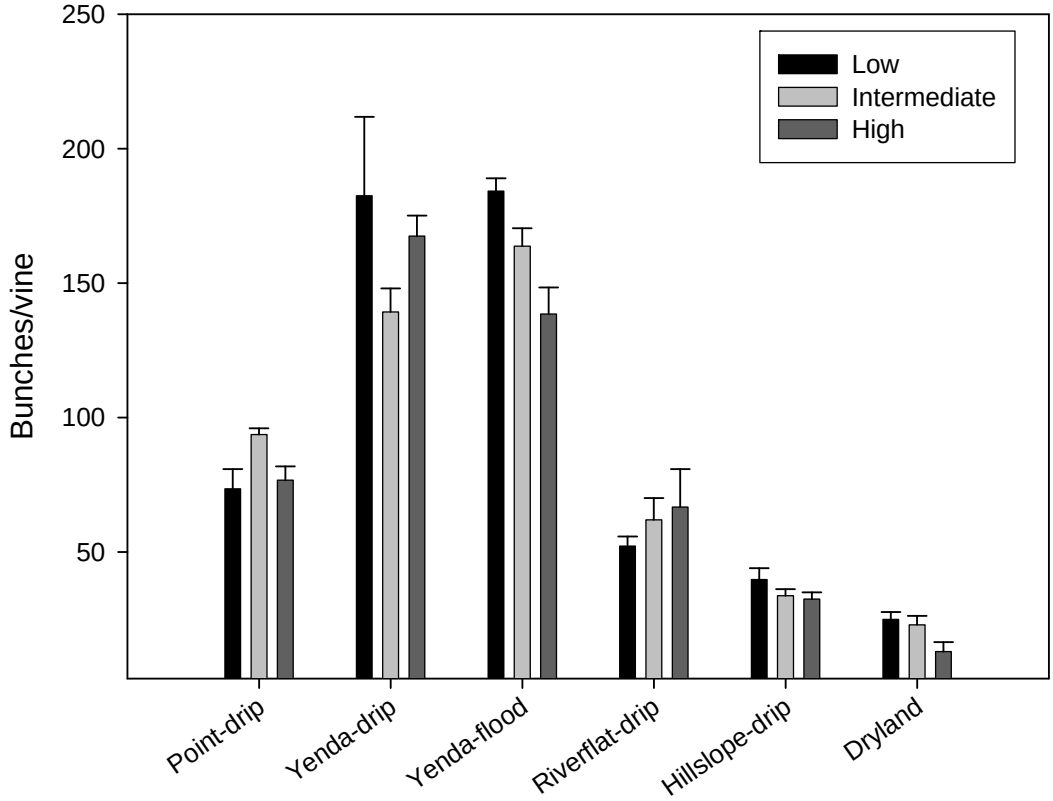


Figure 9. Number of bunches/vine of vines grown in the MIA and the Hunter Valley at Low, Intermediate and High EM locations in the 2007-08 season.

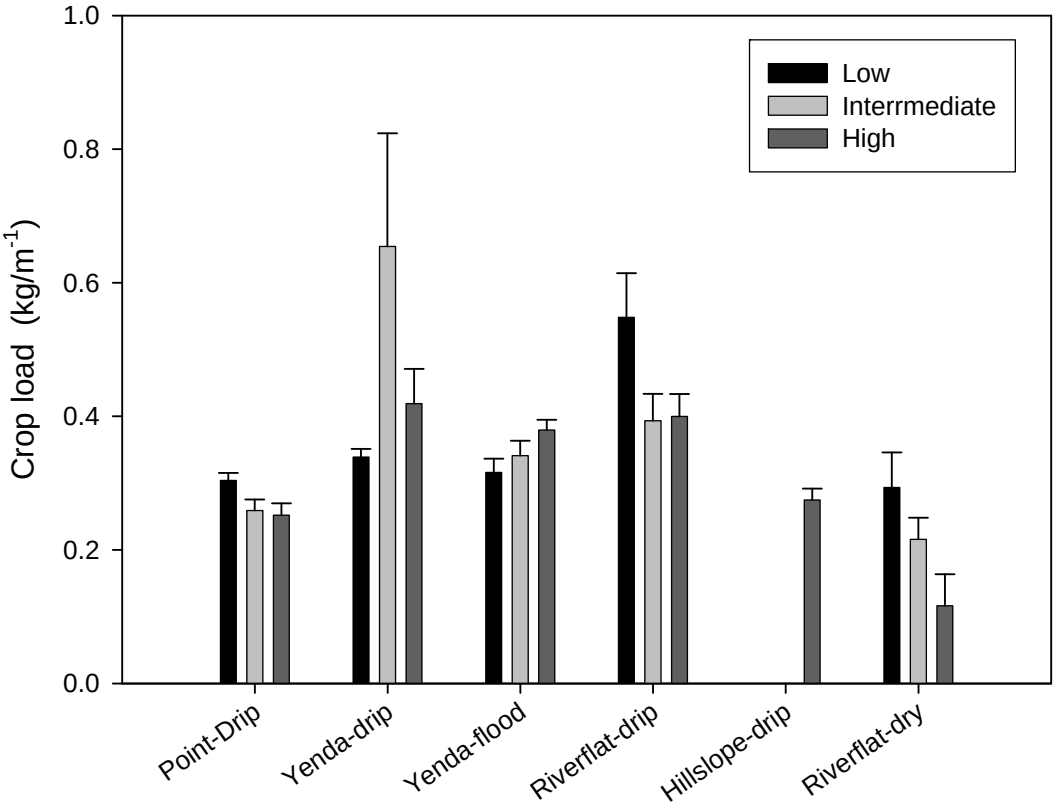


Figure 10. Crop load of vines grown in the MIA and the Hunter Valley at Low, Intermediate and High EM locations in the 2007-08 season.

Table 1. Correlation of mid-day leaf water potential to berry composition of vines grown at the Dryland site in 2007-08.

	Low	Intermediate	High	Correllation to LWP
LWP (Mpa)	-1.36	-0.94	-1.00	
VPD (kPa)	1.13	2.25	2.08	0.99
RAW (%)	-37.80	-13.00	-13.70	0.99
berry fwt (g)	1.66	1.75	1.53	0.04
TSS (°Brix)	14.93	17.75	17.85	0.99
berry dwt (g)	0.28	0.35	0.29	0.70
berry pH	3.29	3.46	3.47	0.98
berry TA (g/L)	9.00	7.53	7.08	-0.93
Shoot length (m/vine)	15.76	11.30	7.43	-0.81
Bunches per vine	31.00	27.00	7.00	-0.51
Crop load (bunches/m)	1.97	2.39	0.94	-0.09

In the Dryland site berries on vines with more negative leaf water potentials (more water stress) were lower in TSS, dry weight, pH and higher in TA (Table 1). The lower TSS was not due to larger berry size, but more likely due to slower ripening. The slowed ripening cannot be explained by a higher crop load. The more negative leaf water potentials in this case were a function of lower %RAW, not due to higher VPD. The bigger canopy size of the vines in the Low location may have increased

the demand for water and thus exacerbated the negative leaf water potentials of these vines.

The field survey did highlight some correlations between vine fruit parameters and vine canopies. Yield increased with leaf area, but beyond a leaf area of 4 m^2/vine yield rose only slightly (Figure 11). There was, however, a linear correlation with yield and vine dry pruning weight (Figure 12). Bunch number/vine was quadratically related to shoot number/vine (Figure 13). Yield was linearly related to bunch number/vine (Figure 14).

There was an interesting quadratic relationship between yield and soil pH (Figure 15). As soil pH increased so did the yield. Bunch weight was correlated to berry fresh weight, and this was strongest in January, about one month before harvest (Figure 16). As expected berry dry and fresh weight was correlated (Figure 17). Berry TSS was linearly correlated to vine leaf area (Figure 18). Berry pH was correlated to berry TSS in a quadratic relationship (Figure 19). A similar relationship was evident between berry TSS and shoot number per vine (Figure 20). Higher vine leaf areas resulted in higher berry pH (Figure 21) and higher soil K levels resulted in higher berry pH (Figure 22). Since high berry pH is an unfavourable characteristic in the MIA, perhaps reducing soil K application rates may be favourable. Field trials will need to be carried out to establish this, since low K may also result in other negative effects on the canopy and vine health.

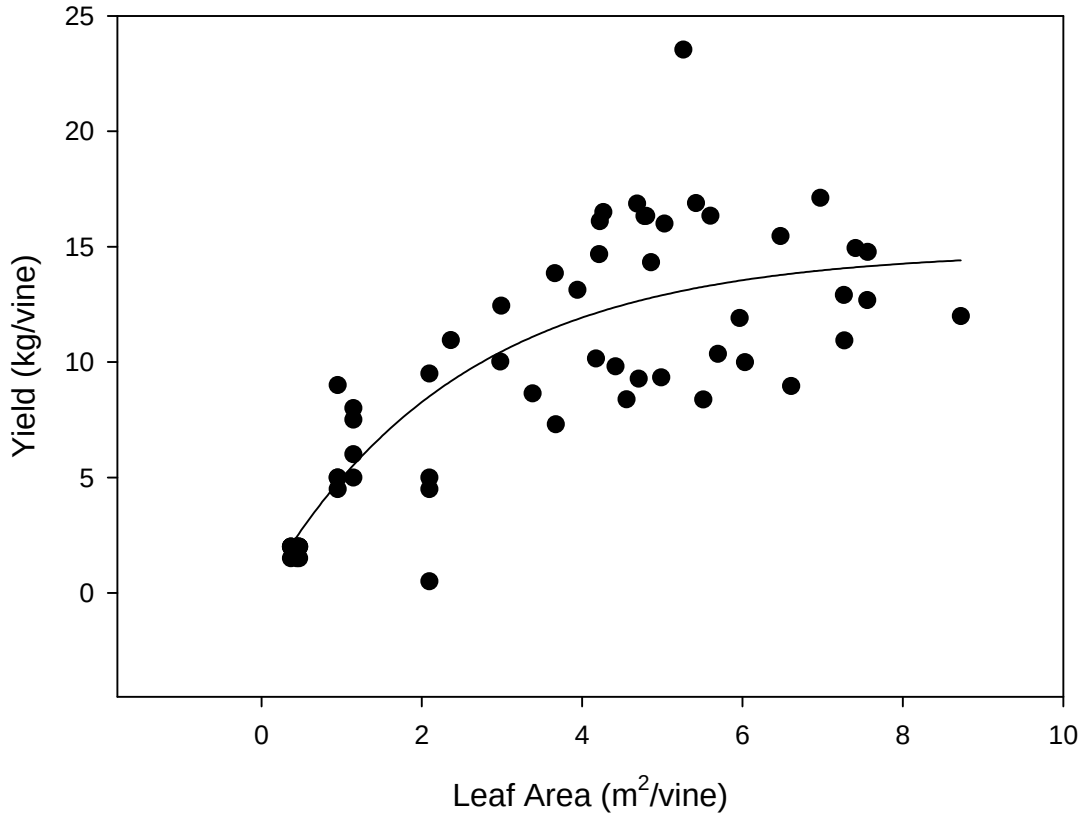


Figure 11. Correlation of yield with vine leaf area.

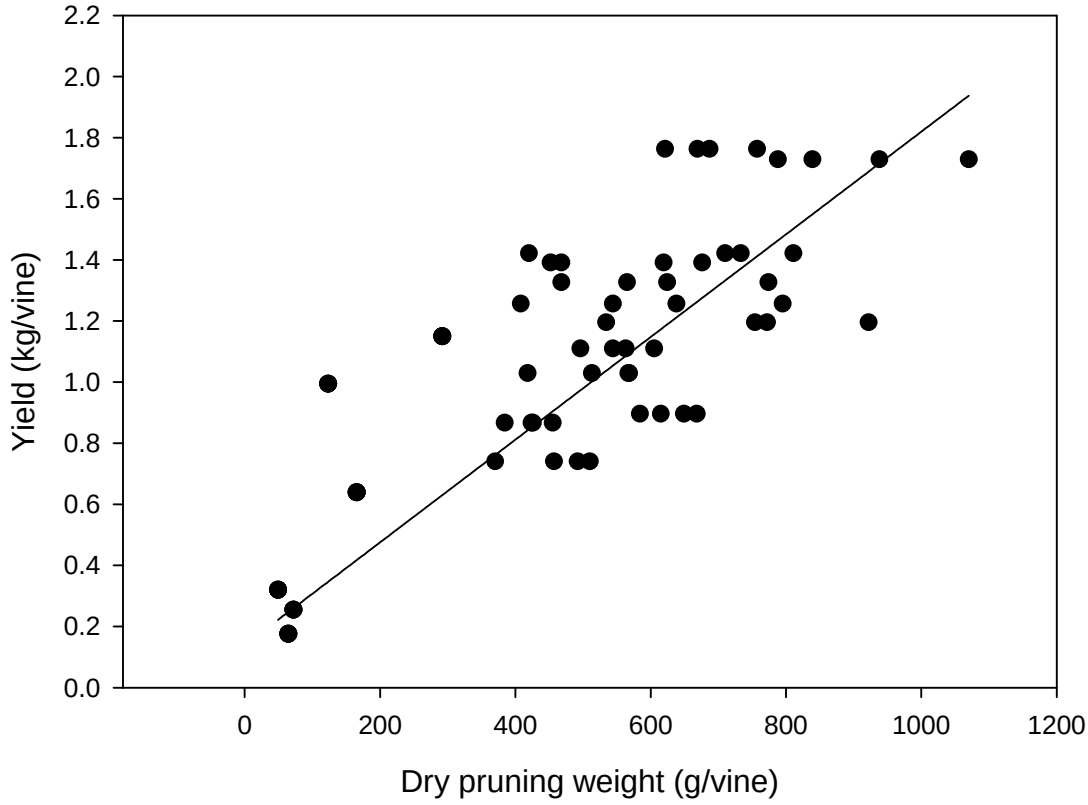


Figure 12. Correlation of yield with vine dry pruning weight.

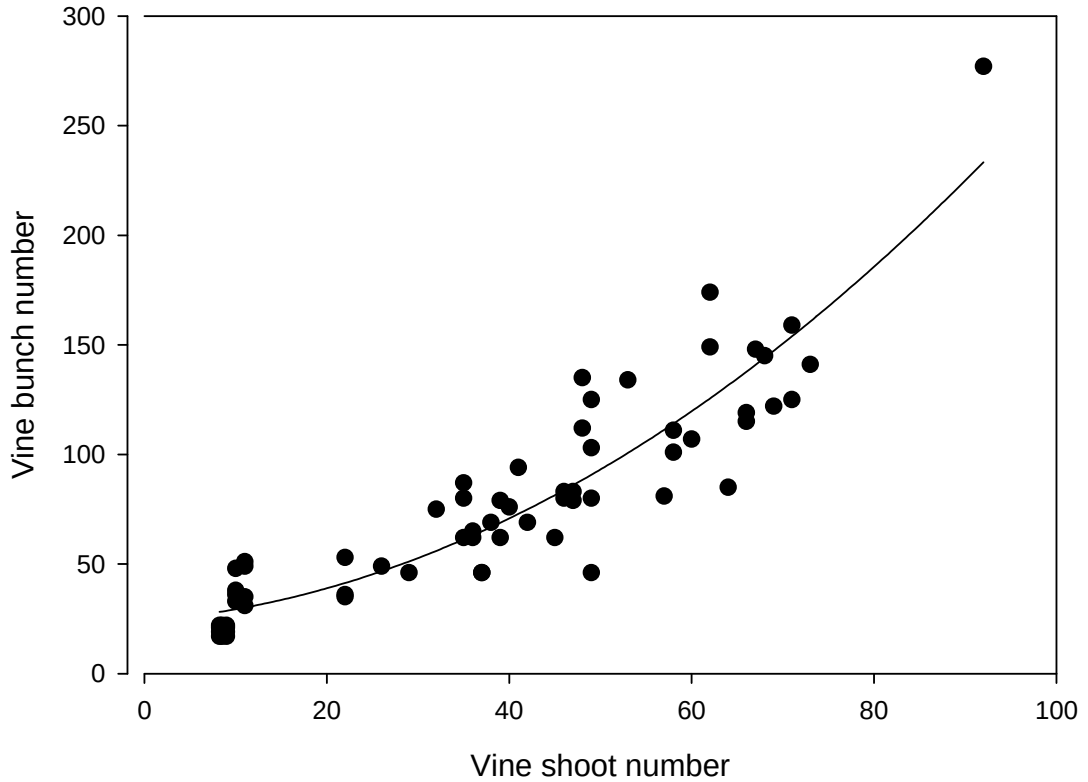


Figure 13. Correlation of bunches per vine with shoot number per vine

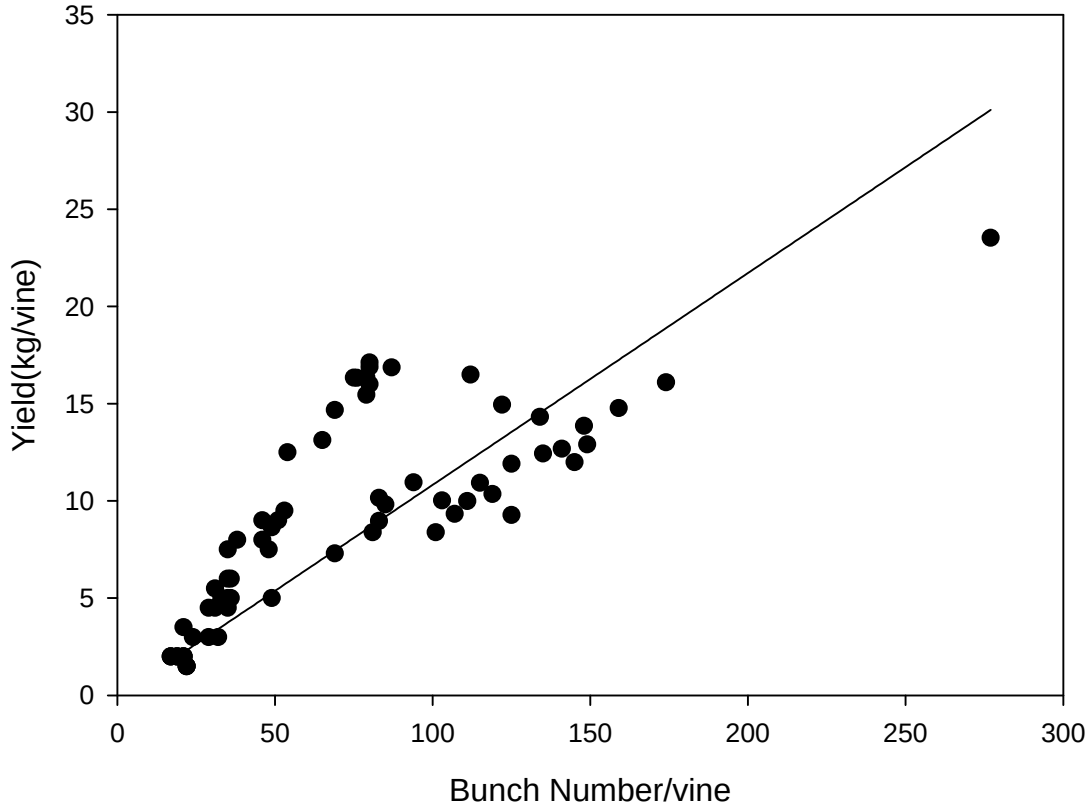


Figure 14. Correlation of yield with bunch number/vine.

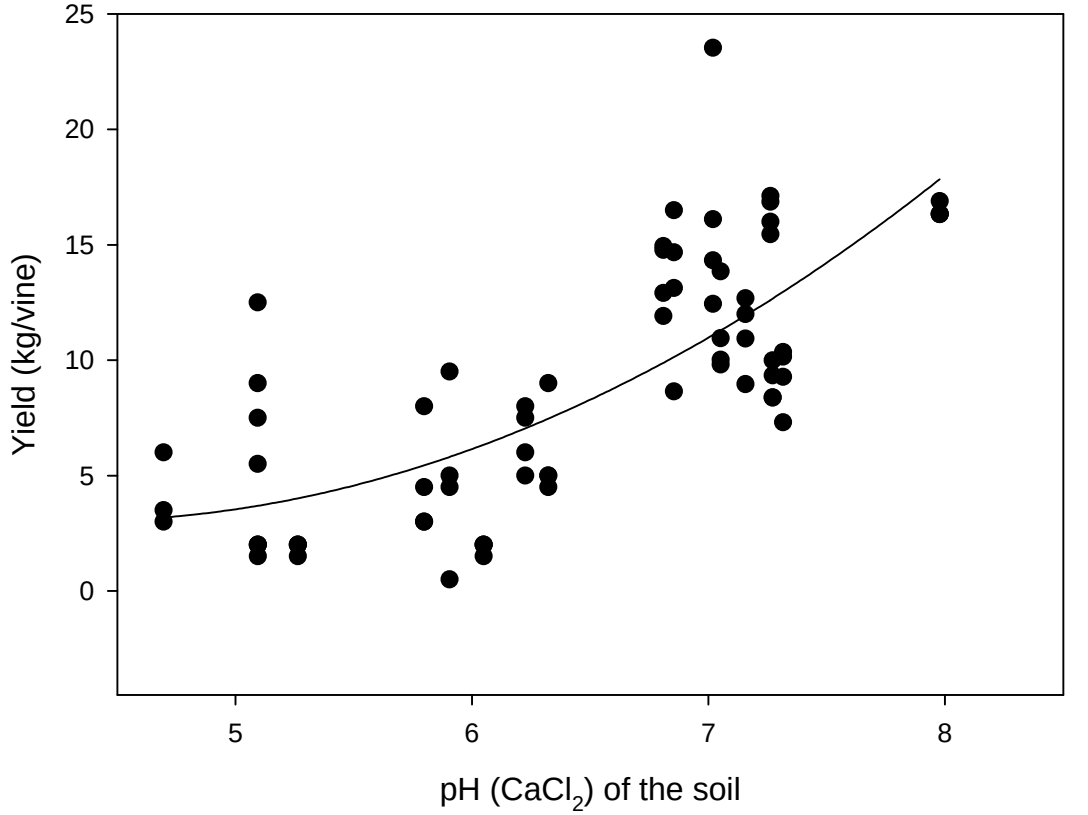


Figure 15. Correlation of yield with pH of the soil.

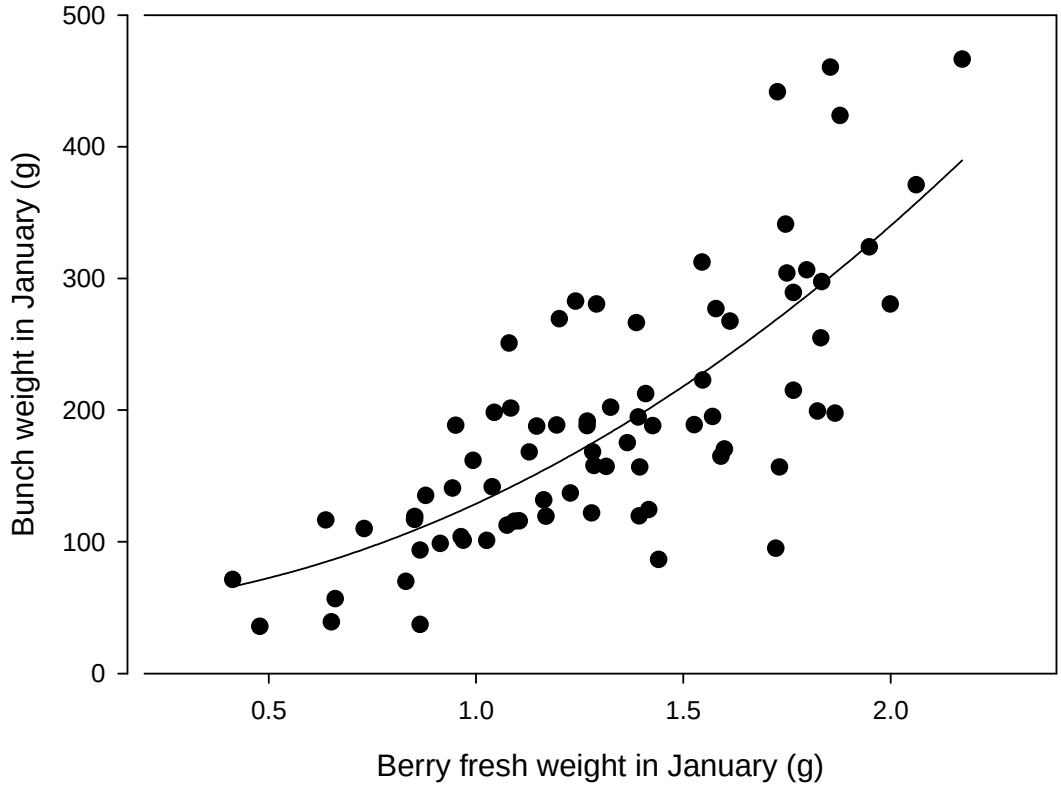


Figure 16. Correlation of bunch weight with berry fresh weight in January, approximately one month before harvest.

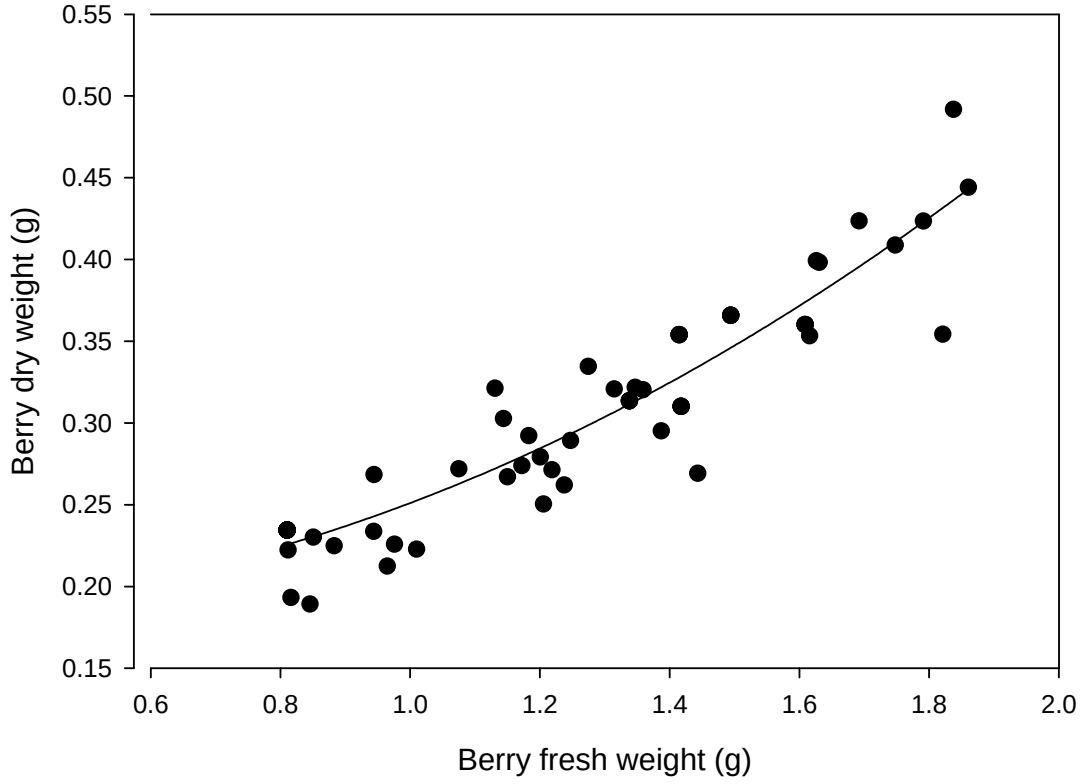


Figure 17. Correlation of berry dry weight and fresh weight.

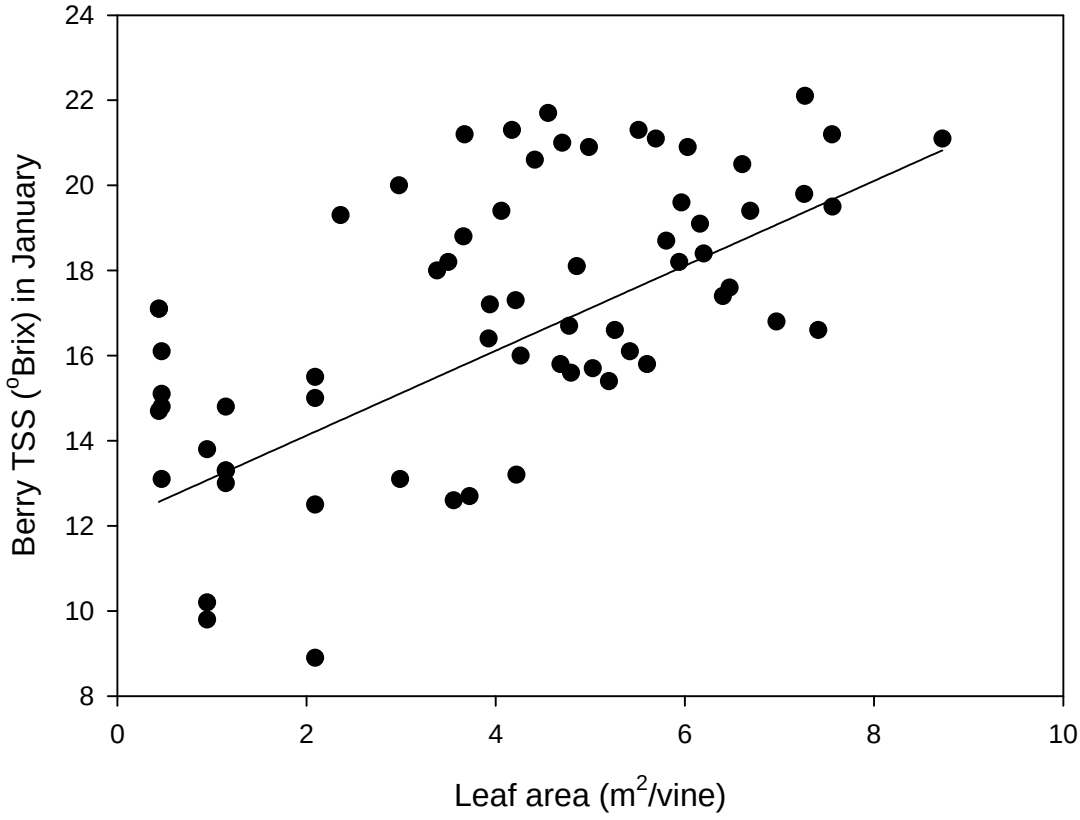


Figure 18. Correlation of Berry TSS with vine leaf area.

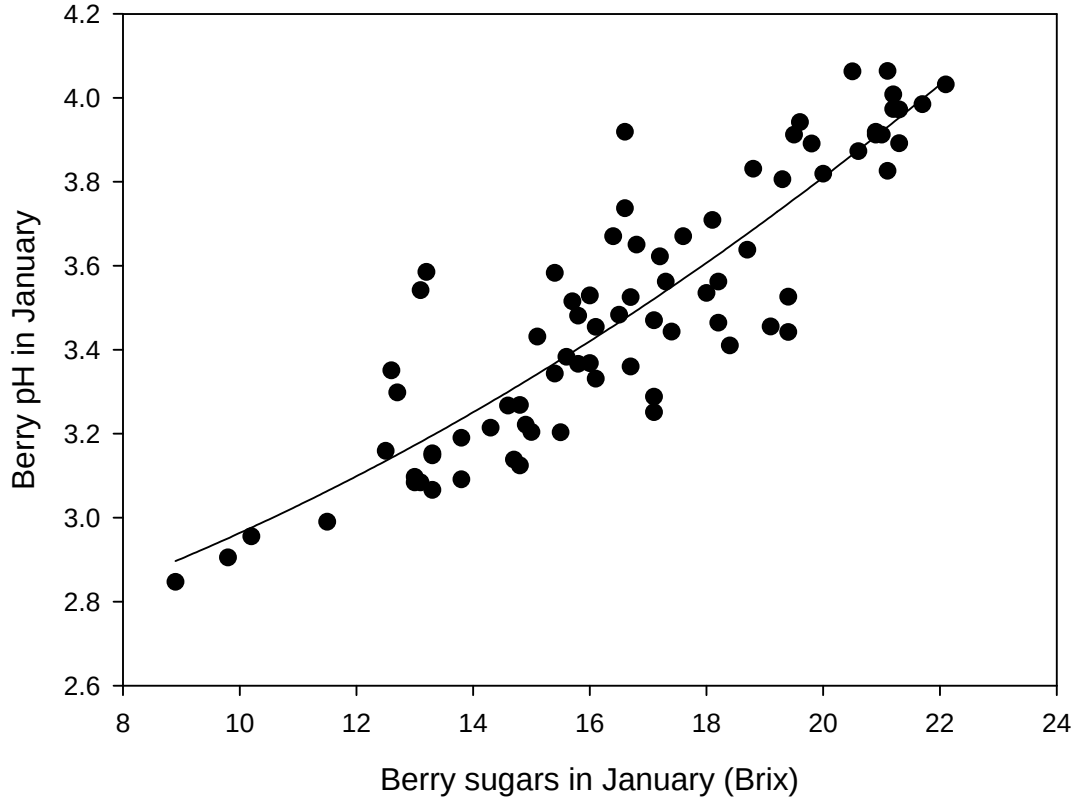


Figure 19. Correlation of berry pH with berry TSS.

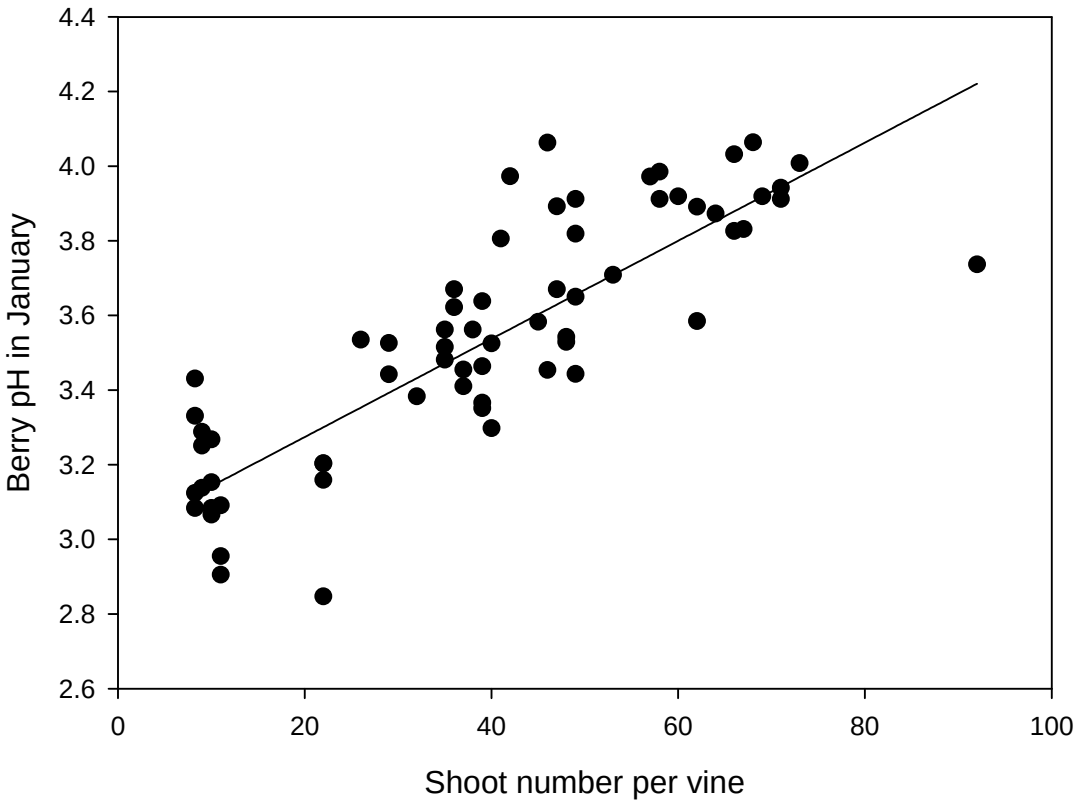


Figure 20. Correlation of berry pH with shoot number per vine.

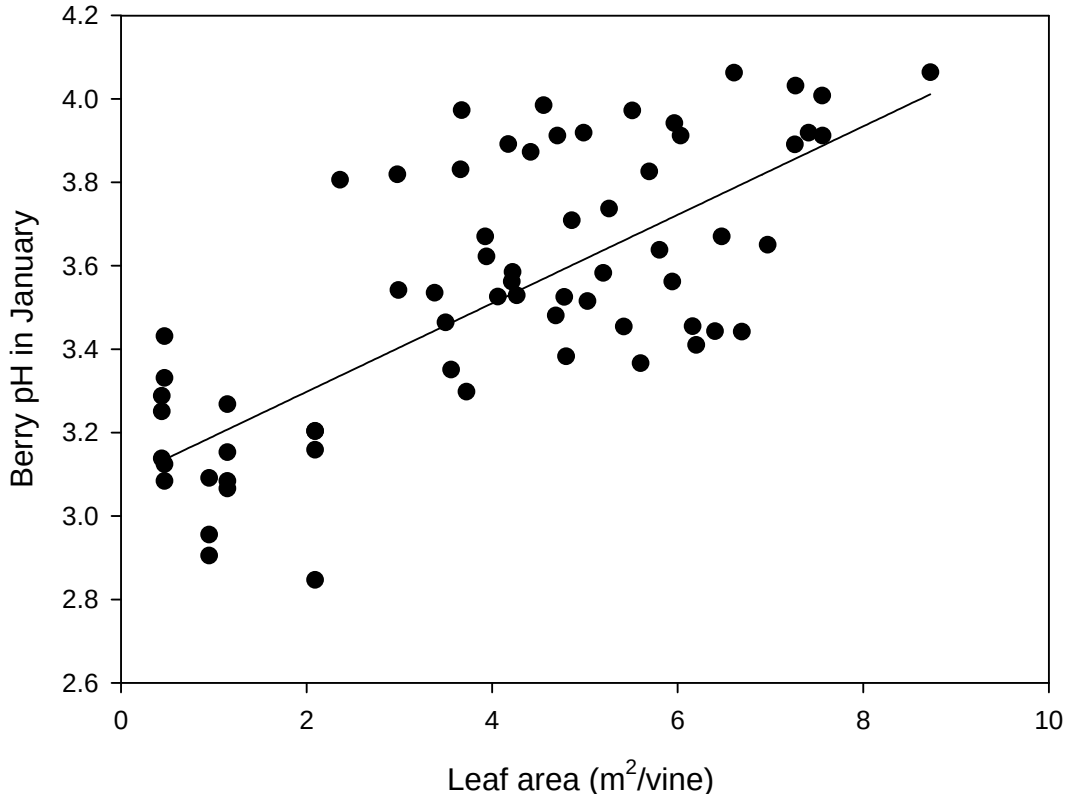


Figure 21. Correlation of berry pH with vine leaf area.

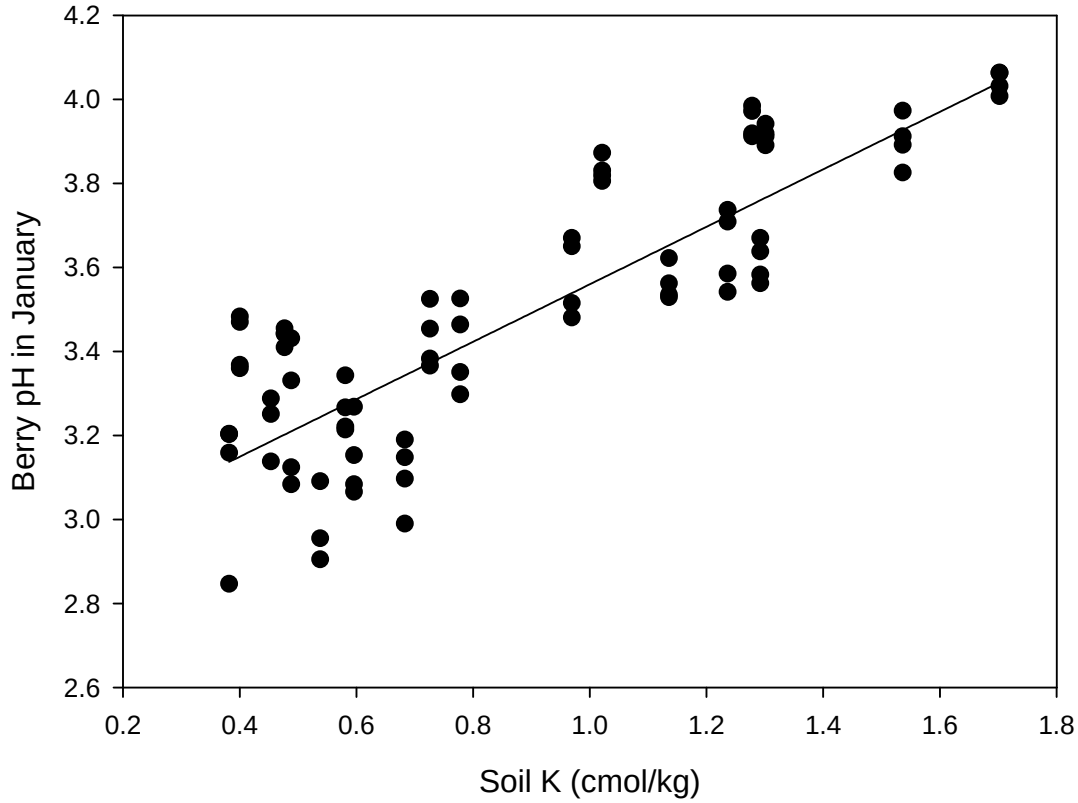


Figure 22. Correlation of berry pH with soil K levels.

6.2: Semillon clones and interactions with rootstocks

Semillon vines are unable to maintain vine water status under conditions of high VPDs, especially under low soil moisture. This section of the project addresses if there are clonal differences in the susceptibility to the water stress and if there are rootstocks currently grafted on Semillon exacerbating or ameliorating the water stress that Semillon experiences.

A phone survey was carried out across the vineyards of Hunter Valley and MIA regions to ascertain which clones are currently planted in Semillon vineyards. Unfortunately, most often the clone was not known, especially in the older plantings. D10V12 and DA16162, however, were two clones that were in use. Rootstocks were not used in about half the vineyards questioned. Schwarzmann was used in the Hunter Valley and Ramsey was used in the MIA.

Subseqently a pot trial was conducted with the following clone and rootstock combinations:

- Macedone on own roots
- D10V12 on own roots
- DA 16162 on own roots
- DA 16162 on Schwarzmann
- DA 16162 on Ramsey
- Shiraz



The clonal/rootstock trial was carried out on potted vines at the NWGIC.

Semillon vines went through budburst in early September. Approximately 10 shoots per vine developed, except for D10V12 on own roots, which had on average two fewer shoots. Inflorescences were also less for this clone at 10 per vine while the other clones averaged at 16 inflorescences per vine. The shoots and inflorescences

were thinned in early October to 6 shoots per vine and two inflorescences per shoot. Cap-fall occurred in early October.

The first dry down cycle was applied in late January. Withholding water for only two days resulted in a halving of soil moisture levels. At the end of the dry down period soil moisture was between 15 and 20%. Soil moisture of the control treatment was maintained to 35-50% (Figure 1). The wide variation in soil moisture despite equal amounts of water application in the control treatment is likely due to the different transpiration rates between the clones/rootstocks. Shiraz and Macedone on own roots had consistently higher soil moisture levels than the other vines. During the deficit irrigation treatment the soil was drier underneath the dripper than at the opposite side of the pot (Figure 1). This is most likely because most of the roots were located directly underneath the dripper and these were drawing the soil moisture down.

Withholding water from Semillon vines for two days during the post-veraison period resulted in leaf burn for all clone and rootstock combinations of Semillon, with Macedone on own roots experiencing the most leaf burn (Figures 2 and 3). Shiraz, however, had less than one leaf per vine with any signs of burning. Leaf temperature was 4°C higher under deficit irrigation as compared with fully irrigated vines (Figure 4). Chlorophyll levels of the vines were not different between clones/rootstocks, nor did they alter with the deficit treatment.

Midday leaf water potentials ranged between -0.8 and 1.0 MPa for standard irrigated vines, but the vines which had no water for 2 days had values between -1.5 and -2.2 MPa (Figure 5). The most negative values were for DA16162/Schwarzmann. This is not surprising since these vines also had the least soil moisture levels (Figure 6). DA16162/Schwarzmann vines that were irrigated did not have lower leaf water potentials than the other clone/rootstock combinations.

Photosynthesis rates declined with decreasing soil moistures (Figure 7). Rates declined from 10 to less than 3 μmol CO_2 $m^{-2}s^{-1}$. DA16162/Shwarzman vines grown at a soil moisture of 32% had higher photosynthesis rates than the other clone/rootstock combinations. Stomatal conductance to water vapour and transpiration also declined with decreasing soil moisture levels (Figure 8), and again DA16162/Shwarzman had higher values than expected for its soil moisture level. The vapour pressure deficit at the leaf's surface increased with declining soil moisture values (Figure 9). When plotted against midday leaf water potential, both stomatal conductance and transpiration declined (Figures 10 and 11). Stomatal conductance was less than 0.03 mol H_2O $m^{-2}s^{-1}$ at leaf water potentials less than -1.6 MPa, a 10-fold drop as compared to the standard irrigated vines. Transpiration declined 4-fold over this range in leaf water potentials.

Stomatal conductance was monitored against soil moisture over a VPD range of 1 to 4 kPa. Soil moisture was the overriding factor to stomatal conductance, with levels dropping to one third with a halving in soil moisture (Figure 12). VPD had less of an effect on stomatal conductance as soil moisture declined (Figure 13). Stomatal conductance dropped by less than 30% with a 4-fold increase in VPD.

At the end of the season, and after one more dry down period lasting for 2 days, vines were harvested and separated into its components. Leaf water potentials were linearly

correlated to root water potentials, however they were on average 0.2 MPa more negative than the roots (Figure 14). The root biomass of deficit treated vines was less than for the control vines (Figure 15). DA16162/Shwarzman was not unusual in its root biomass when compared to the other clone/ rootstock combinations. Therefore it's likely that capacity for water uptake was similar to the other vines. The root:shoot ratio was also average (Figure 16) and therefore it was likely that the demand for water was not greater due to canopy size.

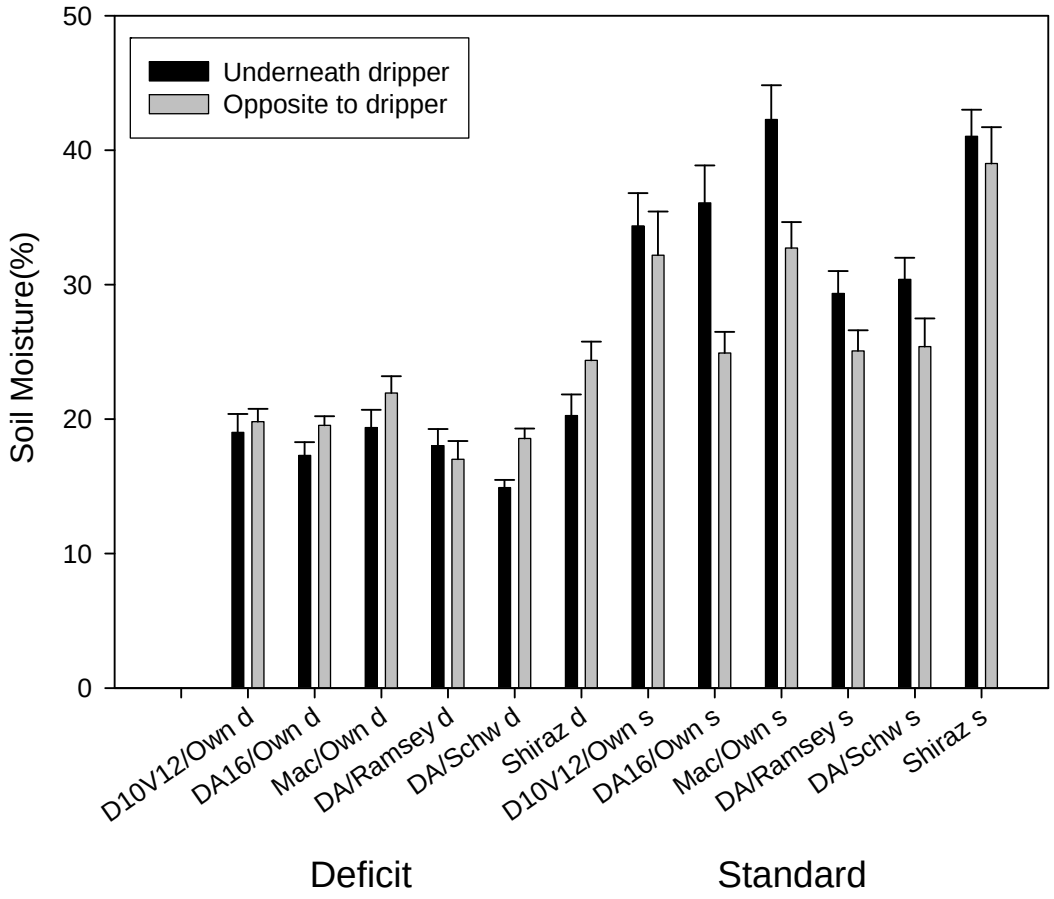


Figure 1. Soil moisture under the dripper and opposite to the dripper of vines with a deficit or standard irrigation treatments



Figure 2: Leaf burn symptoms after the deficit irrigation treatment

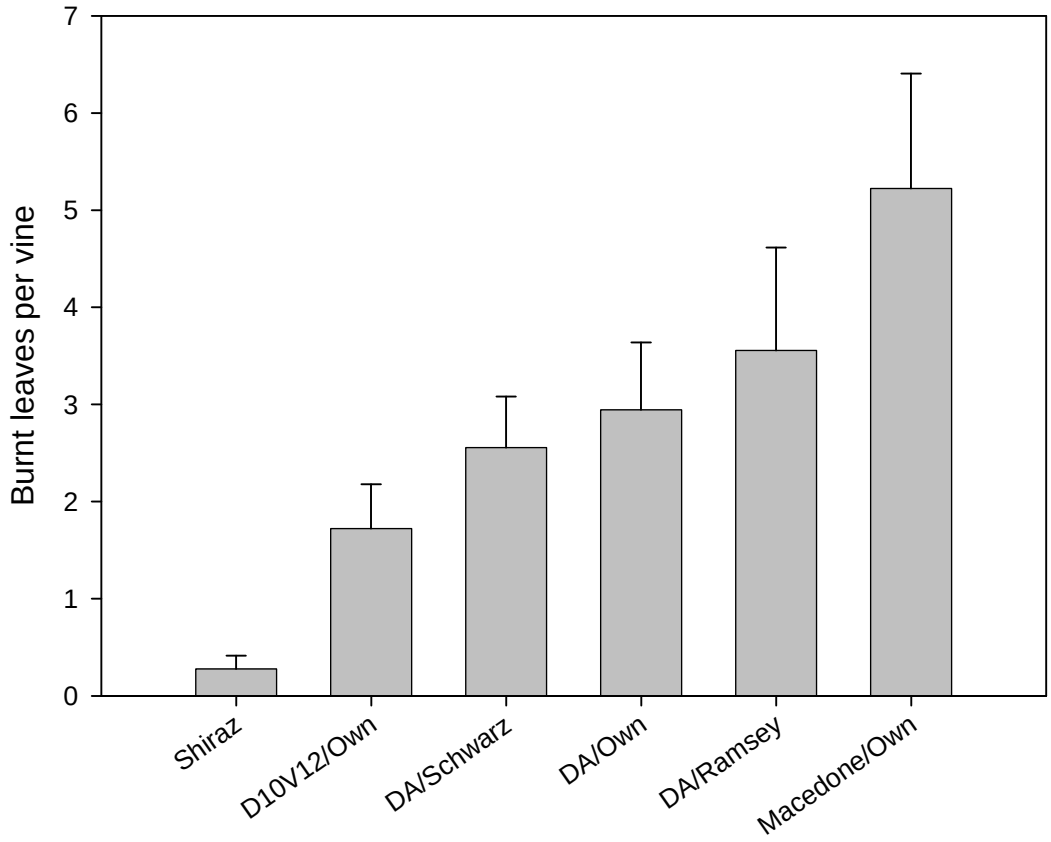


Figure 3. Number of burnt leaves per vine of each clone/rootstock after 2 days of deficit irrigation

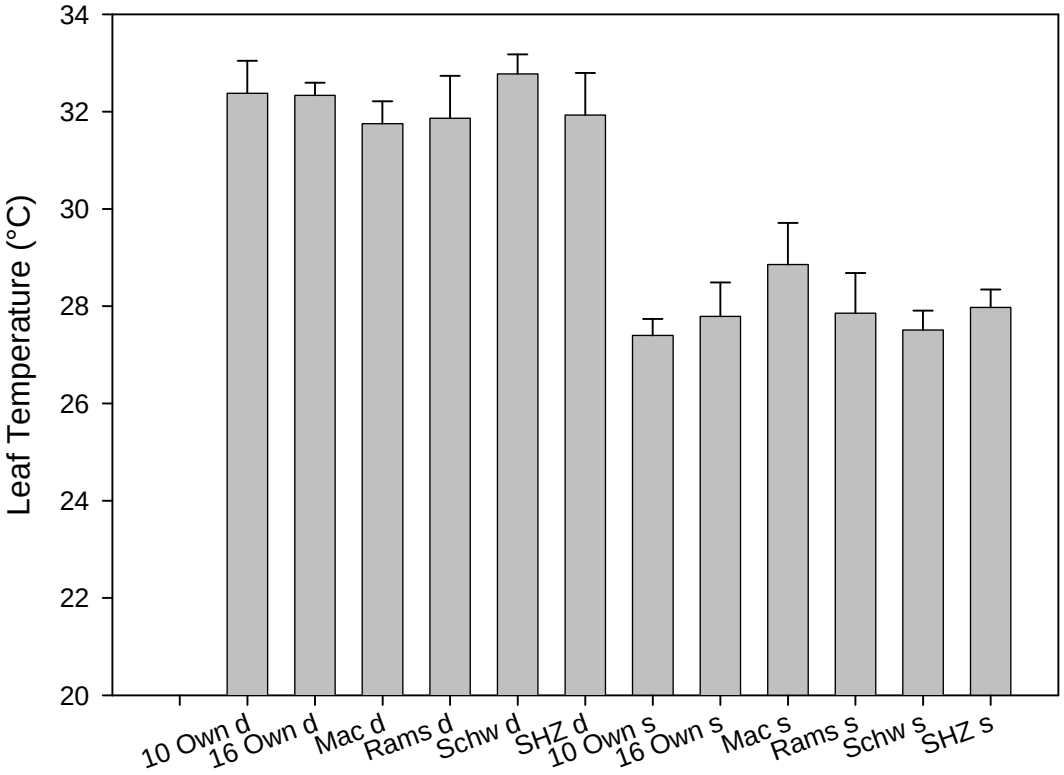


Figure 4. Leaf temperature of clones/rootstocks in deficit (d) or standard irrigation (s).

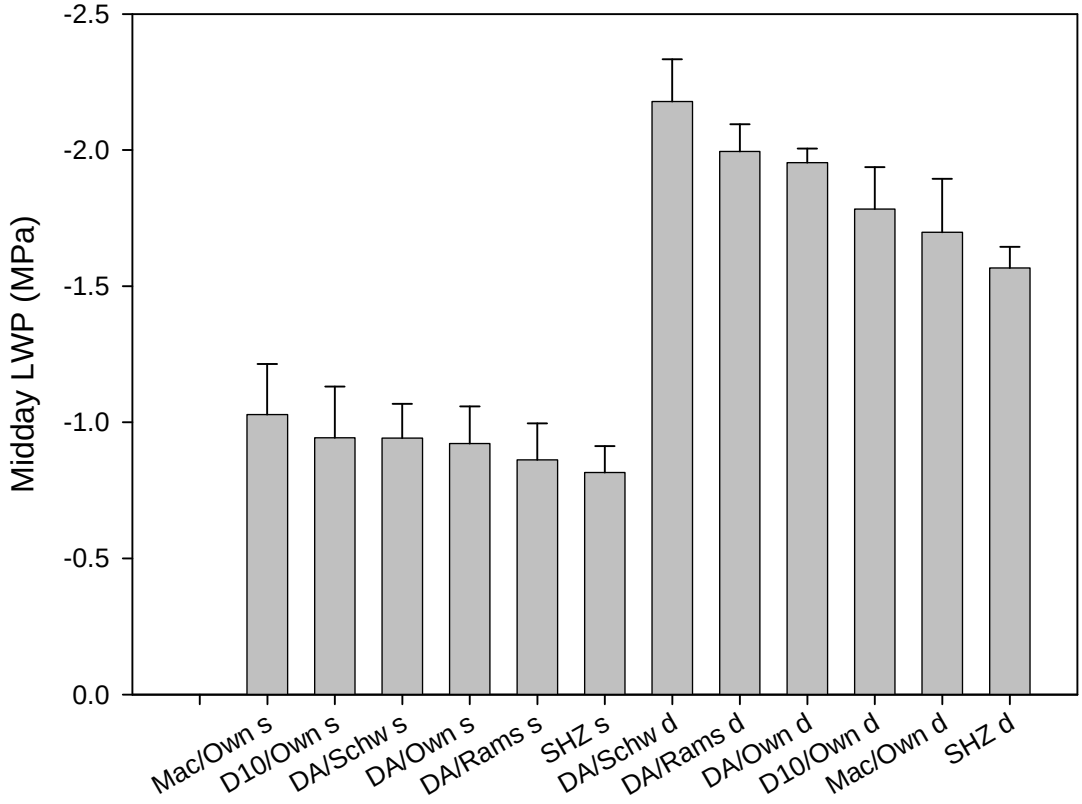


Figure 5. Midday leaf water potential of clones/rootstocks in deficit (d) or standard irrigation (s).

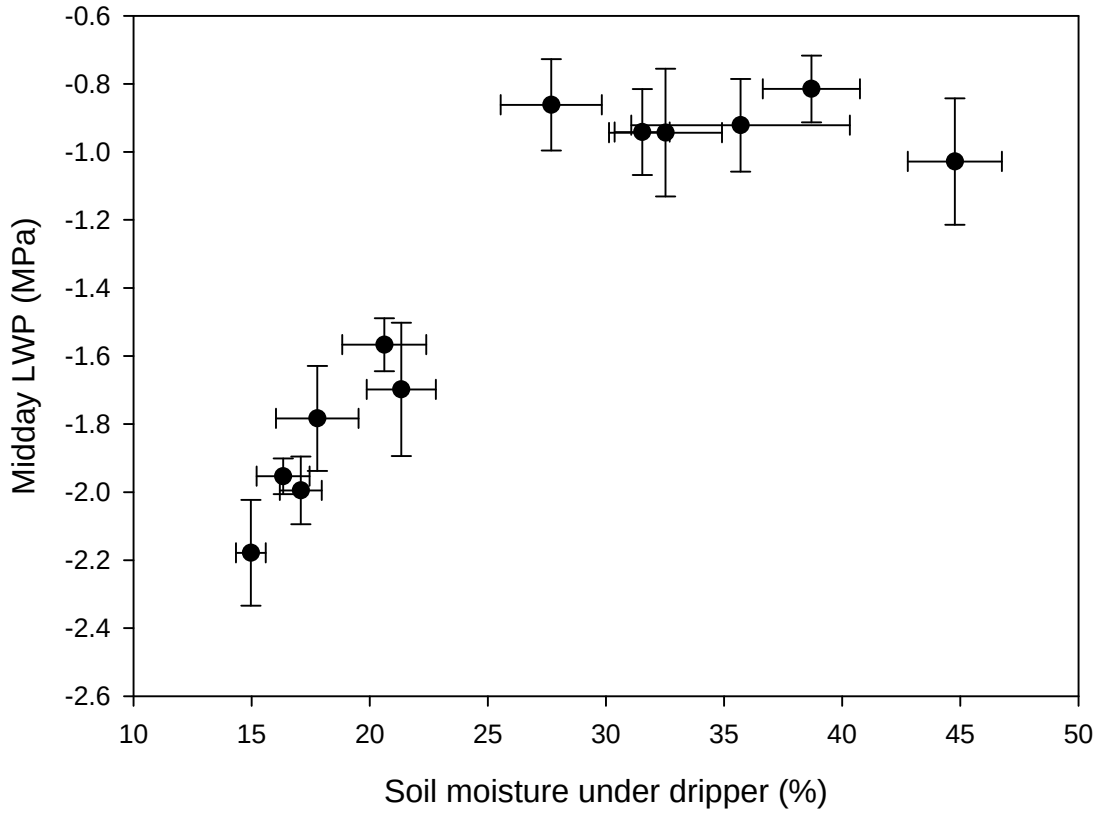


Figure 6. Midday leaf water potential of clones/rootstocks grown at a range of soil moistures.

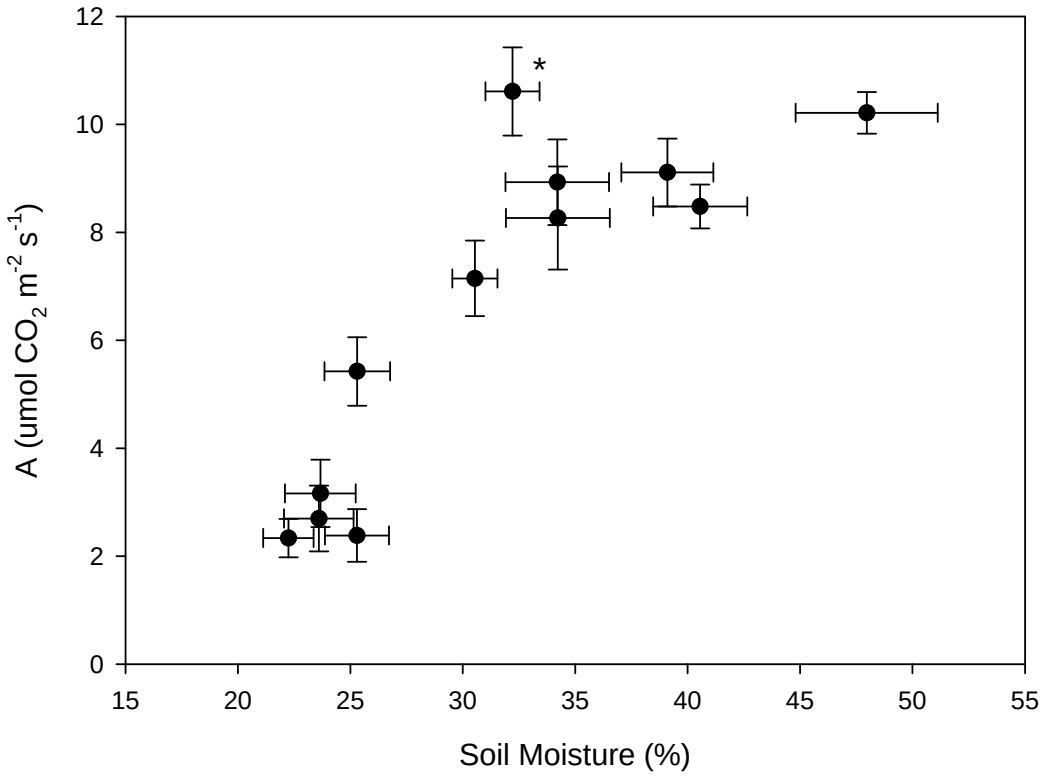


Figure 7. Photosynthesis of clones/rootstocks grown at a range of soil moistures.

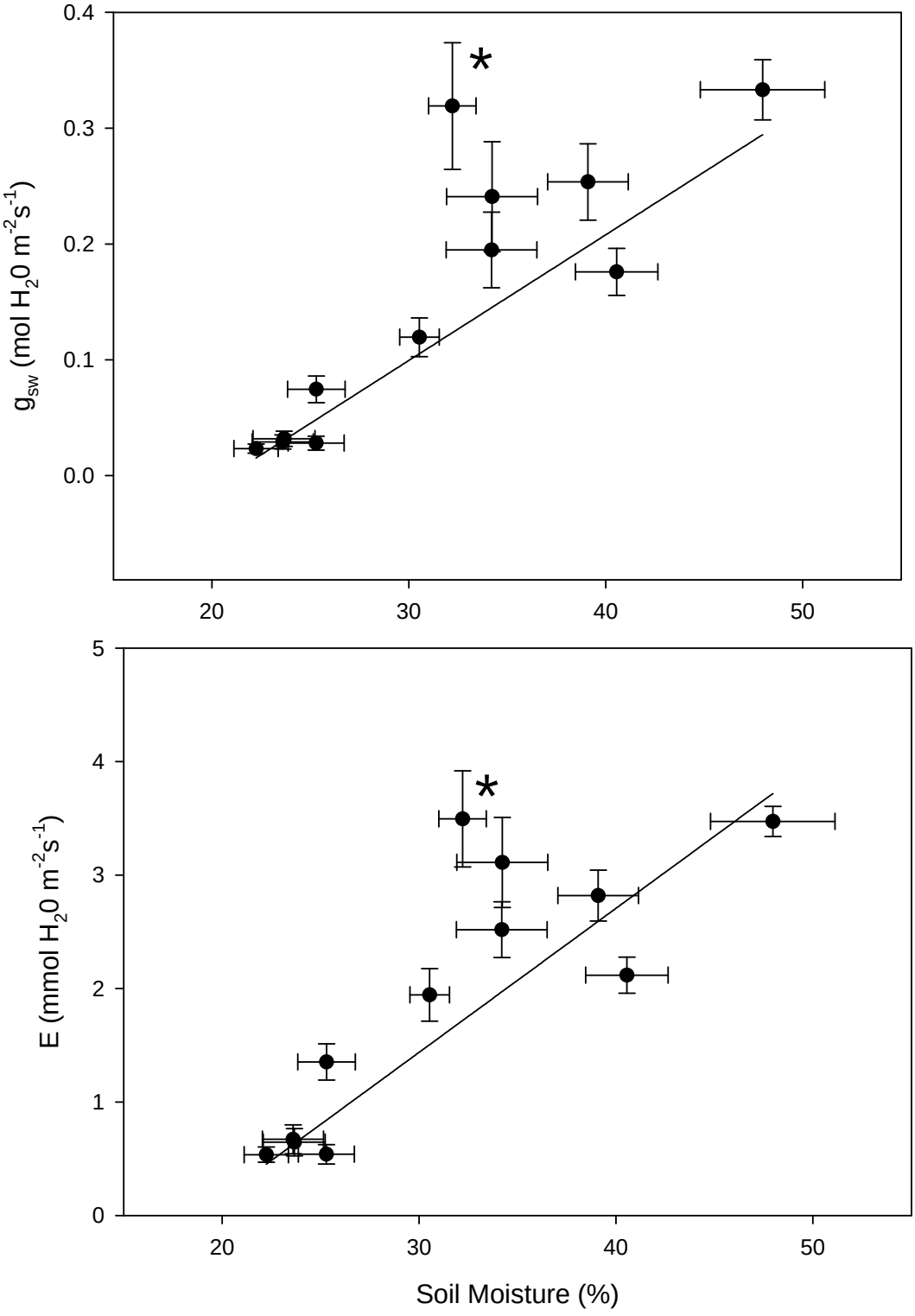


Figure 8. Stomatal conductance (A) and Transpiration (B) of clones/rootstocks grown at a range of soil moistures.

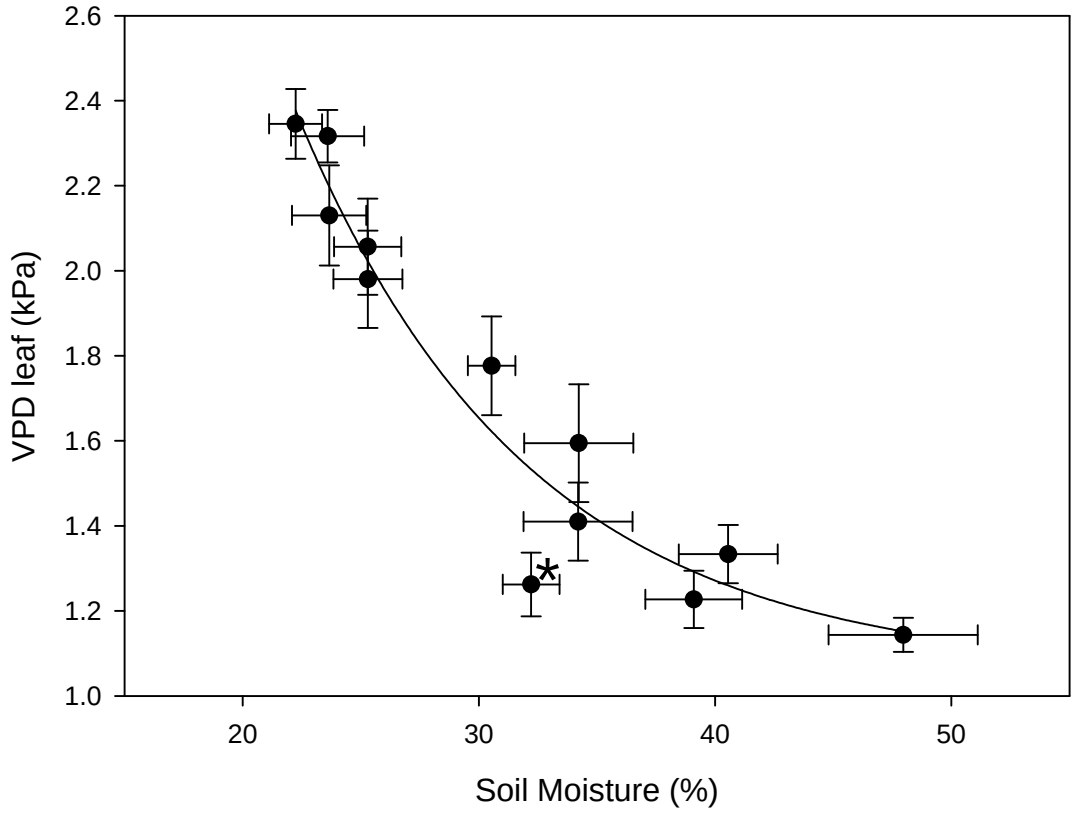


Figure 9. Vapour pressure deficit at the leaf's surface of clones/rootstocks grown at a range of soil moistures.

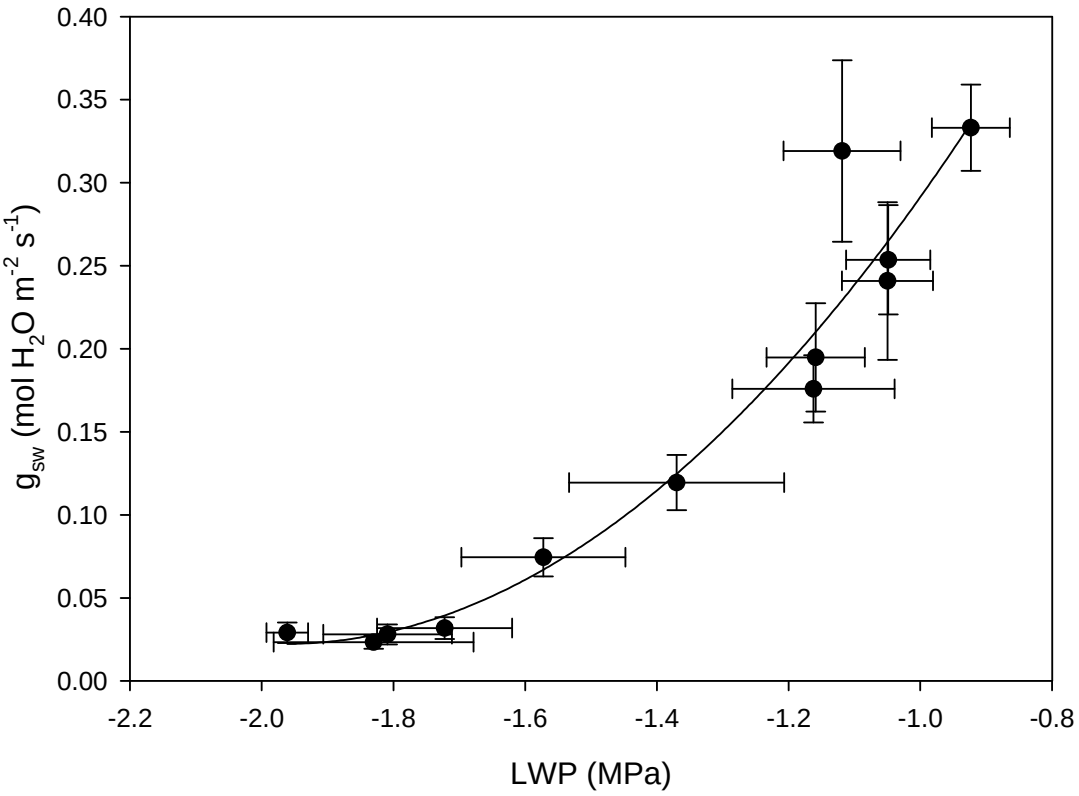


Figure 10. Stomatal conductance of clones/rootstocks correlated against plant water status.

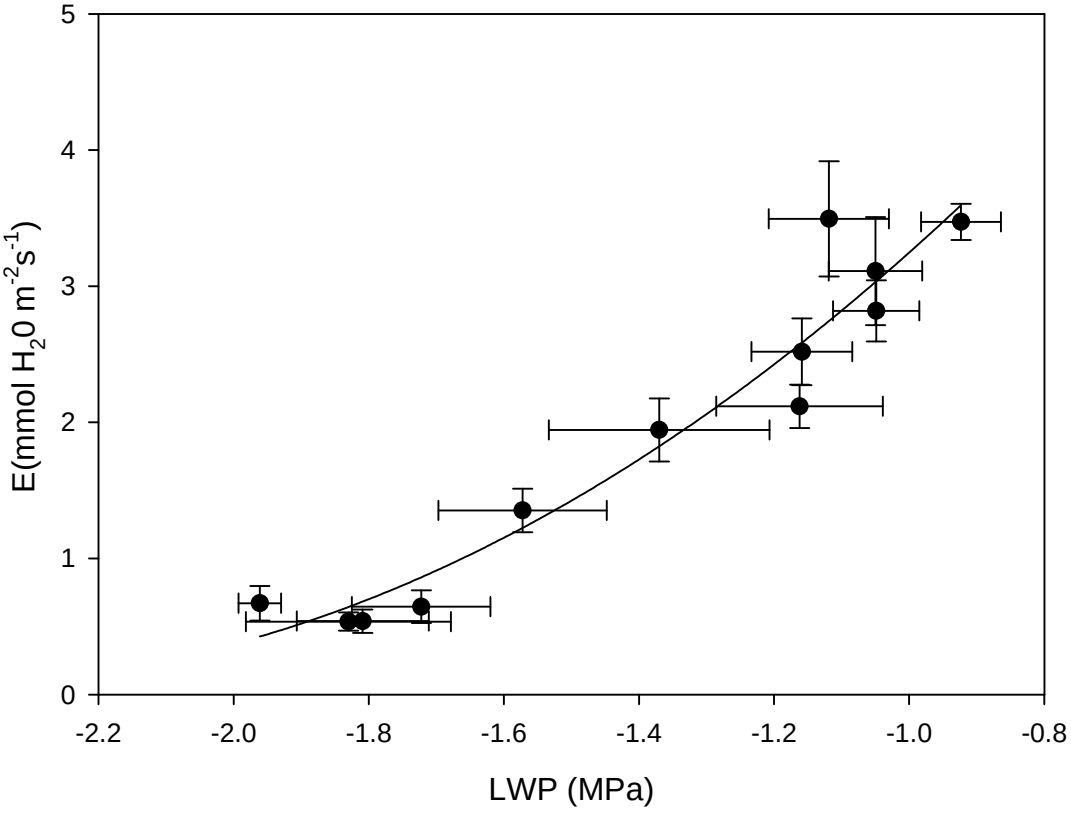


Figure 11. Transpiration of clones/rootstocks correlated against plant water status.

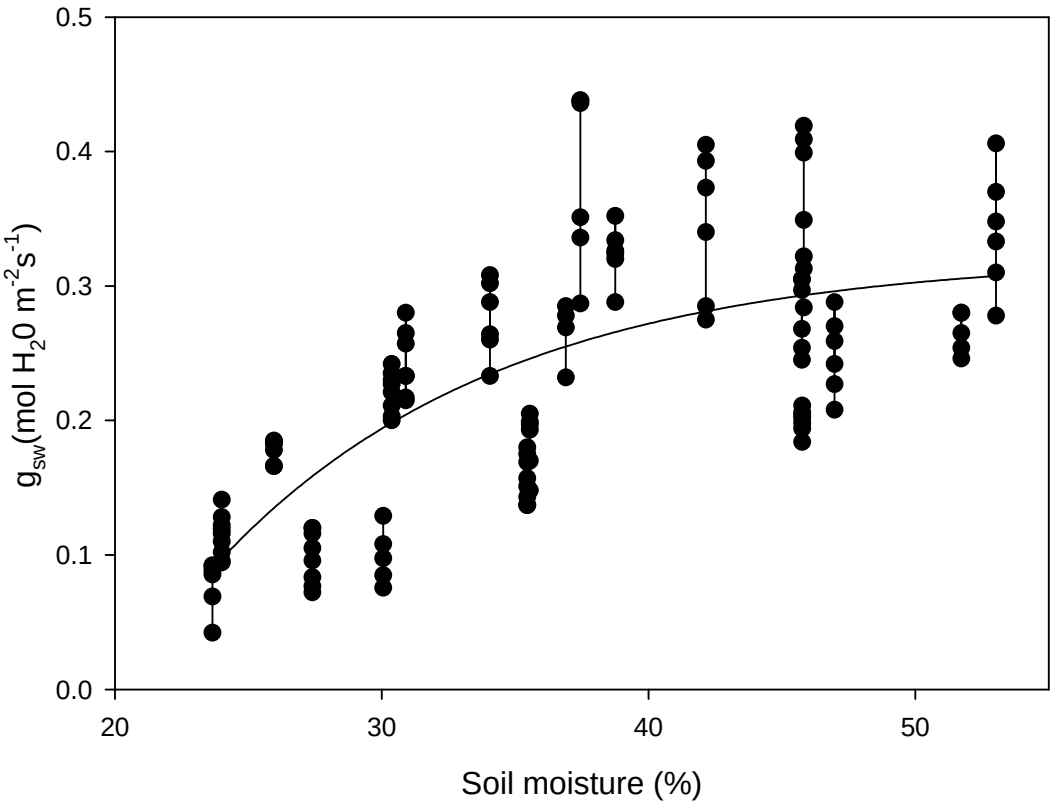


Figure 12: Stomatal conductance to water vapour of vines grown at a range of soil moistures and vapour pressure deficits. Each group of data points represents the VPD range.

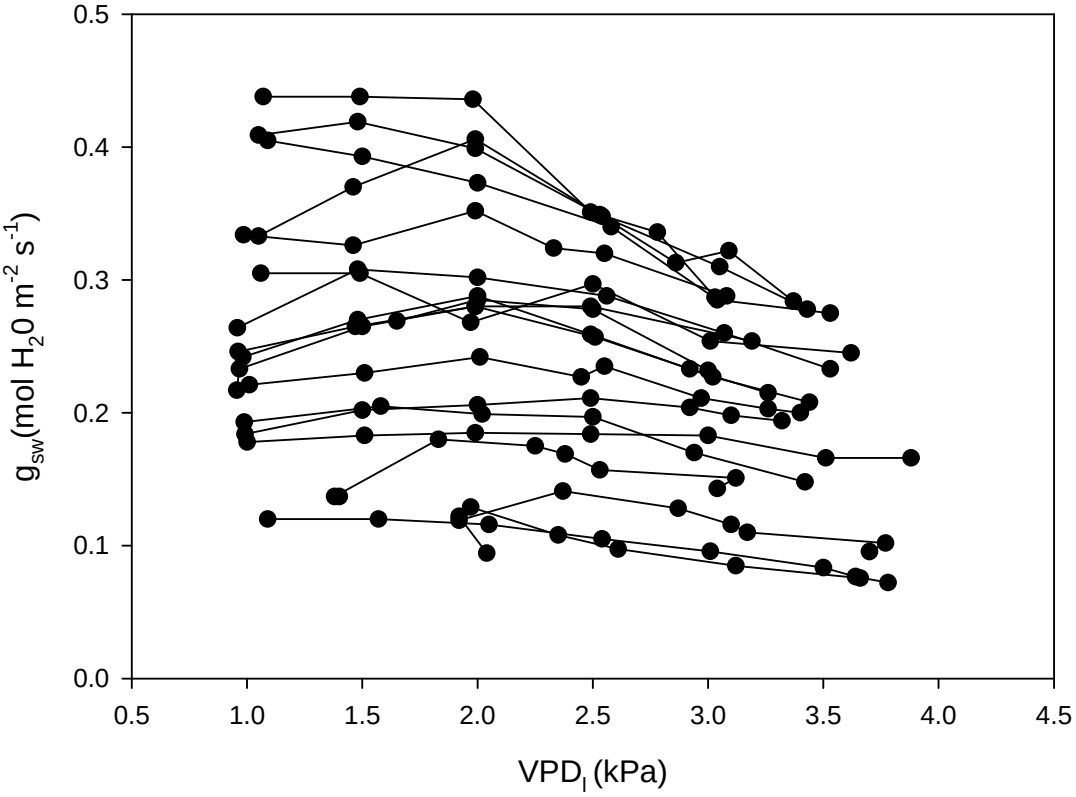


Figure 13. Stomatal conductance of vines grown at a range of soil moistures and exposed to a range of vapour pressure deficits.

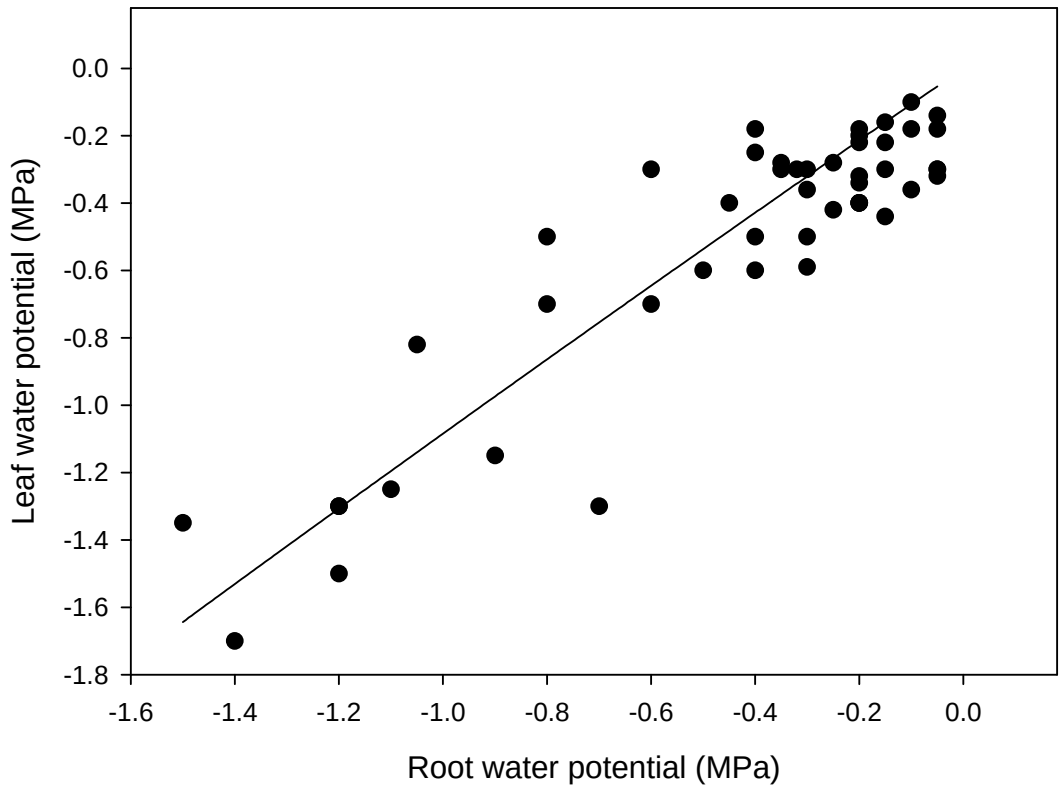


Figure 14. Leaf water potential correlated with root water potential.

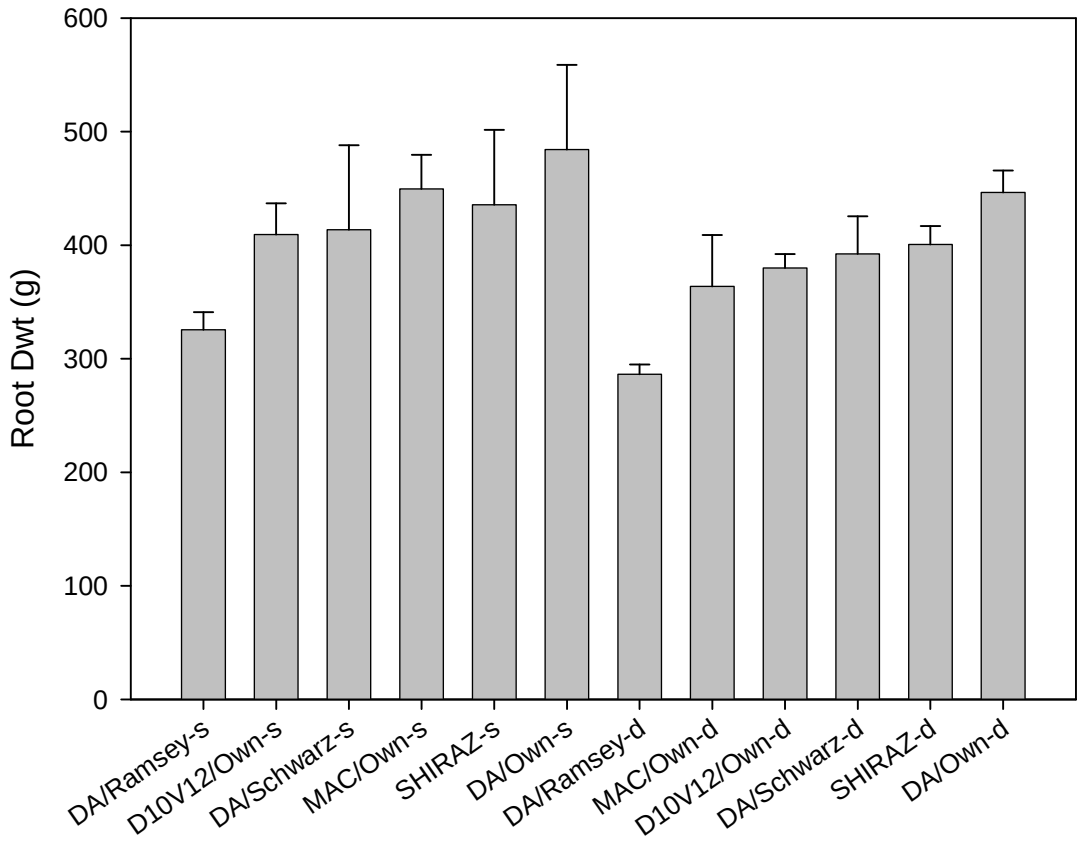


Figure 15. Root dry weight of clones/rootstocks after deficit (d) or std irrigation (s).

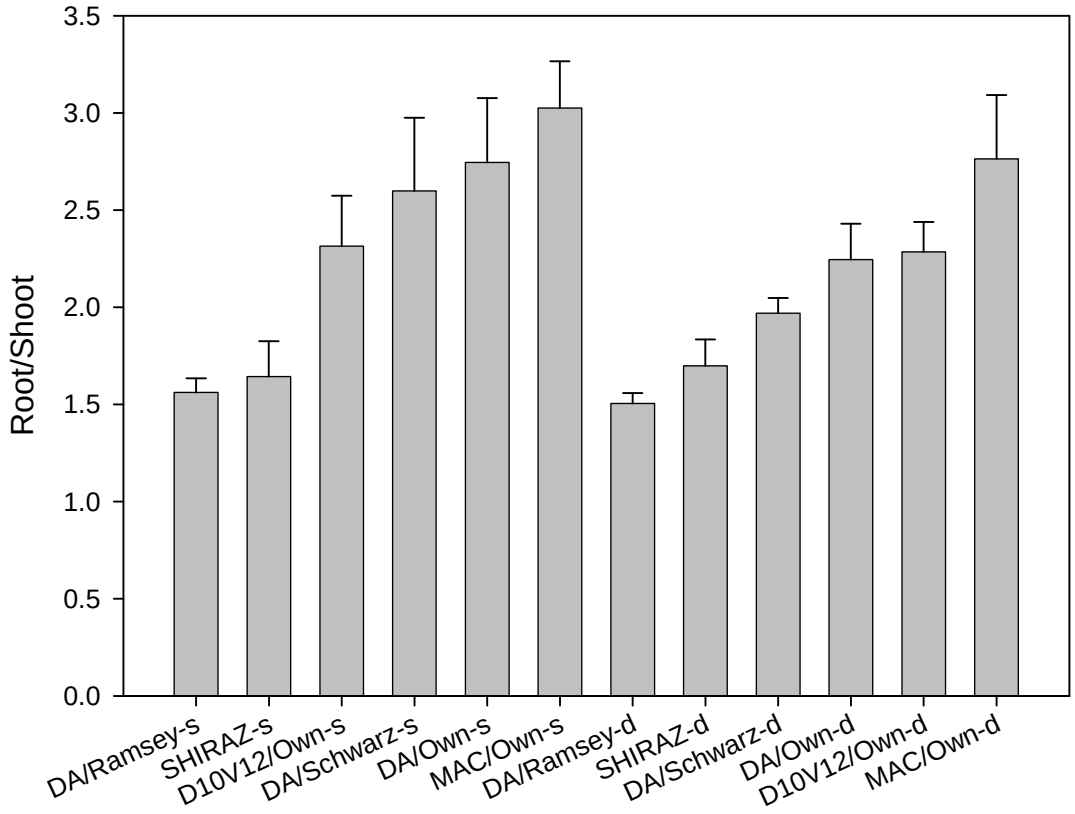


Figure 16. Root/shoot ratio of clones/rootstocks after deficit (d) or std irrigation (s).

Composition Results

Two days of deficit irrigation had a significant effect on bunch weight (Table 1). Bunch weights dropped by 15 g, while berry weight dropped by 50 mg. There were also adverse affects on berry composition. Sugar concentrations were lower by 0.6° and pH was higher by 0.08. TA was slightly lower as well for berries of vines treated with a deficit irrigation

DA16162/Schwarzmann had smaller bunch weight due to smaller number of berries (Figures 17 and 18). This combination also produced berries with higher pH (Figure 19). D10V12 had small bunches but large berries. These berries were of higher TSS and pH, and lower TA. This is most likely because they ripened faster.

Table 1: Berry size and composition after a deficit irrigation treatment of Semillon vines.

	Standard Irrigation	Deficit Irrigation
Bunch Weight (g)	204 ± 10	188 ± 9
Berry Weight (g)	1.58 ± 0.04	1.53 ± 0.04
Brix (°)	21.3 ± 0.4	20.7 ± 0.3
pH	3.70 ± 0.03	3.78 ± 0.03
TA (mL)	5.4 ± 0.1	5.1 ±0.1

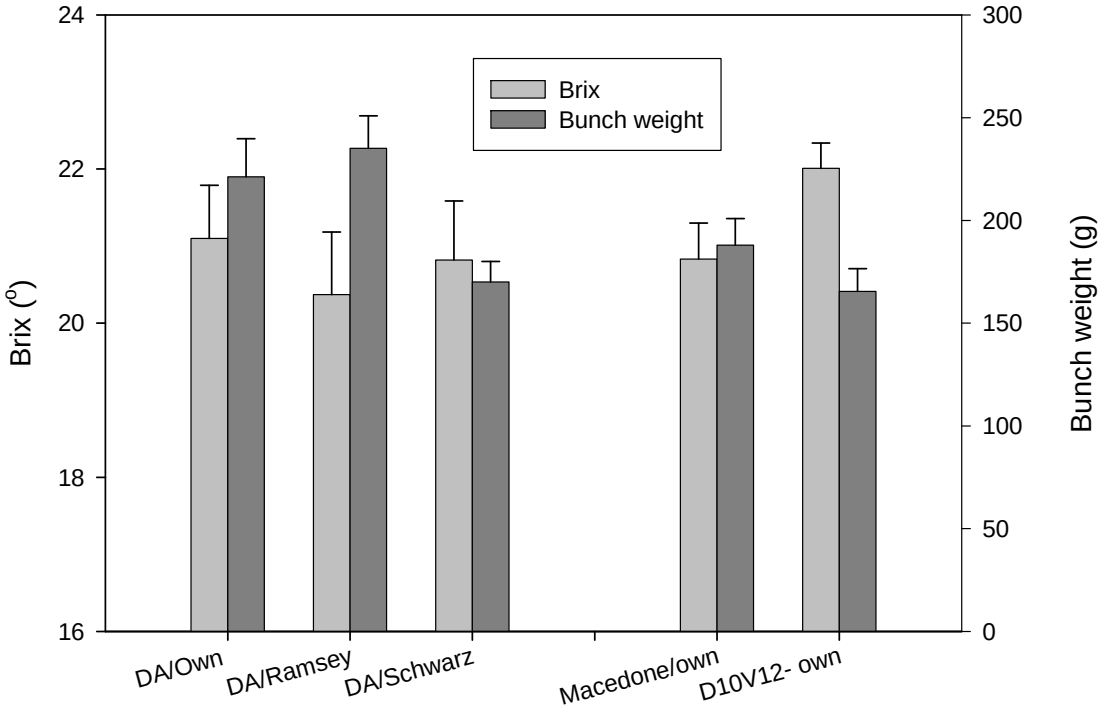


Figure 17. Berry sugar concentrations and bunch weight of clones/rootstocks.

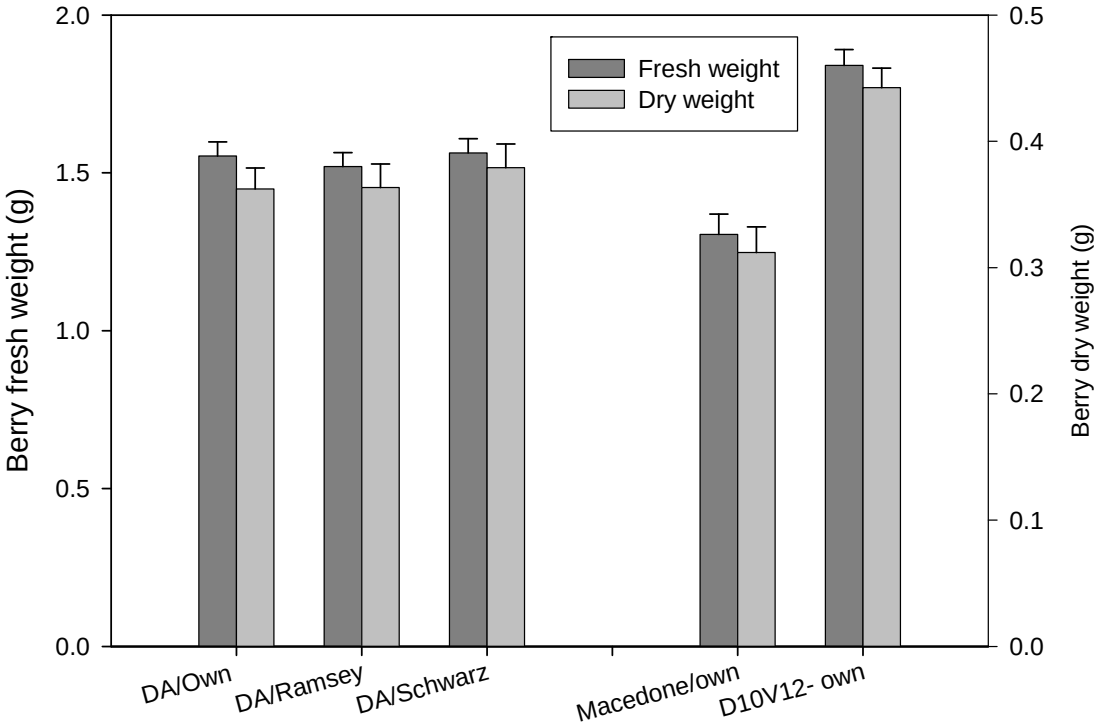


Figure 18. Berry fresh and dry weight of clones/rootstocks.

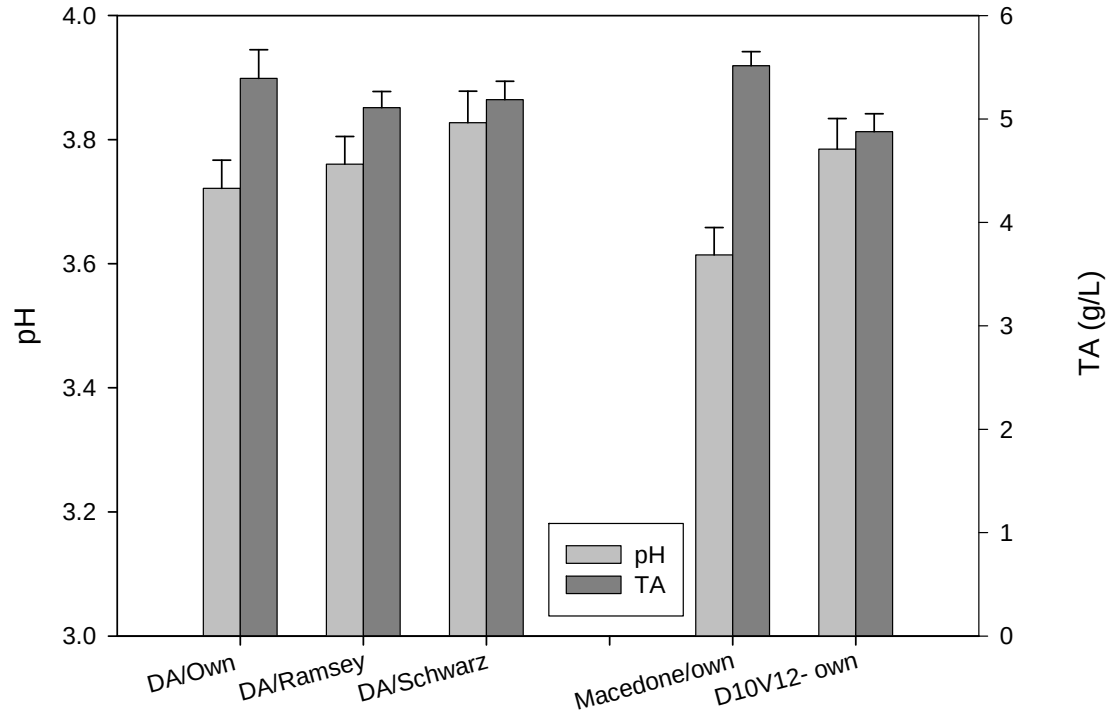


Figure 19. Berry pH and titratable acidity of clones/rootstocks.

The three Semillon clones examined in this study were susceptible to water stress, exhibiting leaf burn with soil moistures below 30%. Shiraz, however, had very little leaf burn. Shiraz is also a mesic variety, but apparently it does not have the same sensitivity that Semillon does. Schwarzmann is a rootstock recommended for phylloxera and nematode resistance and does not confer drought tolerance. Ramsey has some drought tolerance and controls vine vigour. Neither rootstock, however, was able to alleviate the water stress experienced by the Semillon vines. DA16162/Schwarzmann was more water stressed than DA16162/own roots as indicated by more negative leaf water potentials. The root:shoot ratio was not unusual for DA16162/Schwarzmann and therefore it was likely that the demand for water was not greater due to canopy size. The higher transpiration rates brought about through higher stomatal conductances likely lead to the lower water status of these vines. Perhaps there is less signal produced by the roots to act on guard cell action. ABA and xylem pH are two likely candidates for further study.

The tight trend between leaf water potential and transpiration as well as stomatal conductance indicates that vine water status is highly dependent on stomatal activity. These were dependent on soil moisture, but VPD also had an effect. This is opposite to the field study results where there was no obvious relationship between stomatal conductance or transpiration with leaf water potential. The more tightly controlled conditions in this pot study eliminate a number of environmental and management factors allowing more subtle trends to emerge. The LI-cor was temperature adjusted in this pot trial, while in the field trial heating of the chamber may have caused erroneous readings.

The cooling effect of leaf transpiration on leaf temperature was evident in this variety. It is interesting that Macedone had the most leaf burn, but not the most negative leaf water potentials. This indicates that other factors besides vine water status affect leaf burn. Direct effects of temperature may play a role. Salinity also causes leaf burn, but the water used for irrigating these vines was not particularly saline.

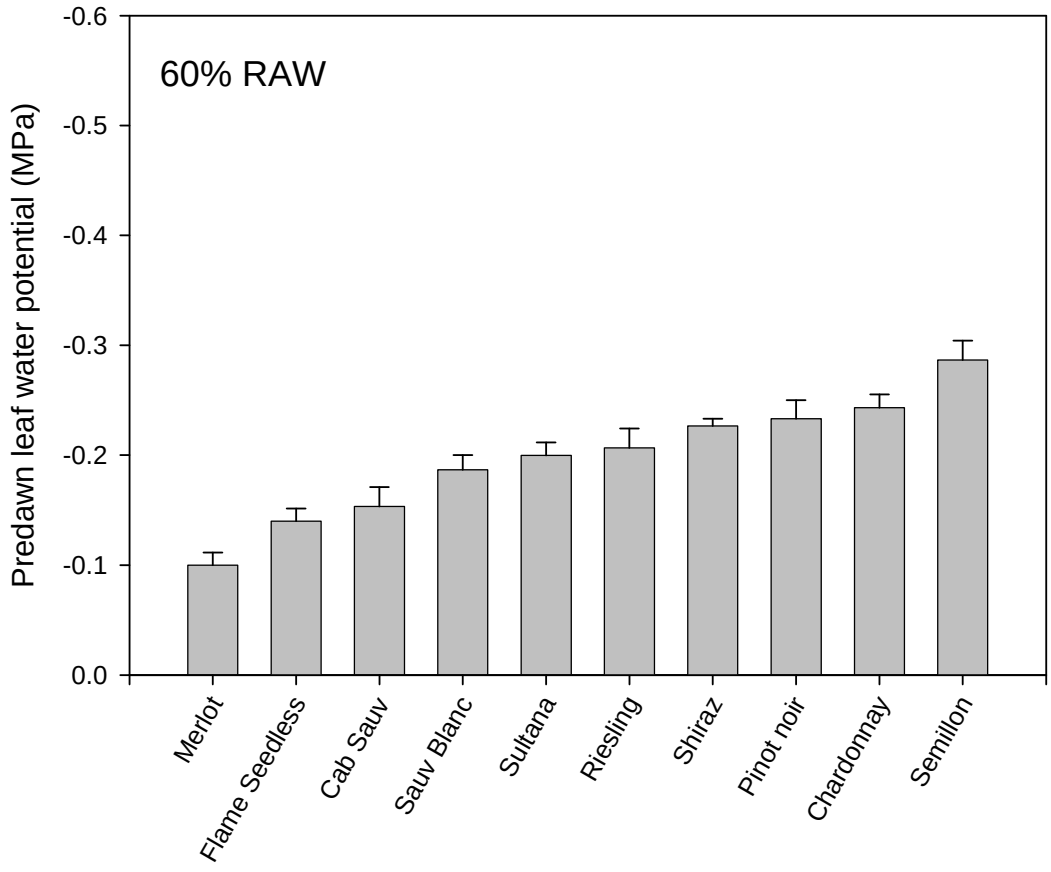
Low soil moisture levels had an adverse effect on not only the canopy but on berry size and composition as well. The loss in berry size did not concentrate sugars or acids to higher levels than berries of well irrigated vines. This indicates that for optimal fruit, Semillon is best grown without any severe water deficits.

6.3: Variety Comparisons of Field Vines

Semillon water relations were compared with nine other varieties in a replicated variety block at CSU. Vine water status (through leaf water potential), transpiration, stomatal conductance and a number of morphological features were compared in order to better understand this variety's sensitivity to warm temperatures and low soil moistures.

Predawn leaf water potential

Predawn leaf water potentials for Semillon vines were consistently more negative than any of the other nine varieties investigated. This was the case for vines that were in soil at 60% or 15% of the RAW and also for vines that were in soil with no readily available water. There was no consistency in the relative order of the other varieties in vine water status when compared at different soil moistures.



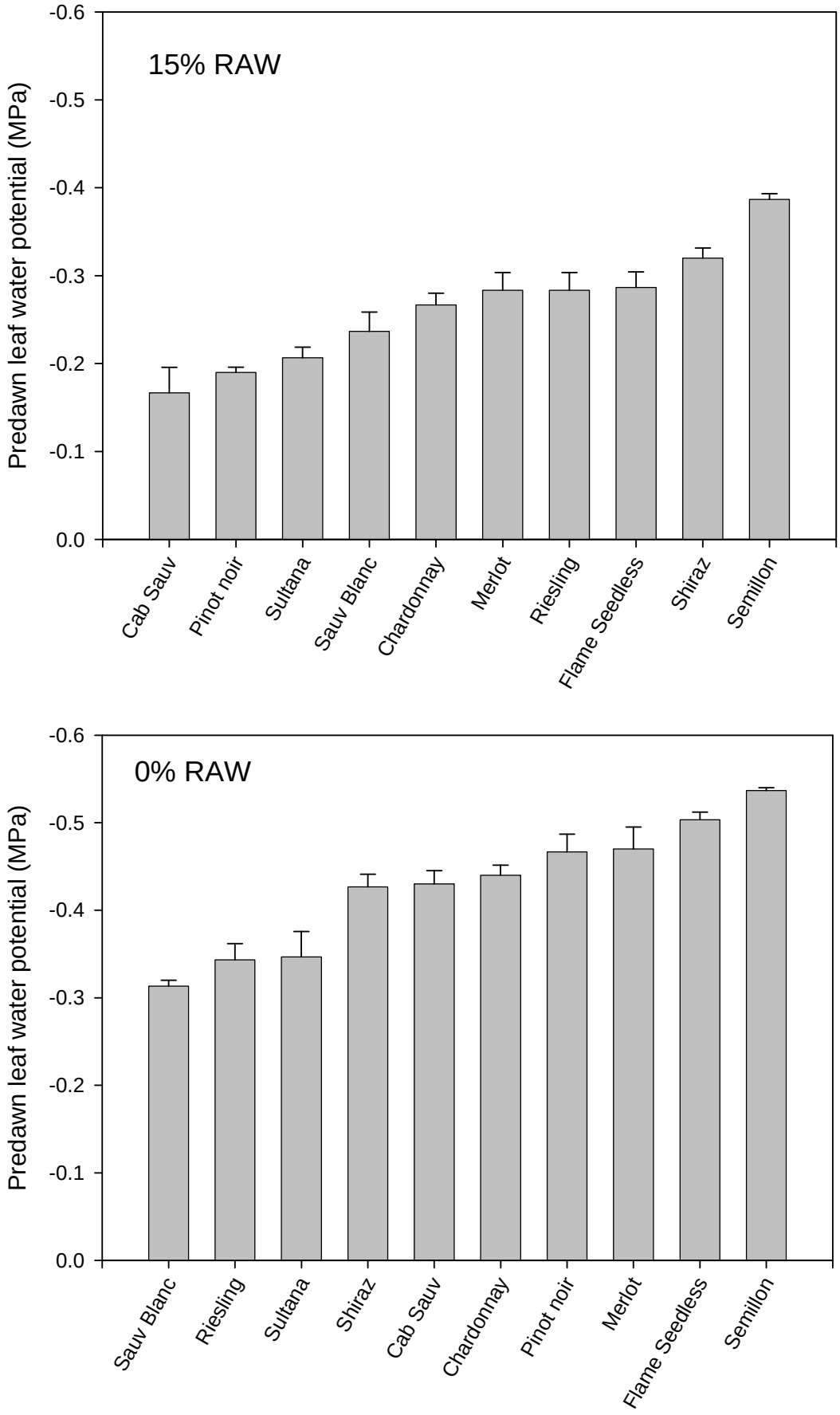


Figure 1. Predawn leaf water potentials of Semillon vines at 60, 15 and 0% readily available water (RAW).

Midday leaf water potential

Midday leaf water potentials were significantly more negative for Semillon vines (Figure 2) reaching -1.2 MPa on a moderate day. Again, there was no consistency in the relative order of the other varieties in vine water status when compared at different points in the season.

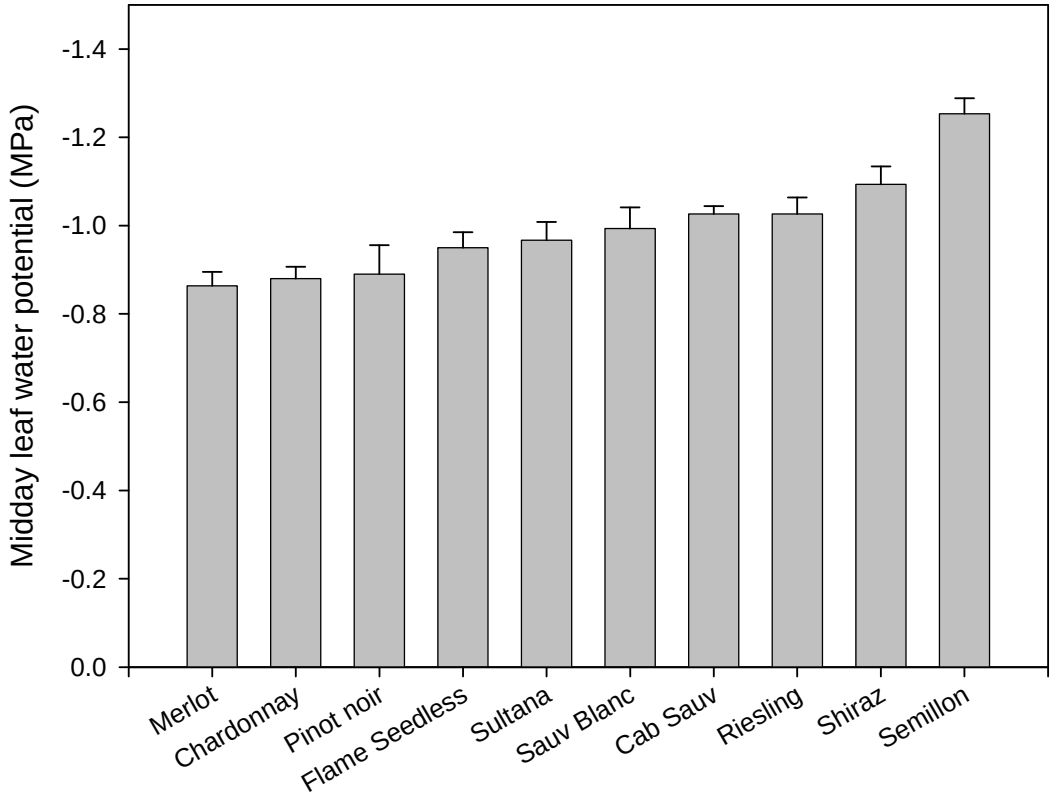


Figure 2. Midday leaf water potential of ten varieties in the replicated variety block at CSU.

Vine gas exchange

Photosynthesis of Semillon vines fell into the high end of the variety spectrum, as did internal CO_2 concentration (Figure 3). Photosynthesis ranged between 10 and 14 µmol CO_2 m^{-2} s^{-1}. Transpiration and stomatal conductance of Semillon vines were also in the high end of this spectrum (Figure 4), however, they were not significantly different from other varieties such as Pinot noir. Transpiration ranged between 3.2 and 4.3 mmol H_2O m^{-2} s^{-1}, and stomatal conductance ranged between 0.2 and 0.4 mol H_2O m^{-2} s^{-1}. Transpiration efficiency was in the low end of the variety spectrum, but not as low as some of the other varieties (Figure 5). Transpiration efficiency ranged from 3.05 to 3.3. The highest transpiration efficiency was for Flame Seedless. This is interesting because this variety tended to have fairly negative predawn leaf water potentials. The low stomatal conductance of Flame Seedless leaves indicates a responsive feed-back system which is operative in this variety.

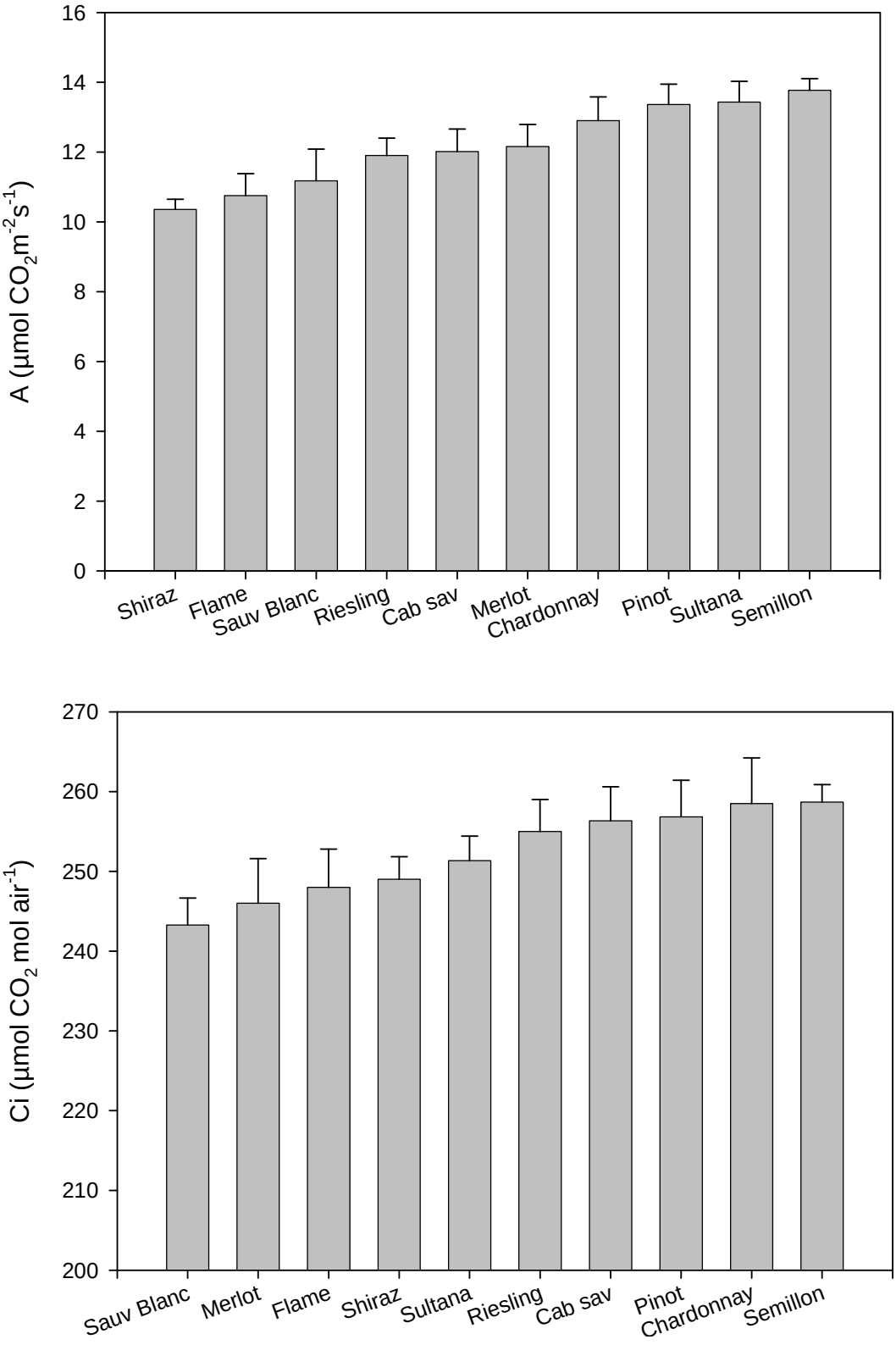


Figure 3. Photosynthesis (A) and internal CO_2 concentratons (Ci) of leaves from ten varieties grown in a replicated variety block.

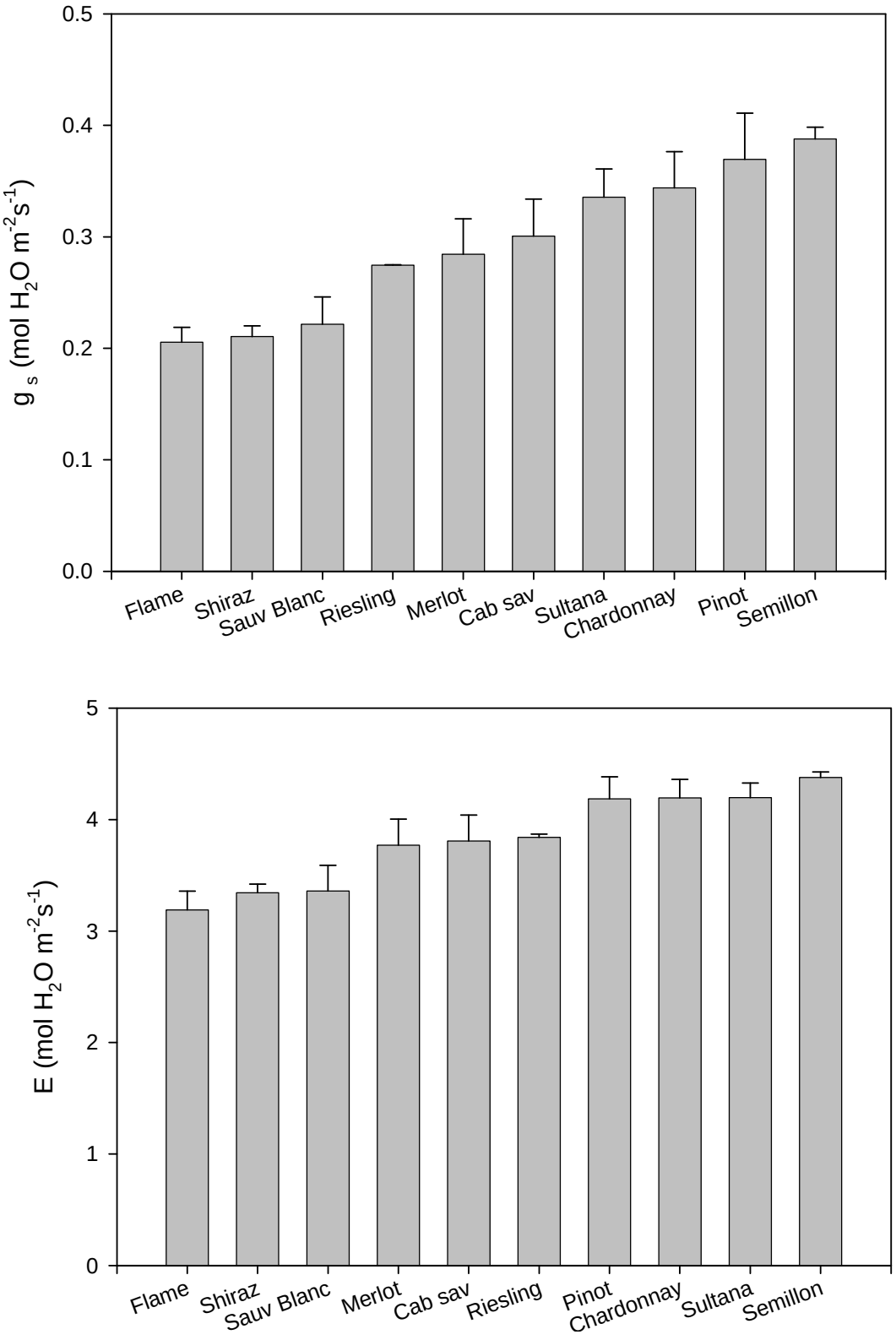


Figure 4. Stomatal conductance (g_s) and transpiration (E) of leaves from ten varieties grown in a replicated variety block.

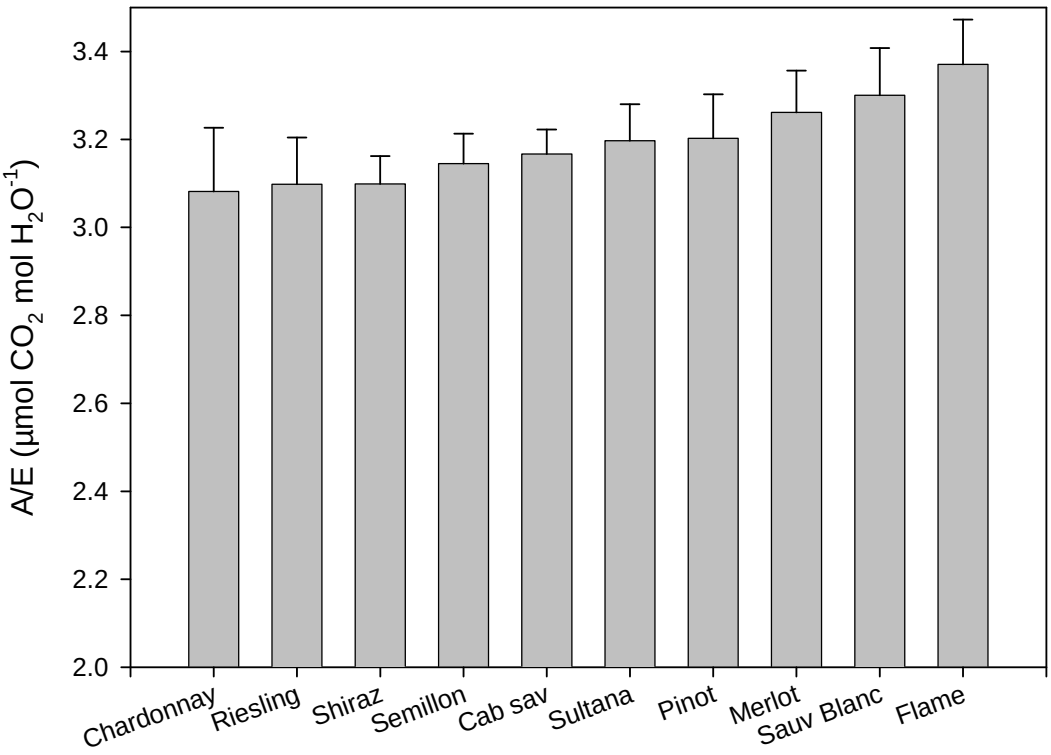


Figure 5. Transpiration efficiency (A/E) of leaves from ten varieties grown in a replicated variety block.

VPD Response

When compared with Shiraz, Semillon leaves had higher transpiration and stomatal conductances over a VPD range of 0.7 to 2.4 kPa (Figure 6). At the lower VPD levels, stomatal conductance and transpiration of Semillon leaves were double that of Shiraz leaves. However, this difference was less pronounced in the higher VPD range where Semillon leaves had conductances and transpiration rates 45% greater than Shiraz leaves.

Photosynthesis was 25% higher for Semillon leaves than Shiraz leaves (Figure 7). Internal CO_2 concentrations of leaves were also generally higher for Semillon leaves across the VPD range tested (Figure 7). Internal CO_2 was greater by up to 60 µmol CO_2 mol air^{-1} at the lower VPDs.

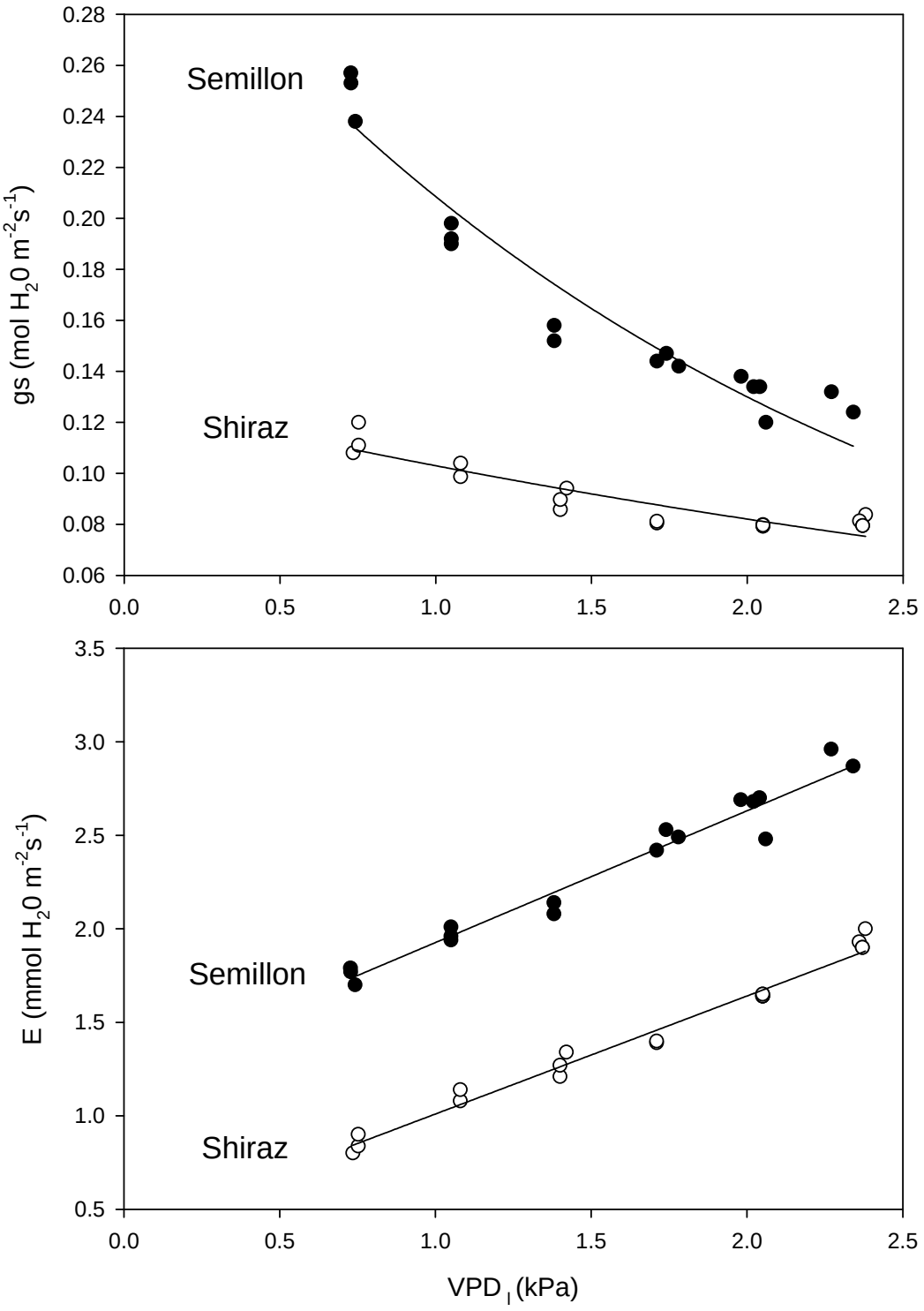


Figure 6. Stomatal conductance (g_s) and transpiration (E) of Shiraz and Semillon leaves across a range of VPDs.

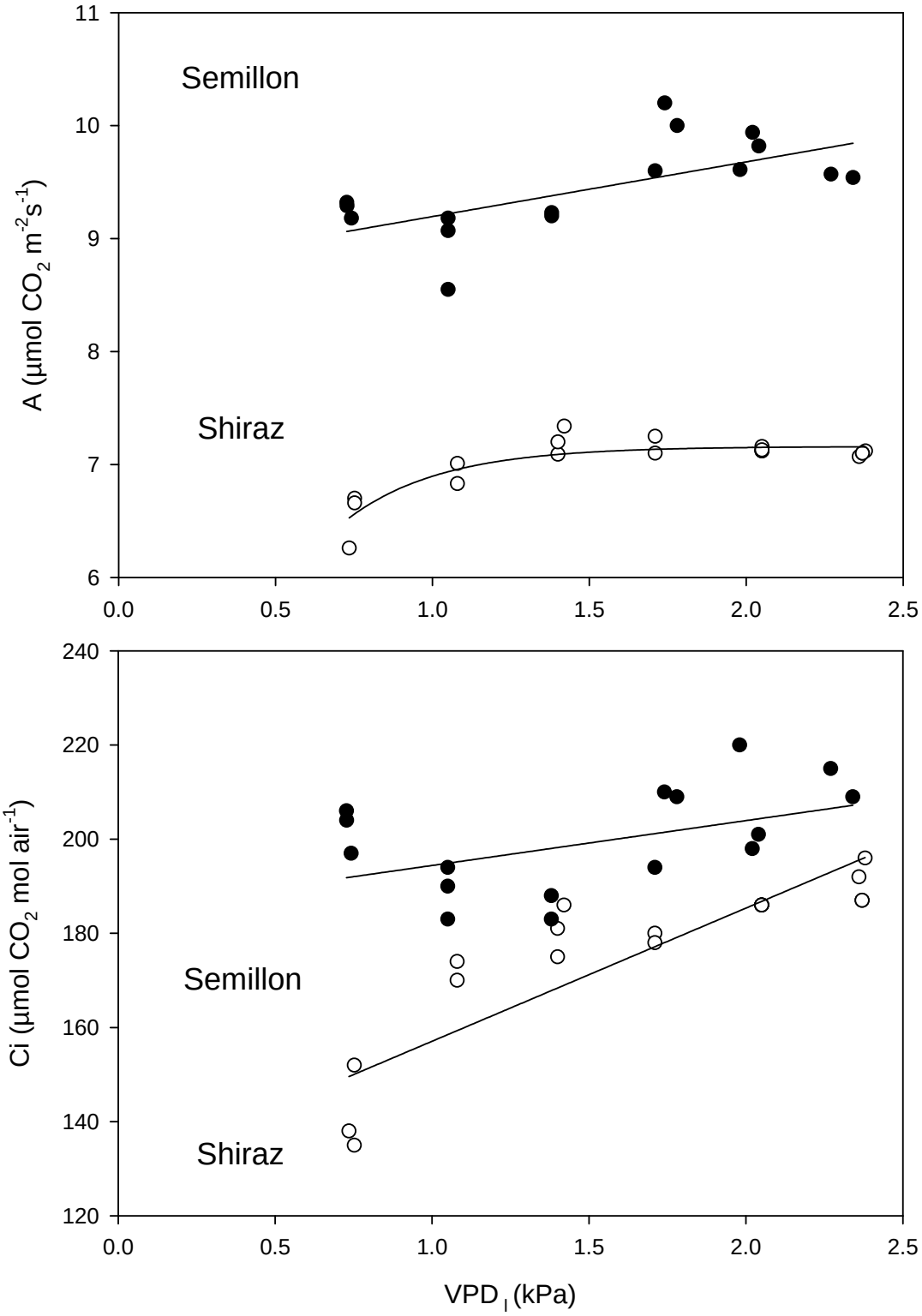


Figure 7. Photosynthesis (A) and internal CO_2 concentrations (C_i) of Shiraz and Semillon leaves across a range of VPDs.

Stomatal density

Stomatal density is related to environmental conditions such as light and temperature. In six forest trees there was a negative relationship between the stomatal pore length and sensitivity to drought (Aasamaa, et al. 2001). Kidney shaped stomata, such as in ferns, are more common to cool and humid natural environments, while dumbell shaped stomata are more common to grasses and have evolved later. Smaller stomata are also able to regulate conductance more rapidly than larger stomata.

Grapevines have kidney shaped stomata. Stomata were found only on the underside of the leaf. There were no consistent differences in stomatal number between the leaf centre, lobes of the leaf, or the leaf margins. Riesling and Chardonnay had higher stomatal density at over 225 stomata mm^{-2}, and Sultana had the least stomata at 162 stomata mm^{-2}. Stomatal density of Semillon leaves was average at 190 stomata mm^{-2}. These results indicate that the higher transpiration measurements recorded for Semillon do not appear to be due to a higher stomatal number, but rather is likely a function of higher stomatal conductance.

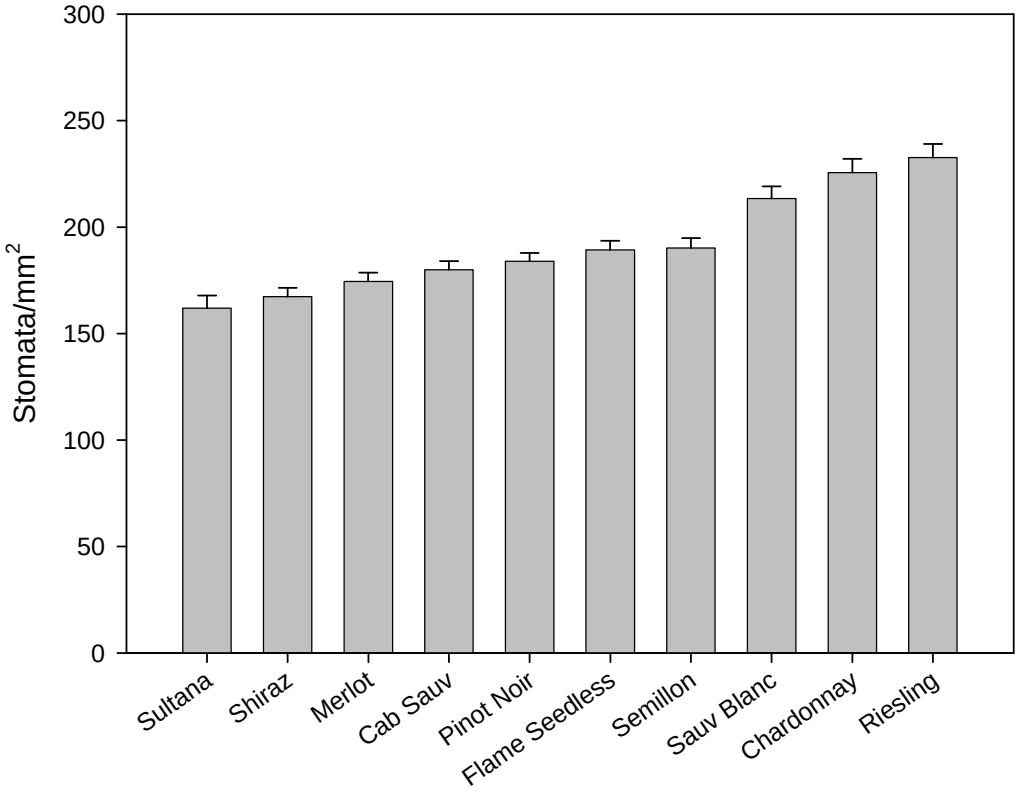


Figure 8. Stomatal density on leaves of ten varieties grown in a replicated variety block.

Leaf temperature

Leaf temperatures of the varieties were measured over a 3 hour period where ambient temperature reached 27.8°C and RH dropped to 31%. Pan evaporation was 10.6 mm. The replicates were measured over time, thus preventing the daily rise in temperature to interfere with variety comparisons. The average canopy temperature for each row increased from 23.0 to 29.2°C, indicating that the leaves were warmer than ambient temperature. On average, leaf temperature was highest for Shiraz and Sauvignon Blanc (27.8°C) and lowest for Pinot noir (25.0°C) and Semillon (25.3°C) (Figure 9). The

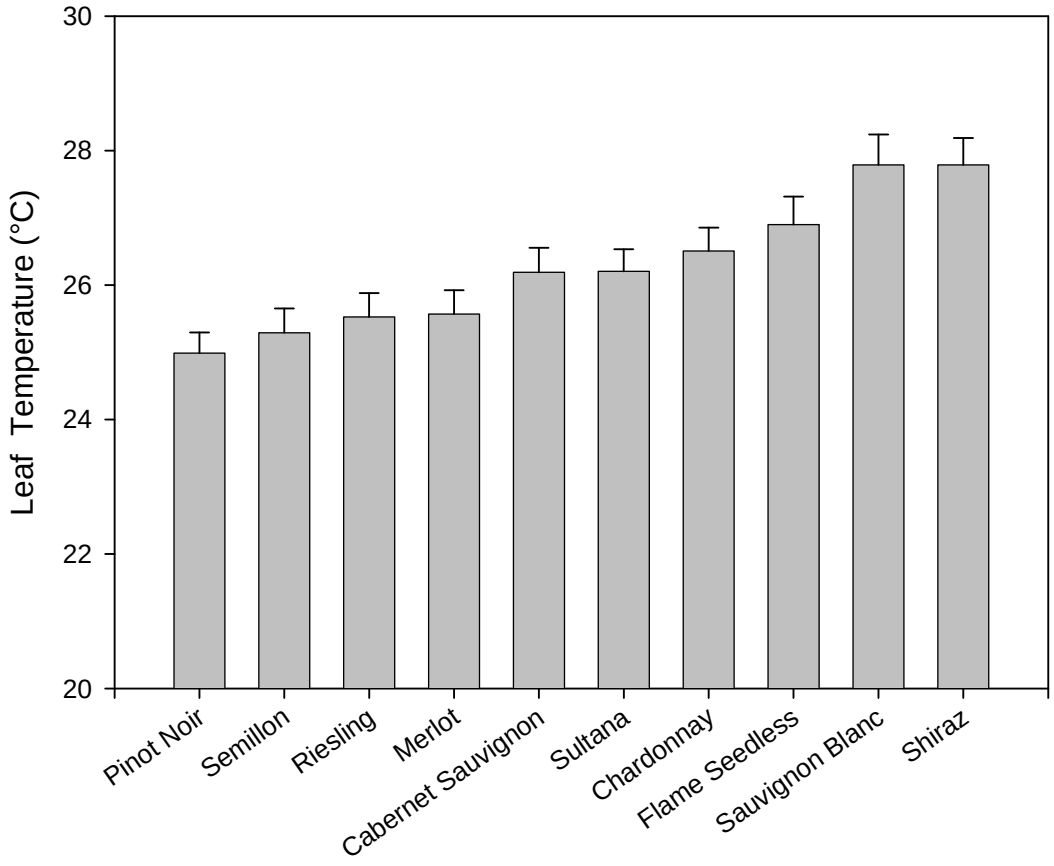


Figure 9. Leaf temperature of ten varieties on a moderate day grown in a replicated variety block.

Leaf dry weight

Amount of leaf dry weight per unit of leaf area was calculated for the ten varieties in order to obtain an estimate of leaf thickness (Figure 10). Flame Seedless stood out with the lowest leaf density at less than 0.12 mg mm^{-2} while Semillon fitted in with most other varieties at around 0.15 mg mm^{-2}. The thinness of Flame seedless leaves could be seen by the naked eye. Flame Seedless also had low root biomass and trunk diameter, indicating that it was a small vine.

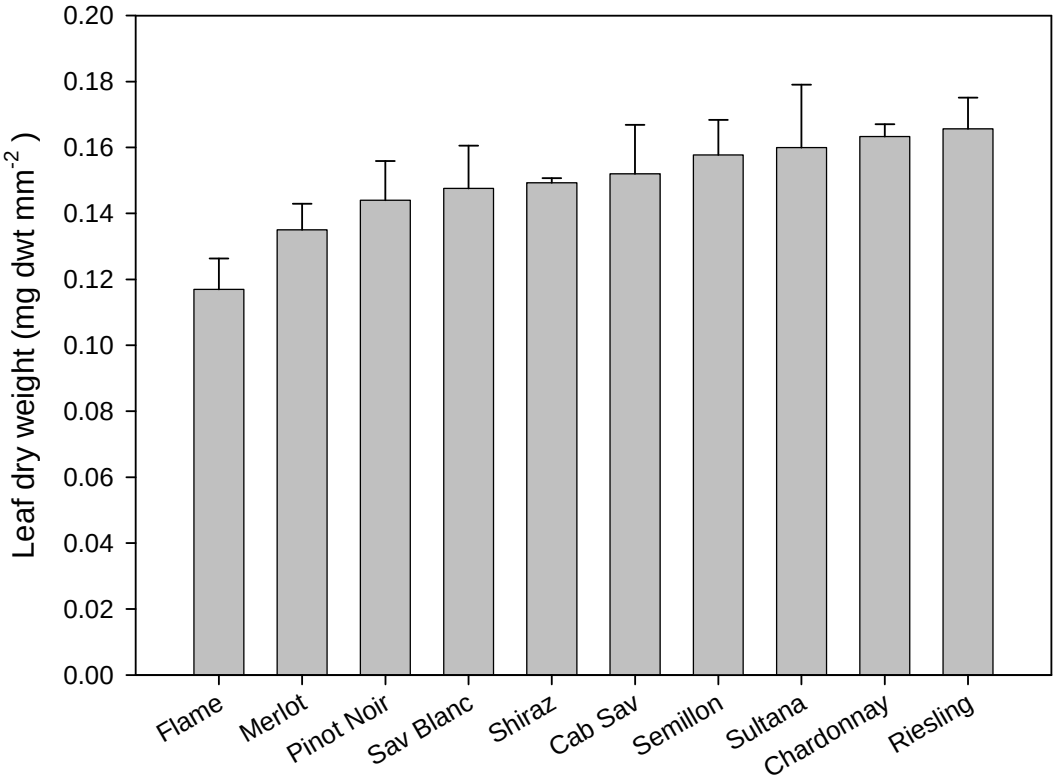


Figure 10. Leaf dry weight of ten varieties grown in a replicated variety block.

Leaf water content

Leaf water content (mg of water/ mg dry weight) was highest for Flame seedless at 3.5 mg H_2O/mg dwt (figure 11). Semillon leaf water content was in the middle of the variety spectrum at 2.2 mg/mg dwt.

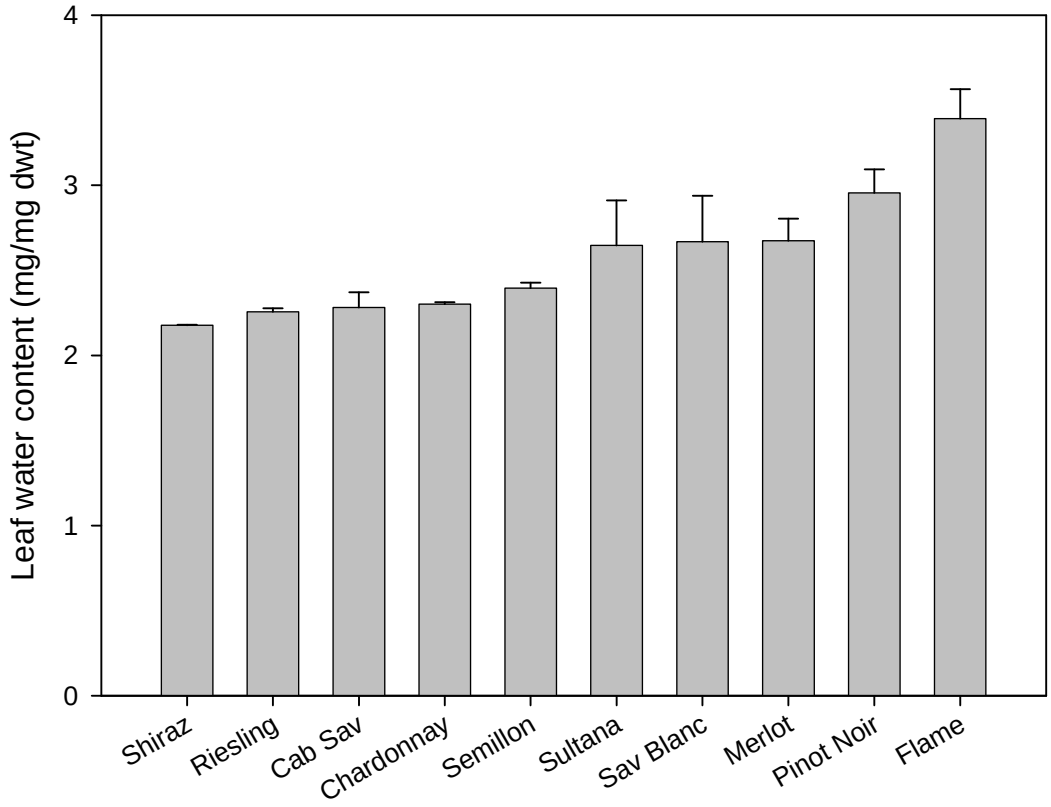


Figure 11. Leaf water content on a dry weight basis of ten varieties grown in a replicated variety block.

Leaf chlorophyll

Leaf chlorophyll concentrations can be an indicator of vine stress. As well as promoting shoot growth, nitrogen increases leaf chlorophyll levels. The vines were treated equally with fertiliser and so differences in leaf chlorophyll may be indicative of vine stress. Semillon vines had leaves with the lowest chlorophyll levels when compared to the other wine grape varieties. The table grapes, however, had even lower chlorophyll levels. Chlorophyll levels were highest for Chardonnay.

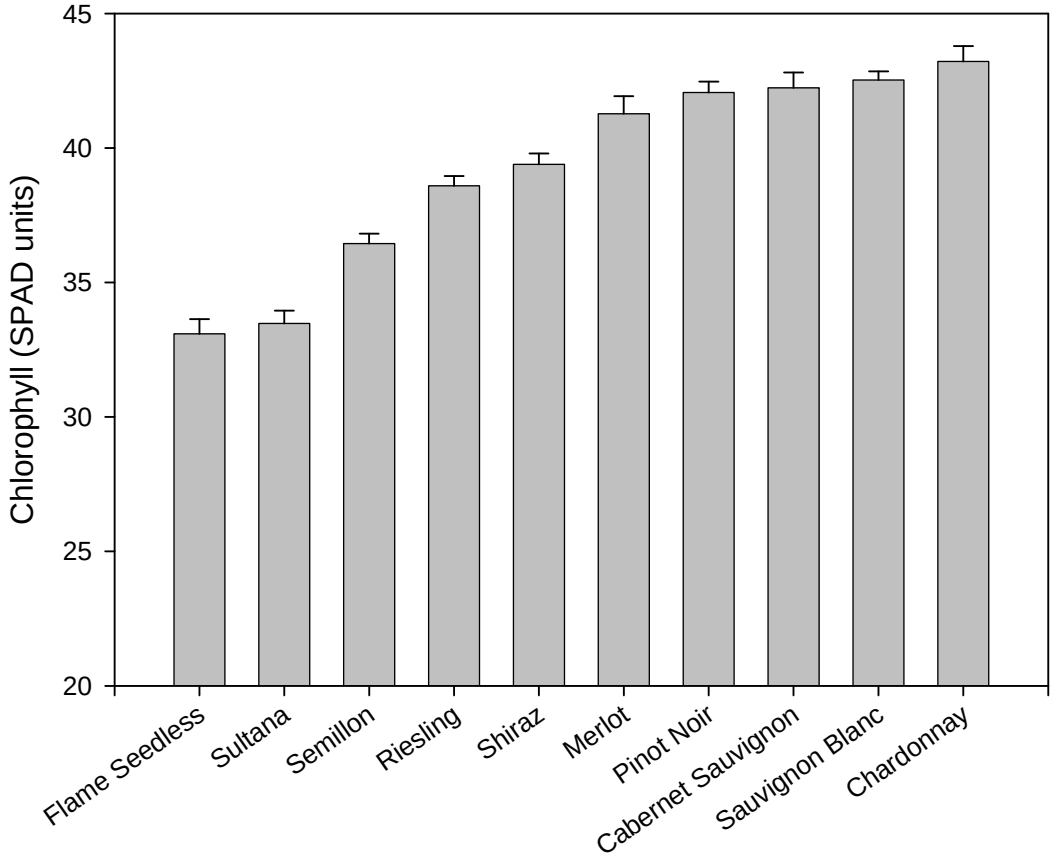


Figure 12. Leaf chlorophyll levels of ten varieties grown in a replicated variety block.

Electrolyte leakage

Water stress can cause membrane damage in leaves. Electrolyte leakage from cells increases with membrane damage and so it is regarded as a stress indicator. Chardonnay had the least electrolyte leakage (11%) while Flame Seedless had the most (15%). All the other varieties, including Semillon, had cell leakage at around 12-13%.

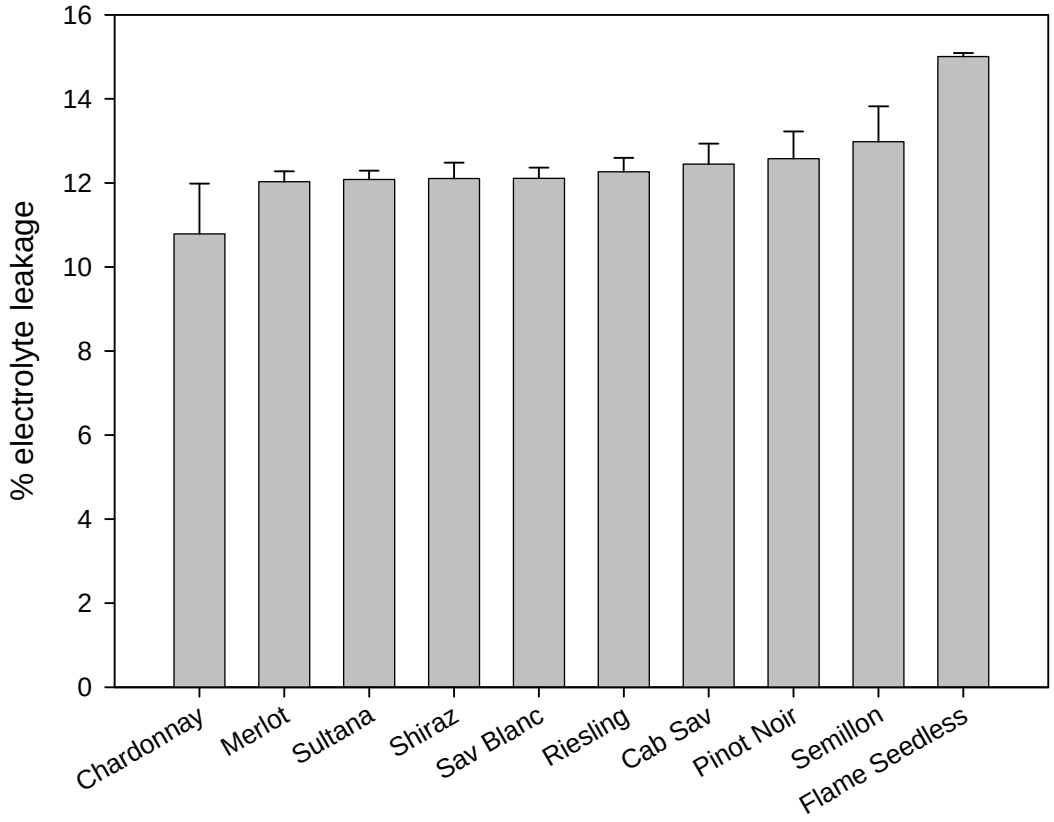


Figure 13. Electrolyte leakage from leaves of ten varieties grown in a replicated variety block.

Size of root system

The root system is important of water uptake from the soil. Smaller root systems that scavenge less area of soil for nutrients and water are more likely to lead to slower shoot growth and smaller shoot systems. Varieties that have less vigorous root systems may also be more prone to water stress. It was expected that these vines, being only 3 years old, and on drip irrigation since planting, would not have an extensive root system extending deep into the inter-row area. Therefore, the amount of root biomass located directly underneath the dripper and 30 cm from the centre of the vine was assessed to a depth of 35cm. It was found that of the six varieties that were compared Chardonnay had the most root biomass, at 5.9 g dm^{-3}. Merlot, Flame Seedless, Semillon and Shiraz all had fairly similar root biomass at about 2-3 g dm^{-3} of soil.

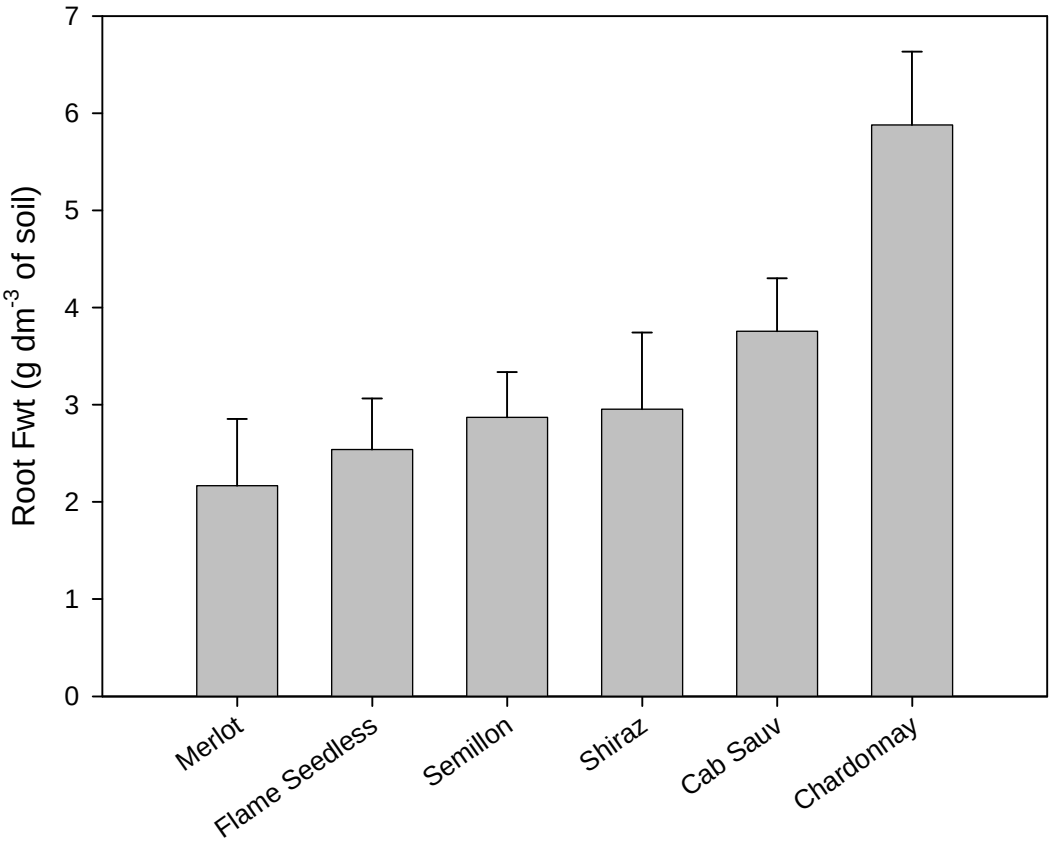


Figure 14. Root fresh weight/ dm^{-3} of soil for 6 varieties grown in a replicated variety block.

Trunk diameter

The woody portions of the vine may offer a water storage reserve to maintain leaf water status during times of high evaporative demand or low soil moisture. The trunk, being closer in proximity to the shoots than the roots, could potentially slowly release water during these critical times to prevent leaves from dehydrating. Trunks with greater cross sectional area would potentially store more water than trunks with smaller areas.

Cross sectional area of trunks varied 2.5-fold after 3 years of growth despite planting at the same time. Flame Seedless had the lowest area at less than 1.5 cm^2 while Sauvignon Blanc had the highest area at 4.0 cm^2. Semillon fell within the moderate range at around 2 cm^2, comparing well with most of the other varieties. Therefore it is not likely that the water stress expressed by Semillon vines is due to less water availability from the potential storage areas within the trunk.

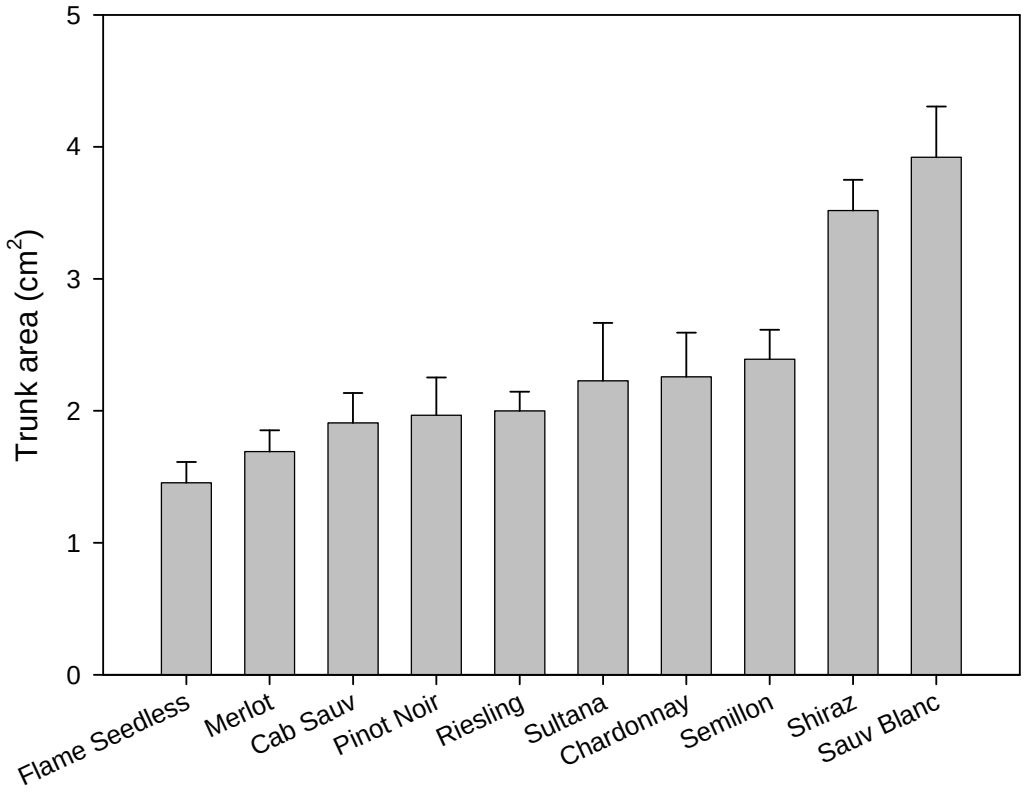


Figure 15. Trunk diameters of ten varieties grown in a replicated variety block.

Canopy Size

Larger canopies may dehydrate a plant more readily than smaller canopies since there is more area for transpiration to take place. Semillon canopies were average in size compared to the other varieties. Total shoot length per vine and average shoot length per vine were 11 m and 47 cm, respectively.

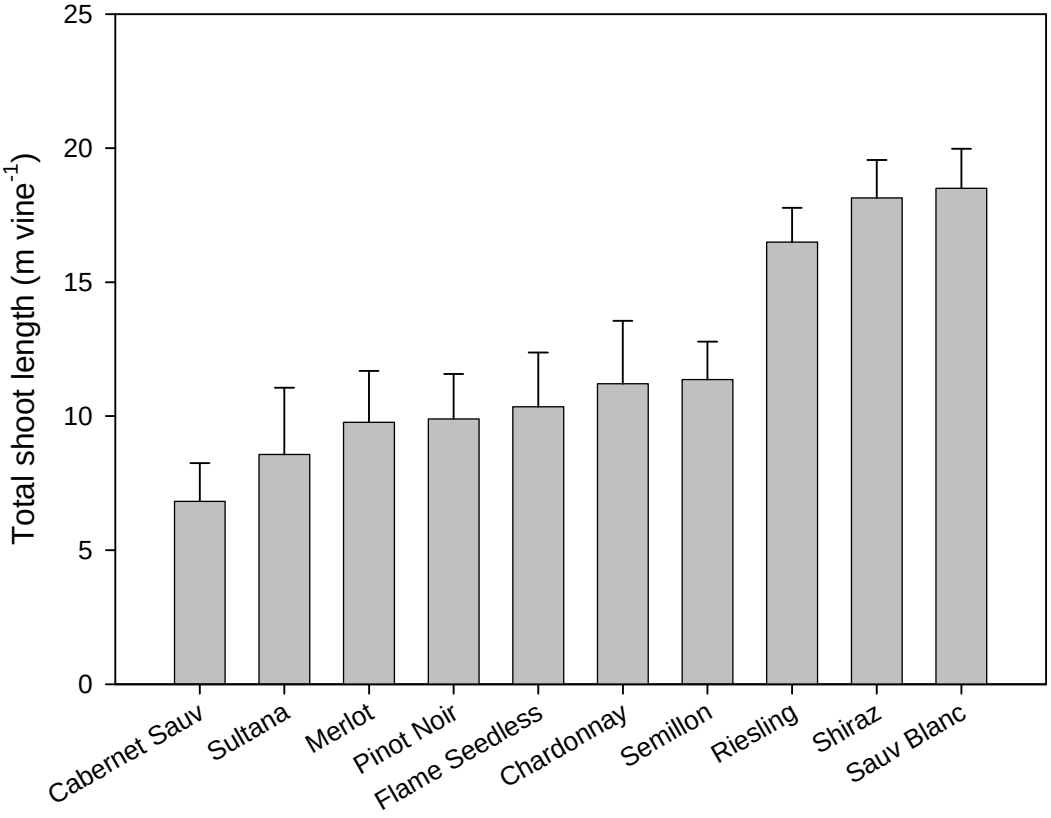


Figure 16. Total shoot length of ten varieties grown in a replicated variety block.

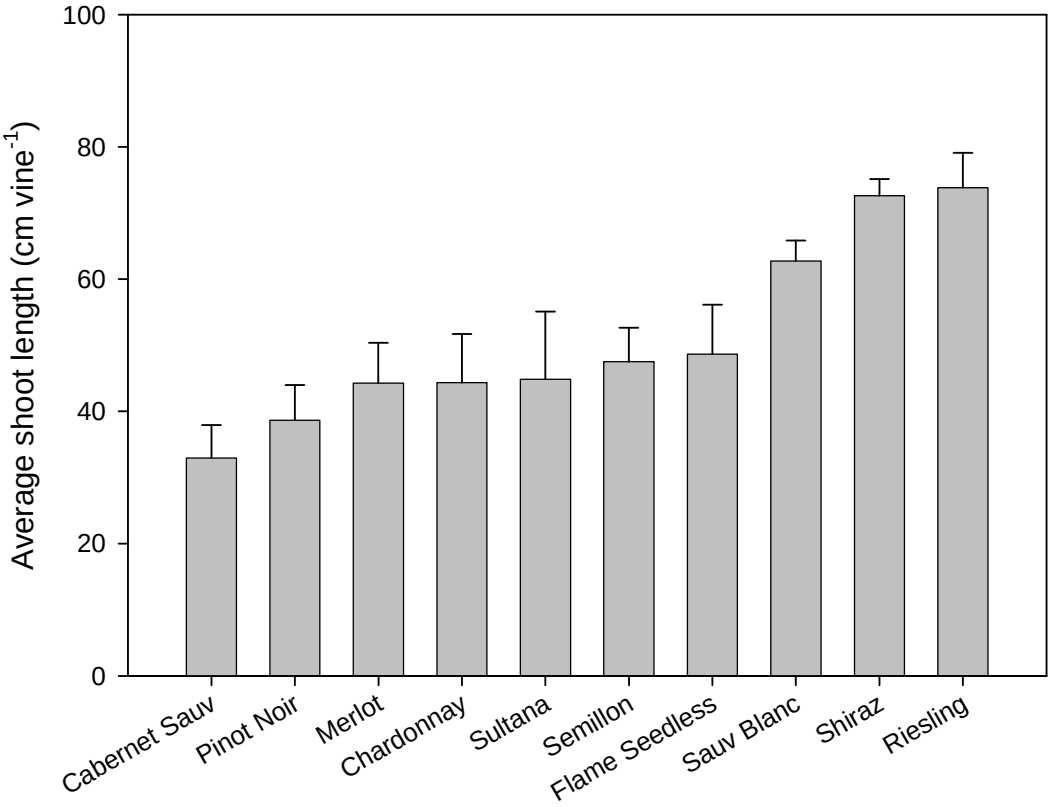


Figure 17. Average shoot length of ten varieties grown in a replicated variety block.

Summary

Semillon vines were consistently more water stressed than other varieties when grown under identical conditions. Both predawn and midday leaf water potential values were more negative for this variety under moderate and low soil moisture levels, and this trend continued throughout the day as temperature increased. Transpiration and stomatal conductance of Semillon vines were amongst the highest of the ten varieties examined, while transpiration efficiency was amongst the lowest. These results compare well with other estimates of transpiration and stomatal conductance for Semillon (Regina and Carbonneau, 1996; Gibberd et al. 2001). We found that when examined over a range of VPDs, transpiration and stomatal conductance were significantly higher for Semillon. The high transpiration rates resulted in relatively cool leaves, when compared to the other varieties. Despite this, Semillon vines were the only ones to undergo leaf burn when exposed to 40°C days.

Aside from high stomatal conductances, other vine parameters may have resulted in the highly negative water potentials for this variety. Stomatal density, however, was not unusual when compared to other varieties. The biomass of the root system was average, as was the trunk cross-sectional area, canopy size and leaf thickness. Leaf chlorophyll was the lowest amongst the wine grape varieties, possibly due higher stress levels. Membrane damage, however, as assessed by electrolyte leakage was average. The absence of any outstanding morphological feature points to the role of the stomata in this variety's susceptibility to leaf burn. Further work to elucidate why stomatal conductances are so high is required.

6.4: Variety Comparison Study- Growth Cabinet

In the vineyard study, plant water status and the stomatal behaviour of Semillon vines stood out when compared to nine other varieties. Further work to elucidate the effect of dry soils on vine gas exchange was required. A comparison was carried out with Grenache, an isohydric species with Mediterranean origins. Grenache is able to maintain plant water status during times of water stress (Schultz 2003). Figure 1 illustrates two different plant responses to fluctuation in soil moisture. Isohydric species are able to maintain midday leaf water potentials throughout the wet and dry cycles. Anisohydric species, however, develop progressively more negative midday leaf water potential as soils dry down, then recover upon increased soil moisture. There are variety differences within *Vitis vinifera* in their capability to do this, for example Chardonnay has been labelled as an anisohydric species. Semillon vine response to drying soils was compared to Grenache in order to determine if it is an isohydric or anisohydric species.

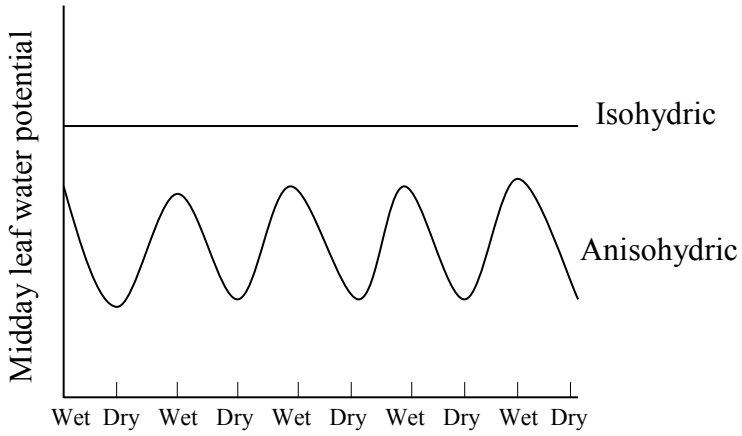


Figure 1. Isohydric and anisohydric response to wet and dry cycles.

Experiment 1

During the 12 days of dry down the soil moisture declined from 27% to less than 15% (Figure 1A). There was no significant differences between Grenache and Semillon pots in soil moisture throughout this dry down period. The VPD_{leaf} increased over the 12 days as the soil moisture declined (Figure 1B). Stomatal conductance of leaves from Semillon vines was approximately 0.02 mol H_2O $m^{-2}s^{-1}$ higher than Grenache vines throughout the dry down (Figure 2A). Transpiration of Semillon leaves was up to 2 fold higher (0.2 to 0.6 mmol H_2O $m^{-2}s^{-1}$) than Grenache leaves (Figure 2B). Photosynthesis was also higher for Semillon leaves by up to 30% (2 μmol CO_2 $m^{-2}s^{-1}$) (Figure 3A). Internal CO_2 concentrations did not vary greatly over the dry down period and they were not different between the varieties (Figure 3B).

When stomatal conductance and transpiration were plotted against soil moisture it was evident that at less than 20% soil moisture these two parameters were much reduced and remained constant with further decreases of soil moisture to 13% (Figure 4A and B). At the higher soil moisture levels Grenache leaves had approximately 30-50% lower stomatal conductance and transpiration, but at soil moisture levels less than 15% this difference was less pronounced.

Midday leaf water potentials of Semillon vines were more negative than Grenache vines at both high (53%) and low (14%) soil moistures (Figure 5). The midday leaf water potential of Semillon vines at the low soil moisture was more than double that of Grenache vines. At the high soil moisture, the midday leaf water potential was 20% higher for Semillon leaves.

Leaf petiole ABA concentrations at the end of the dry down cycle were similar for Grenache and Semillon vines at 0.8 nmol mL^{-1} (Figure 6).

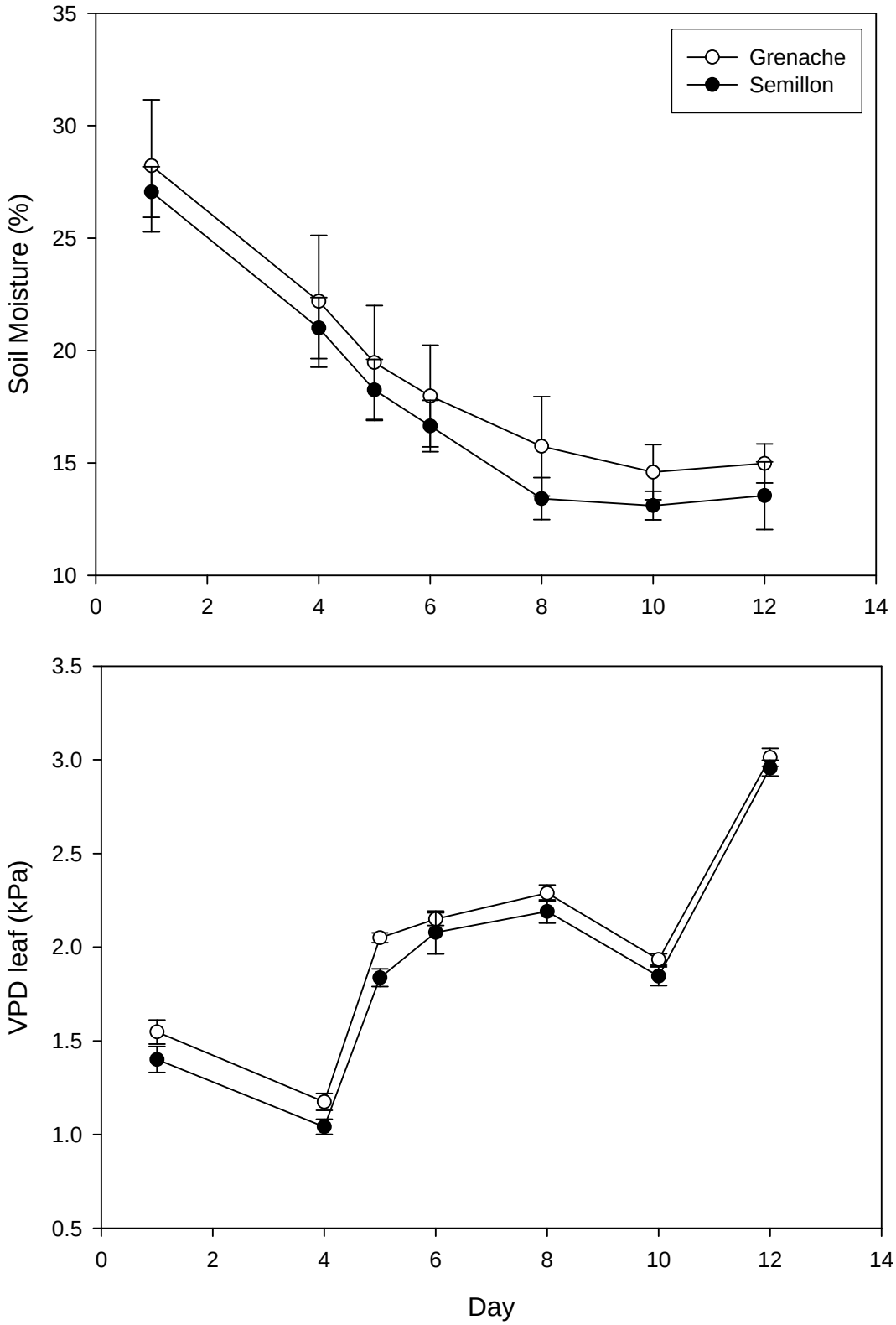


Figure 1. Changes in soil moisture (A) and VPD_{leaf} (B) of Grenache and Semillon during a dry down cycle.

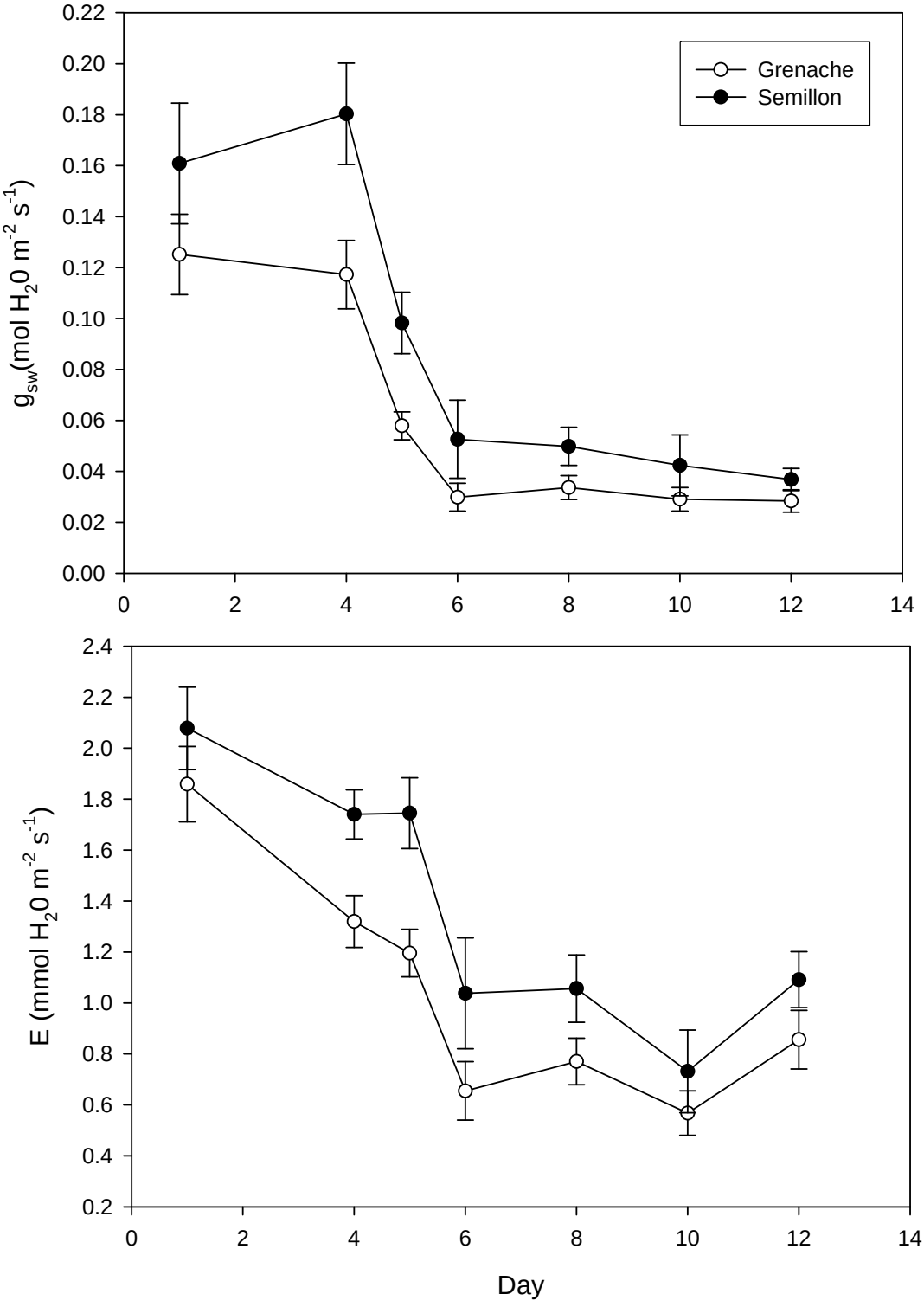


Figure 2. Changes in stomatal conductance (A) and transpiration (B) of Grenache and Semillon during a dry down cycle.

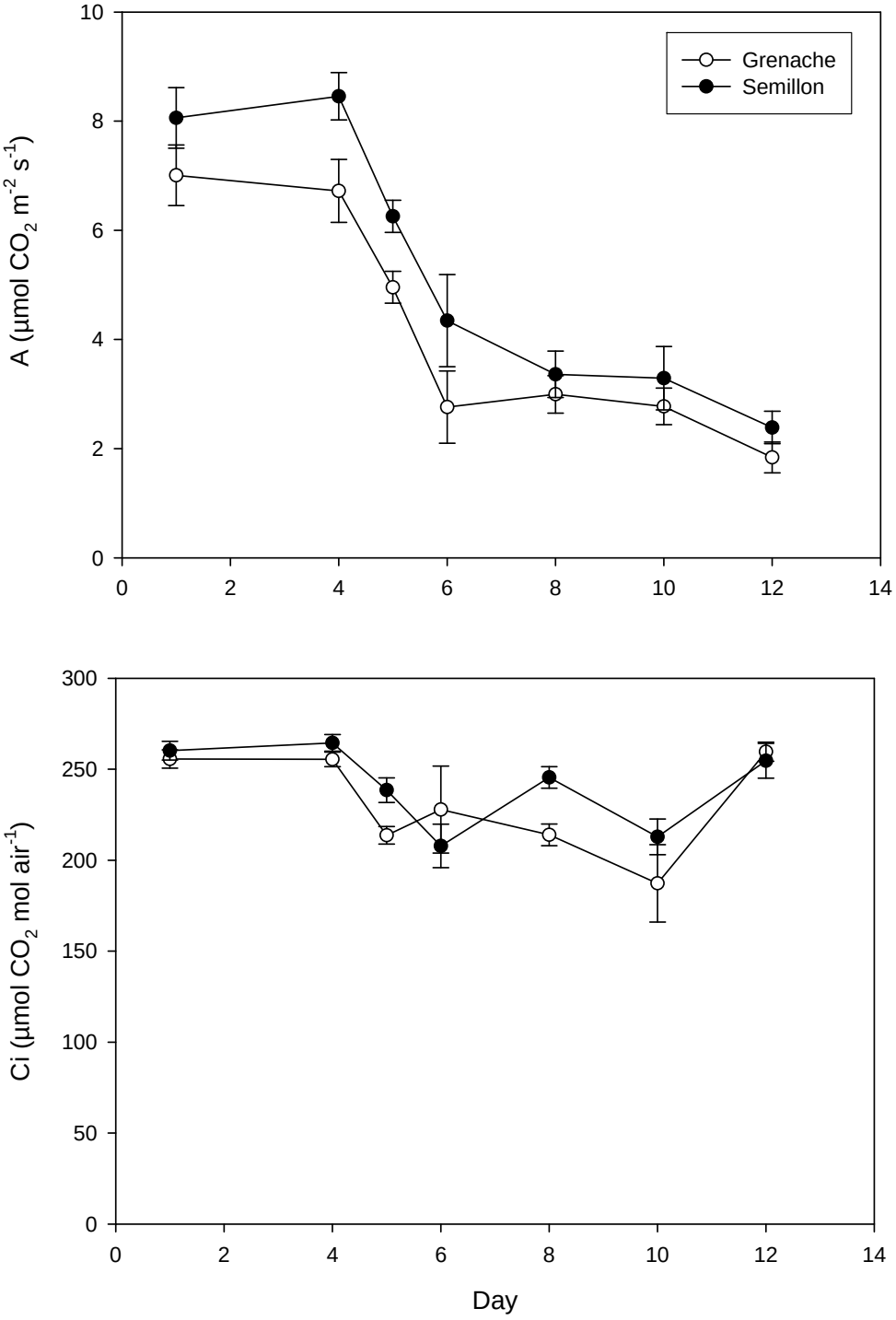


Figure 3. Changes in carbon assimilation (A) and internal CO_2 concentrations (B) of Grenache and Semillon during a dry down cycle.

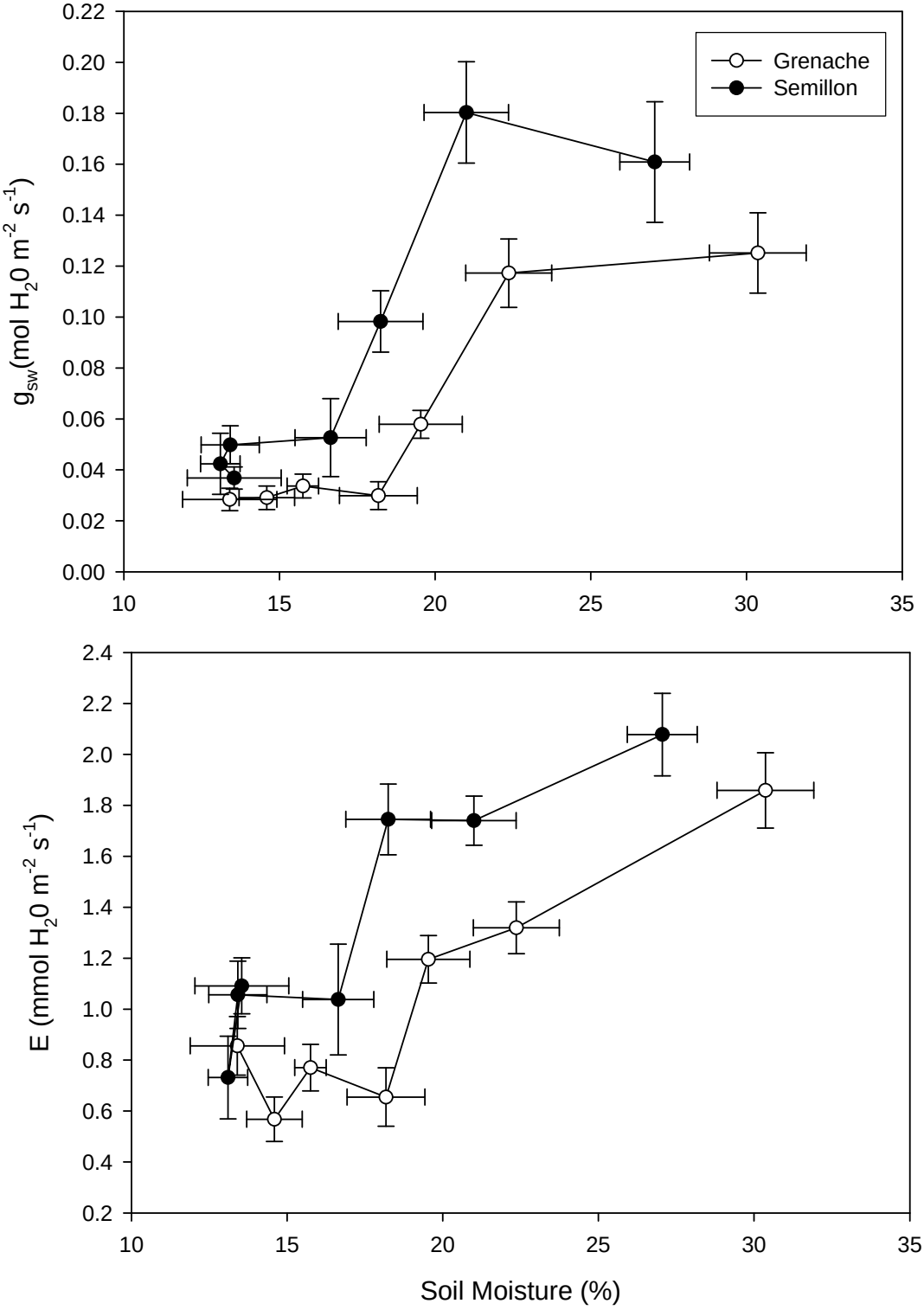


Figure 4. Stomatal conductance (A) and transpiration (B) of Grenache and Semillon leaves in response to declining soil moisture.

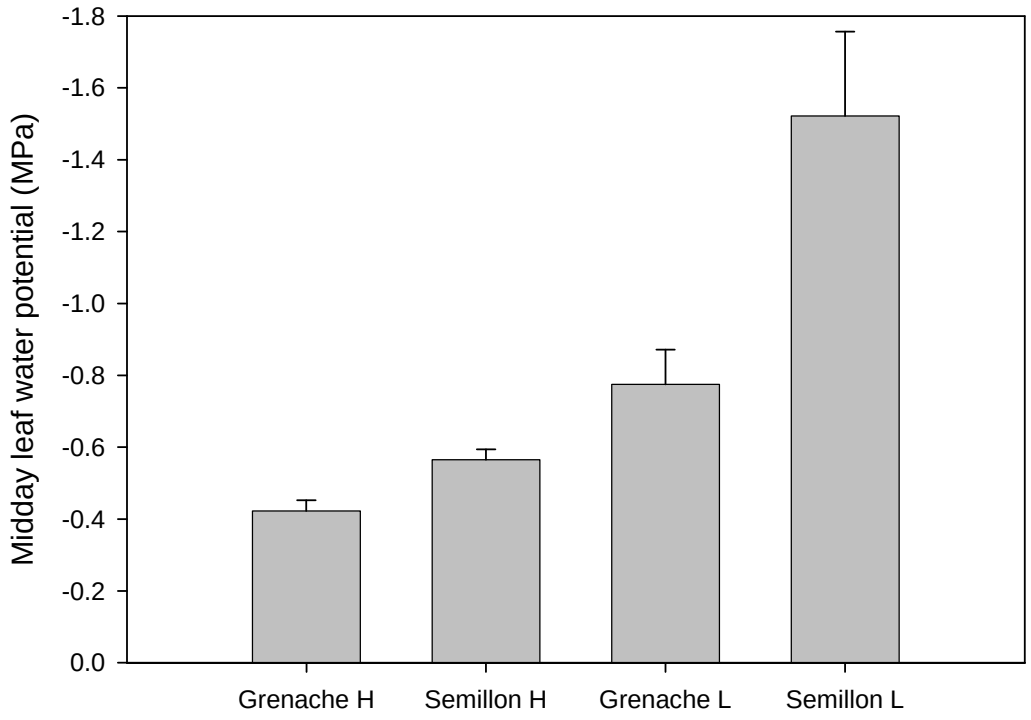


Figure 5. Midday leaf water potential of Grenache and Semillon at the start of the dry down cycle when soil moisture was high (H, 53%) and at the end of the dry down cycle when soil moisture was low (L, 14%).

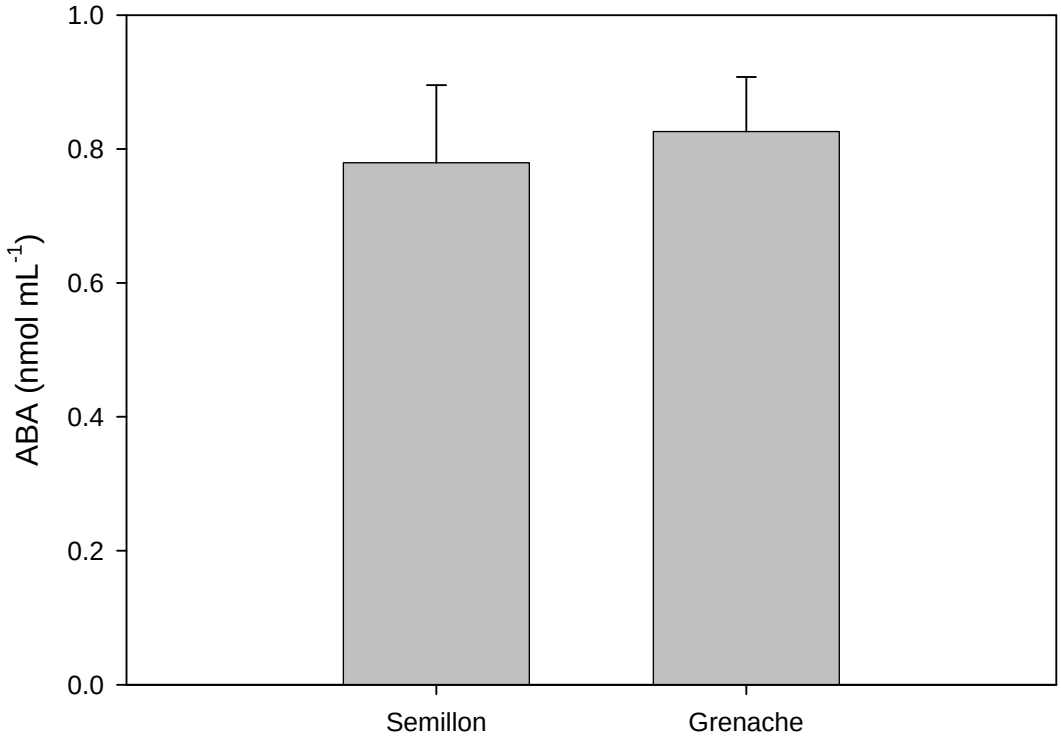


Figure 6. ABA concentrations in xylem sap of Grenache and Semillon vines at the end of the dry down cycle.

Experiment 2

In this experiment the vines of the deficit irrigation treatment were allowed to dry down for 11 days, while the control vines were watered every day. Semillon vines of the control and deficit treatments had consistently more negative leaf water potentials, both prior to dawn and at midday (Figures 7 and 8). Midday leaf water potentials were more negative than predawn values for both control and deficit treated vines. The difference between Semillon and Grenache vines was more pronounced at the lower soil moisture levels with 60% more negative midday leaf water potentials.

Soil moisture levels at the end of the dry down period were 16% for the deficit treatment and 37% for the control treatment (Figure 9). Root water potentials at these soil moisture levels were similar to leaf water potential measurements for vines treated with a water deficit (Figure 10). However in the standard irrigated vines the leaf water potential of Semillon vines was more negative than the root water potential. The reverse occurred for Grenache vines with more negative leaf water potentials than root water potentials

Root, shoot and trunk dry weights were higher for Grenache vines as compared to Semillon vines in both treatments (Figure 11A). For both varieties, those vines with a water deficit treatment had smaller root, shoot and trunk dry weights. There were no obvious differences in shoot/root or shoot/trunk ratios for either variety in either treatment (Figure 11B).

Leaf fresh and dry weight on an area basis was higher Grenache than Semillon (Figure 12A). In Grenache both leaf fresh and dry weights were less for those vines with a deficit irrigation treatment. For Semillon vines, however, only leaf dry weight was less in the deficit treatment. Electrolyte leakage from leaf cells was higher for Grenache vines than Semillon vines after both a standard and deficit irrigation treatment (Figure 12B).

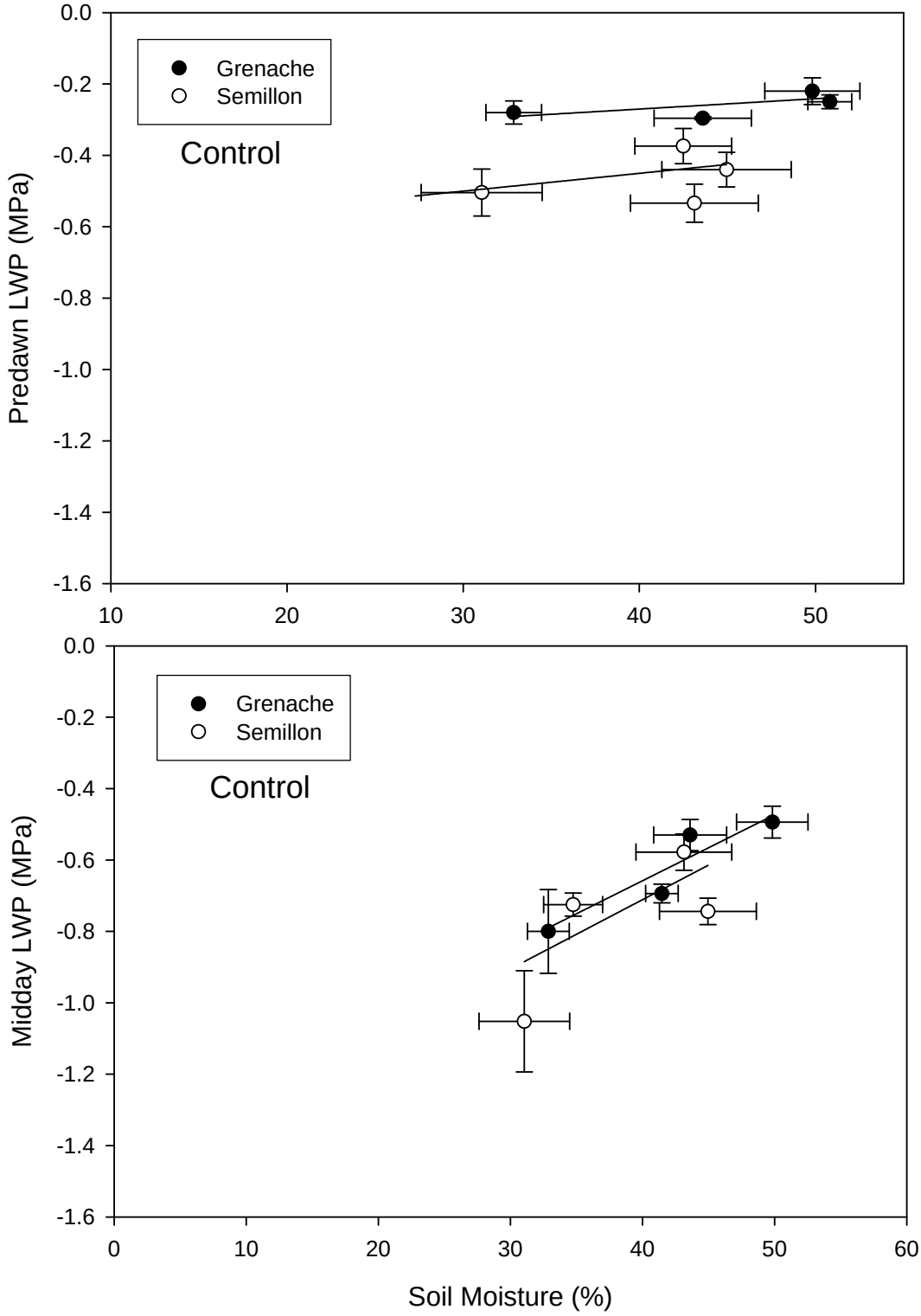


Figure 7. Predawn and midday leaf water potentials of Semillon and Grenache vines grown in a control irrigation treatment.

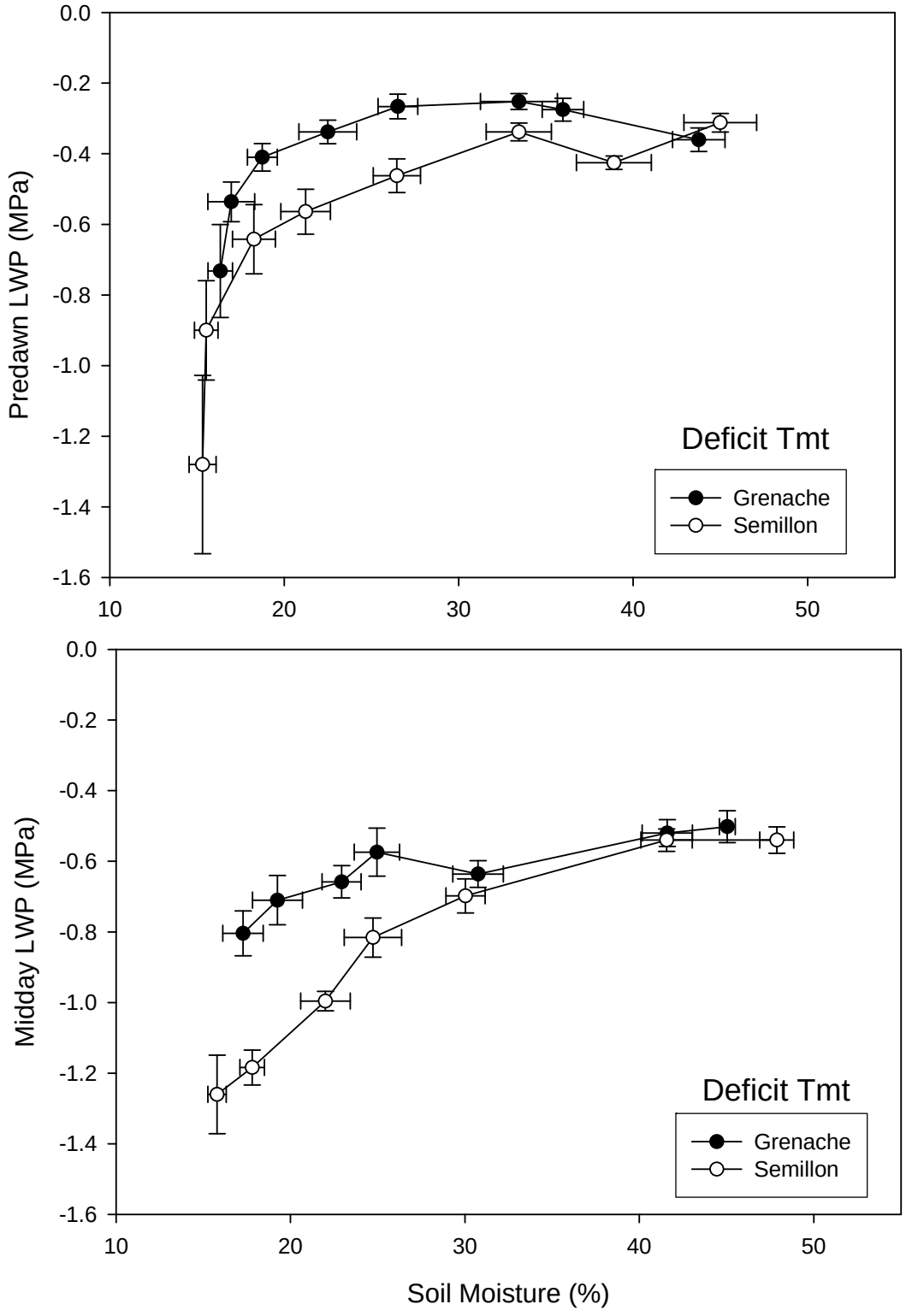


Figure 8. Predawn and midday leaf water potentials of Semillon and Grenache vines grown in a deficit irrigation treatment.

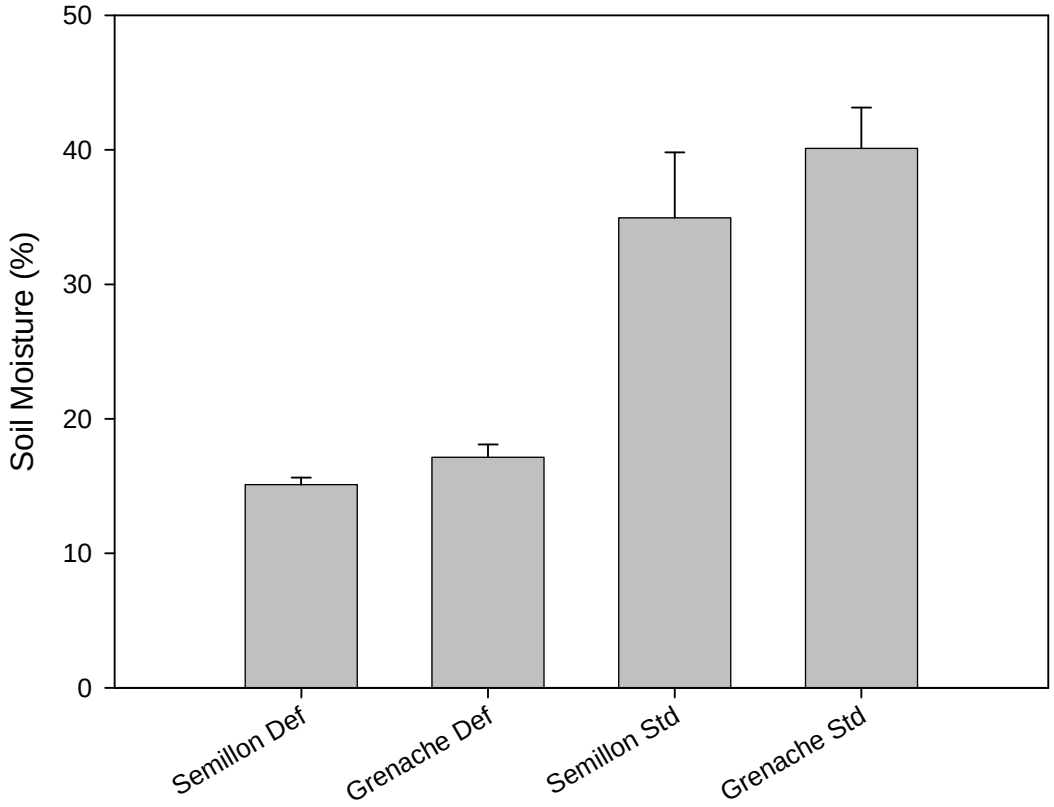


Figure 9. Semillon and Grenache soil moisture at the end of the dry down cycle and at the end of the standard irrigation treatment.

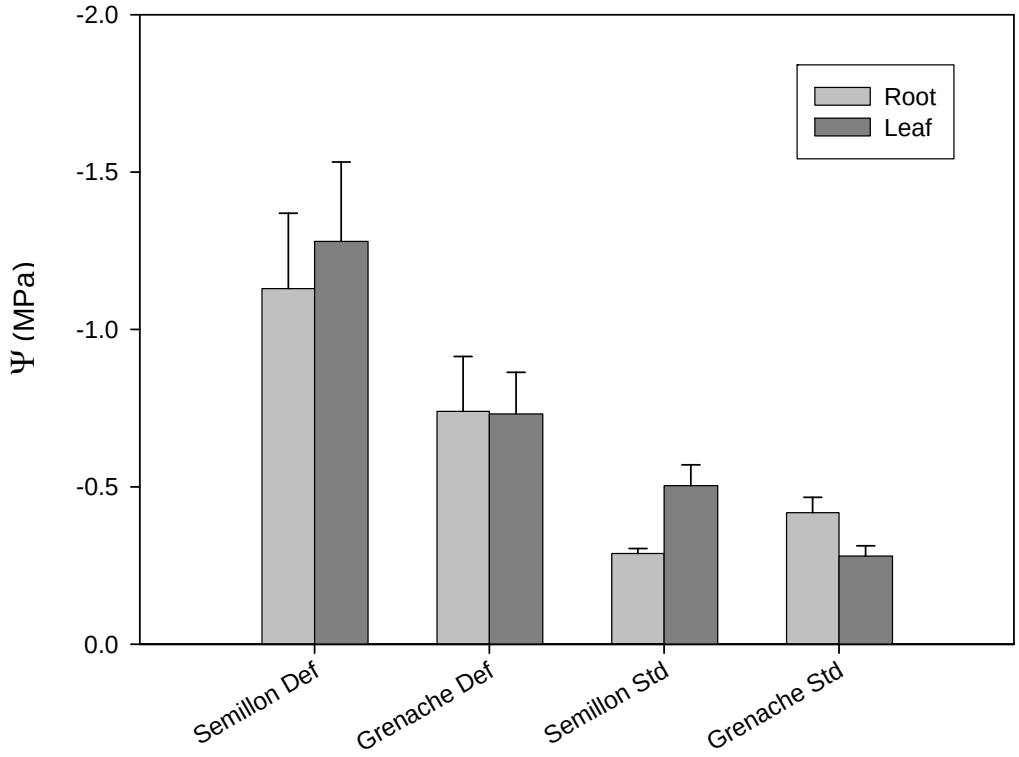


Figure 10. Semillon and Grenache root and leaf water potential at the end of the dry down cycle and at the end of the standard irrigation treatment.

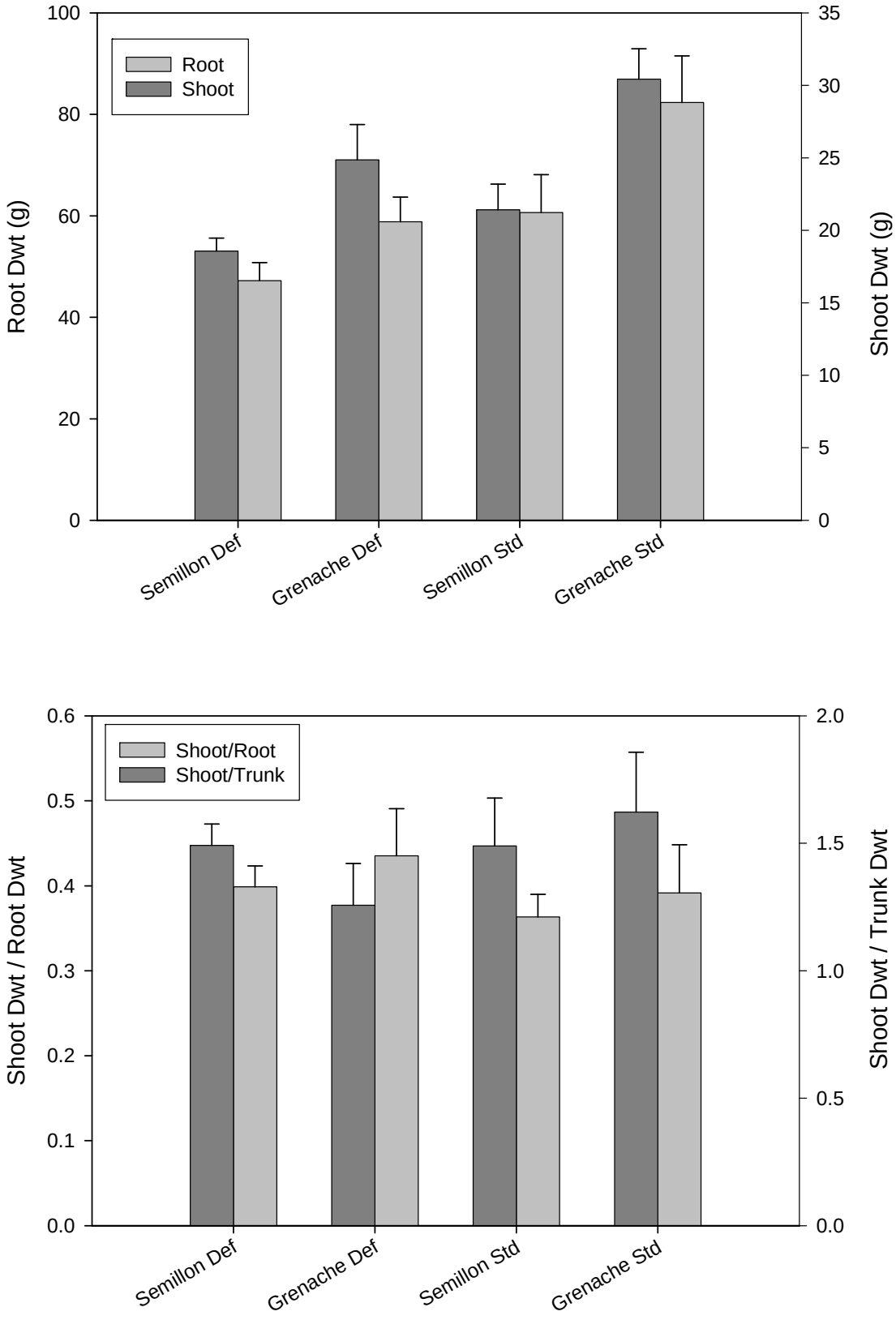


Figure 11. Semillon and Grenache (A) root and shoot dry weights and (B) shoot:root and shoot:trunk dry weight ratios at the end of the dry down cycle and at the end of the standard irrigation treatment.

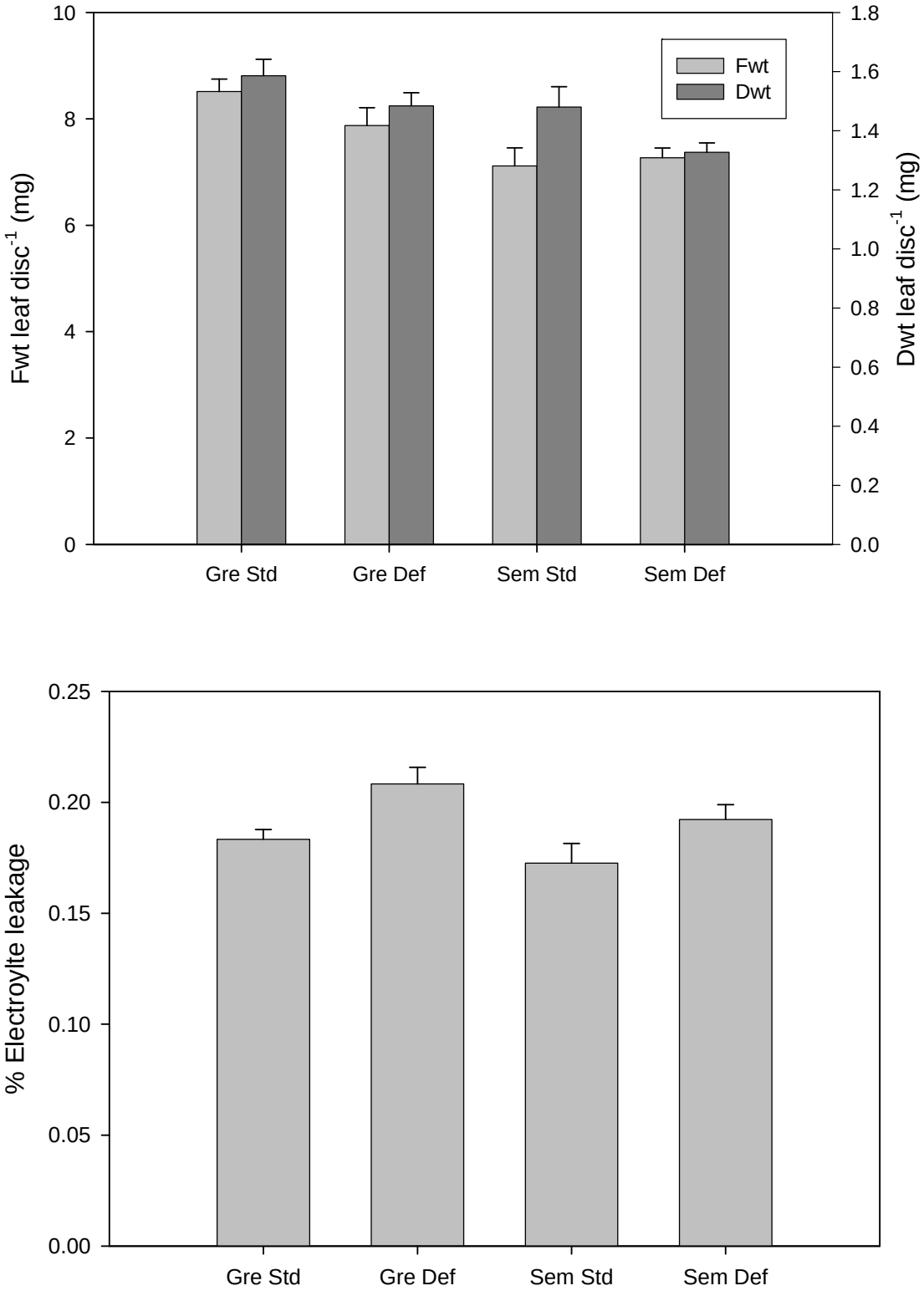


Figure 12. Electrolyte leakage from Semillon and Grenache leaves at the end of the dry down cycle and at the end of the standard irrigation treatment.

Experiment 3

In this experiment the stomatal response to vapour pressure deficit (VPD) was monitored for three varieties (Figure 13A). With VPDs ranging from 1.5 to nearly 4.0 kPa, Semillon stomatal conductance to water vapour was consistently highest and ranged from 0.25 to 0.16 mol H_2O $m^{-2}s^{-1}$. Stomatal conductance of Shiraz vines were slightly higher than Grenache vines. Stomatal conductance declined for Semillon and Shiraz leaves but remained steady for Grenache leaves as VPD increased. Transpiration increased for all three varieties as VPD increased (Figure 13B). Transpiration was highest for Semillon leaves across the range of VPDs (3 to 6 mmol H_2O $m^{-2}s^{-1}$). Photosynthesis was again highest for Semillon vines, ranging between 9 and 10.5 µmol CO_2 $m^{-2}s^{-1}$ (Figure 14A). Photosynthesis ranged between 7 and 8 µmol CO_2 $m^{-2}s^{-1}$ for the two other varieties and was not responsive to VPD. Leaf Internal CO_2 concentrations ranged between 180 and 240 µmol CO_2 mol air^{-1}, was not responsive to VPD and were not different between the varieties (Figure 14B).

Stomatal density was highest for Grenache vines with values between 200 and 250 mm^{-2} depending on the location on the leaf's surface (Figure 15). Shiraz and Grenache stomatal densities ranged between 130 and 150 mm^{-2}. There were no differences in stomatal densities between the different locations on both Shiraz and Semillon leaves.

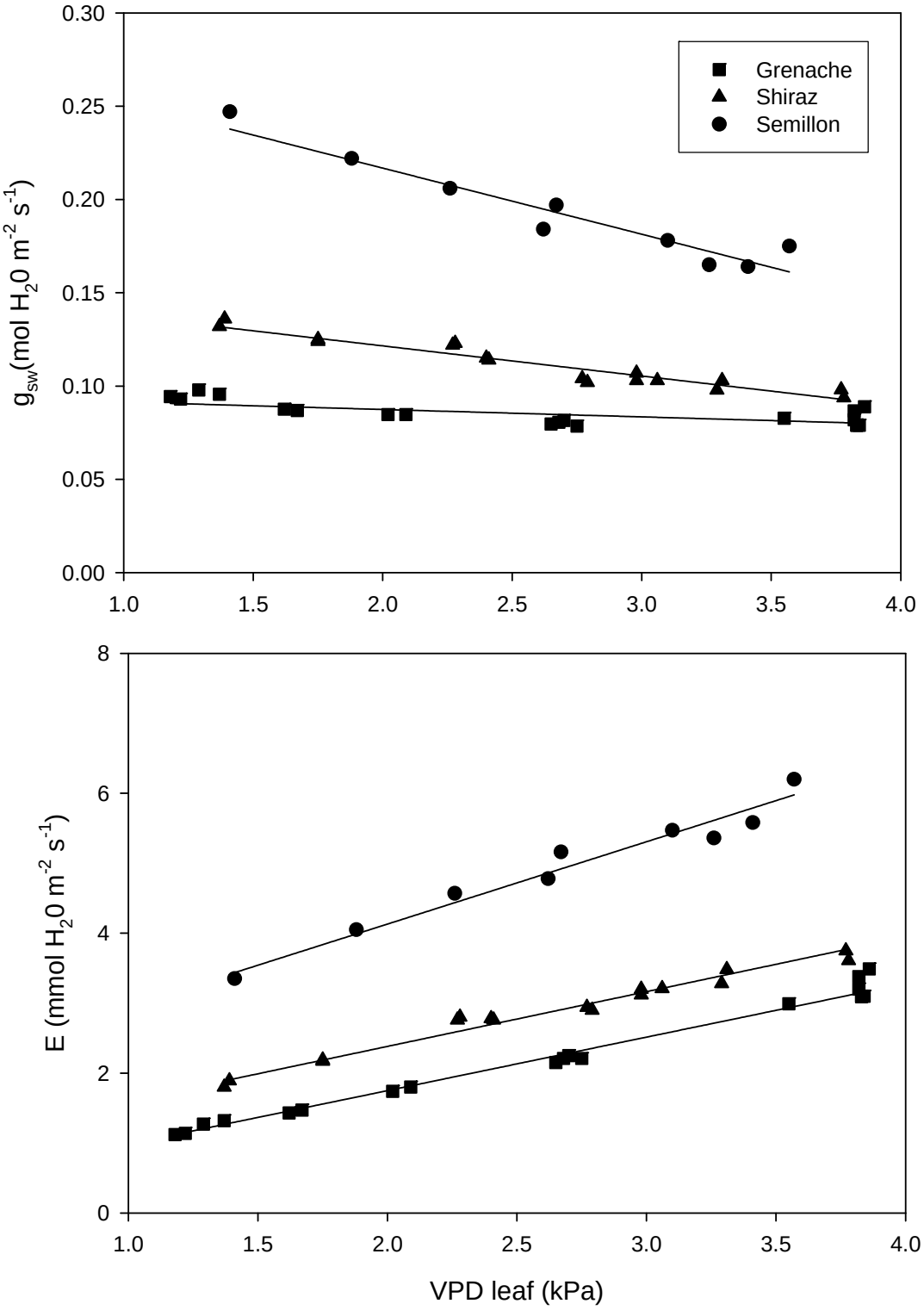


Figure 13. Stomatal conductance (A) and transpiration (B) of Semillon, Grenache and Shiraz leaves over a VPD range from 1 to 4 kPa.

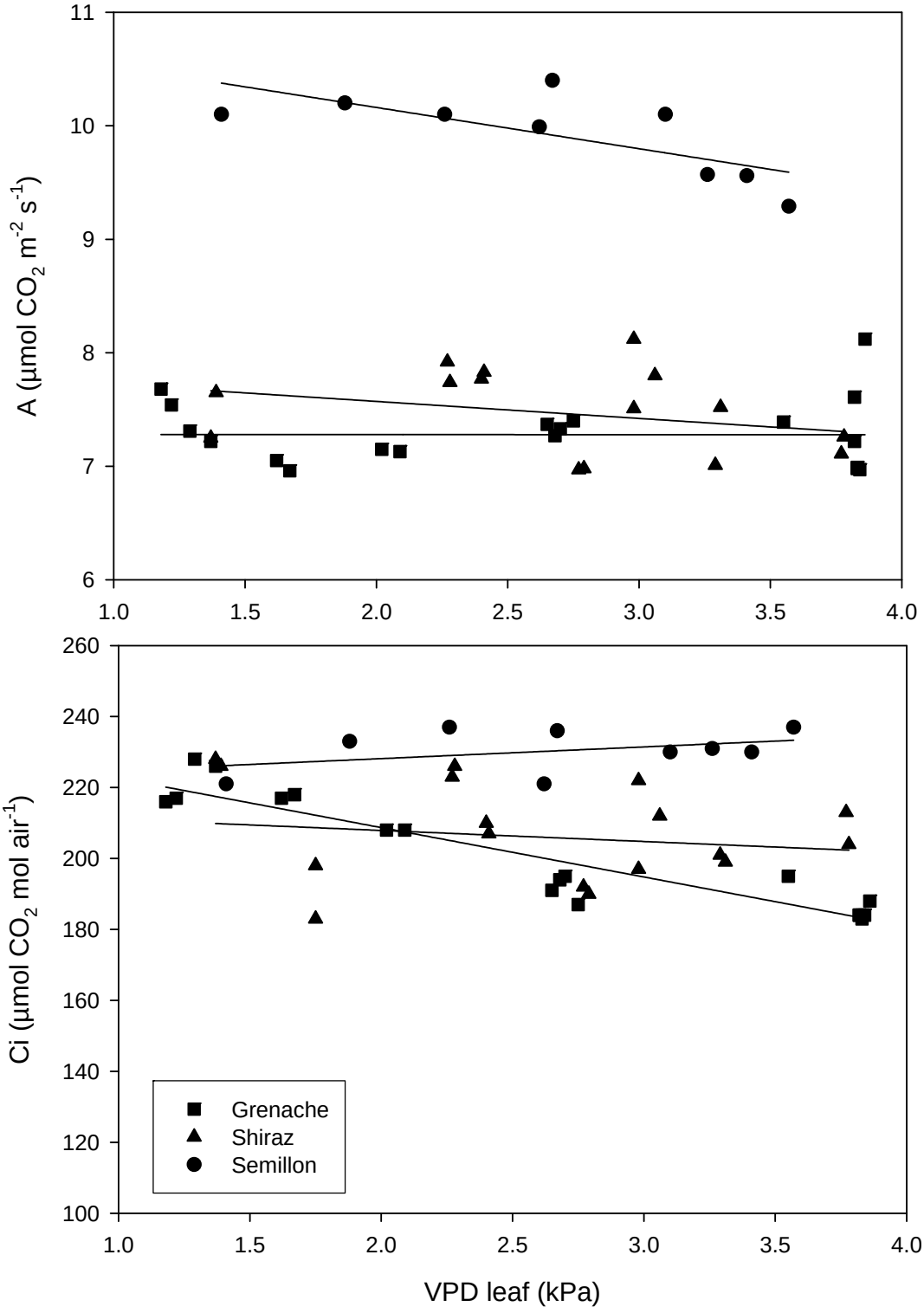


Figure 14. Photosynthesis (A) and internal CO_2 concentrations (B) of Semillon, Grenache and Shiraz leaves over a VPD range from 1 to 4 kPa.

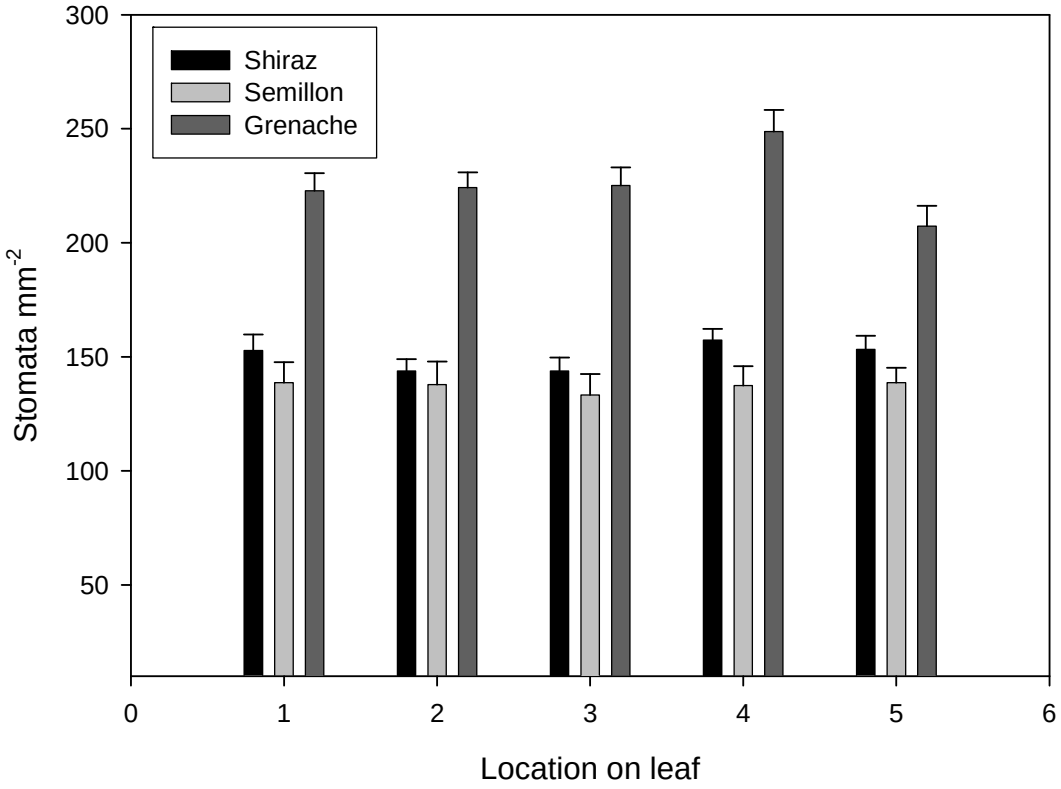


Figure 15. Stomatal density of Semillon, Grenache and Shiraz leaves grown under identical conditions.

Discussion

Semillon vines had higher transpiration rates across a range of soil moistures and VPDs as compared to Grenache vines. This higher transpiration may be partly explained by the higher stomatal conductances. The higher transpiration rates resulted in more negative predawn and midday leaf water potentials. Stomatal conductance was responsive to VPD and soil moisture but resistance to water diffusion was not as great as Grenache. It is uncertain whether fewer stomata closed within a particular leaf patch, or if stomata did not close to the same extent as in Grenache vines. The lower stomatal densities of Semillon leaves do not explain the higher transpiration rates of this variety. The possibility remains that along with stomatal transpiration, cuticular transpiration is also higher for Semillon leaves.

Grenache had thicker leaves, and possibly greater water holding capacity and this may have offered some buffering capacity to evaporative demand. The abaxial surface of Grenache leaves was relatively smooth with fewer trichomes as compared to Semillon leaves. It would be expected that these features would, however, decrease the boundary layer and increase transpiration rates. Water stress did damage cell membranes of leaves since electrolyte leakage was increased in both varieties. The extent of membrane damage was, however, not greater for Semillon leaves.

Because the shoot:root and shoot:trunk ratios were similar for both varieties it is likely that canopy water demands relative to the root and trunk biomass was not different. Roots were responsive to soil moisture levels in both varieties. According to the water potential measurements, roots were more water stressed than shoots for Grenache vines, but in Semillon the roots had less water stress than the leaves. It is possible that in Semillon, the trunk and shoot hydraulic conductance is inadequate for transpirational demands. The inefficient transfer of water from the below ground to the above ground portions of the vine may have resulted in more negative leaf water potentials.

ABA levels in the xylem sap of leaf petioles were not different between the two varieties, indicating that the roots of both varieties had similar capacities to produce ABA in response to low soil moisture levels. These results are different from another study where vines experienced high VPDs. When compared to Shiraz, Grenache had higher concentrations of ABA in the xylem sap (Loveys et al., 2005). However, it was unclear whether the differences were due to differences in root responses or differences in ABA synthesis within the canopy itself (Loveys et al., 2005). Quantification of the ABA concentrations at the actual site of the guard cells is required to better understand the role of this hormone in *Vitis vinifera*.

6.5: The role of ABA in Semillon vines

The chemical signal, abscisic acid (ABA), accumulates in many drought stressed plants and can cause stomatal closure. The role of ABA in regulating stomatal conductance, and thus plant water status, has been studied intensively in *Vitis vinifera* (Loveys, 1984; Correia, et al, 1995; Stoll et al, 2000). ABA is produced by the roots under water deficits but it is also produced by leaves and it is uncertain which of these pools is acting as a signal to regulate stomatal aperture. Unlike other more drought tolerant varieties, Semillon may be a variety in which the ABA signalling system does not function effectively. The inability to regulate stomatal closure in response to the environment may be one characteristic leading to Semillon's susceptibility to water stress. ABA, however, is not the only signal thought to be important in regulating stomatal conductance. Other signals such as xylem pH are thought to play a role in some species. Recent work has also investigated the role of carbohydrates in regulating stomatal aperture.

ABA concentrations in the xylem sap of leaf petioles were quantified for ten varieties grown in a replicated variety block. An earlier study comparing the ABA concentrations in xylem sap of Grenache and Semillon in a growth cabinet study during water stress indicated no significant differences (See Section 5). In this study, ABA concentrations in Semillon fell in range with the other varieties (Figure 1), thus indicating that the roots of both varieties had similar capacities to produce ABA in response to low soil moisture levels.

Leaf water potentials of Semillon vines were more negative at dawn than Chardonnay vines and this was consistent through until dusk (Figure 2). Throughout the course of the day vine LWP was approx. 0.2 MPa more negative. ABA concentrations in the xylem sap of Semillon vine increased throughout the day as well (Figure 3).

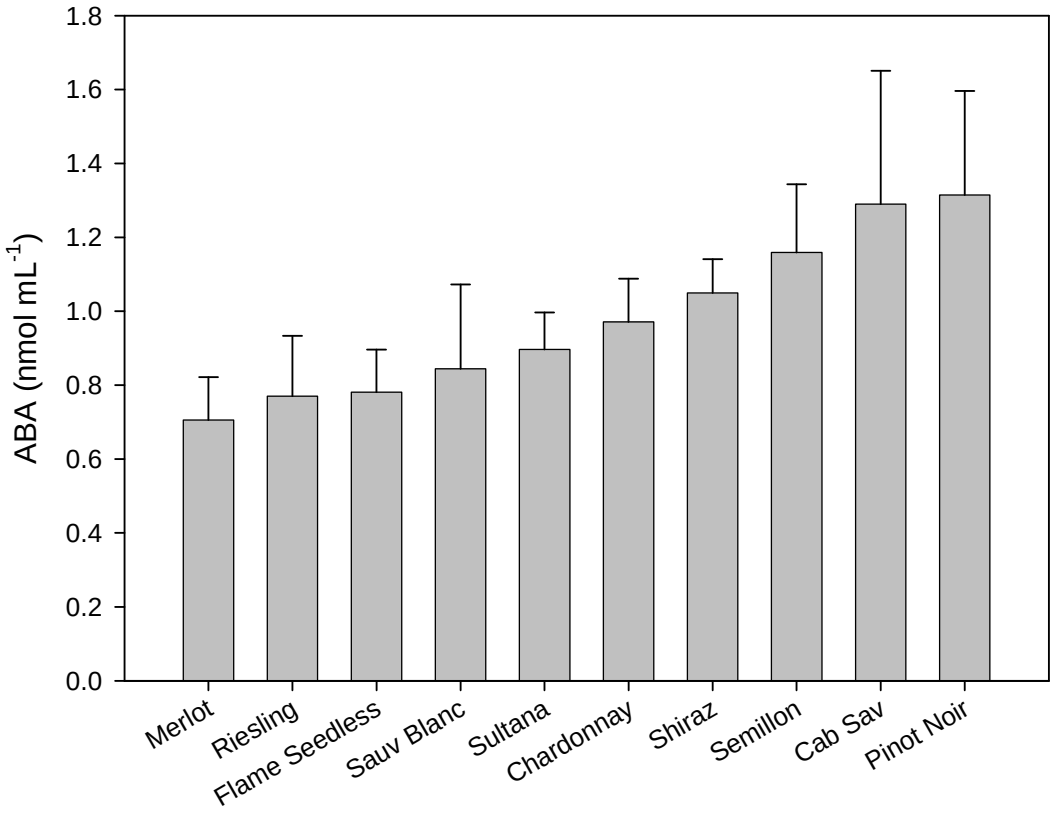


Figure 1. ABA concentrations in leaf petiole xylem sap of ten varieties grown under similar conditions in a replicated variety block.

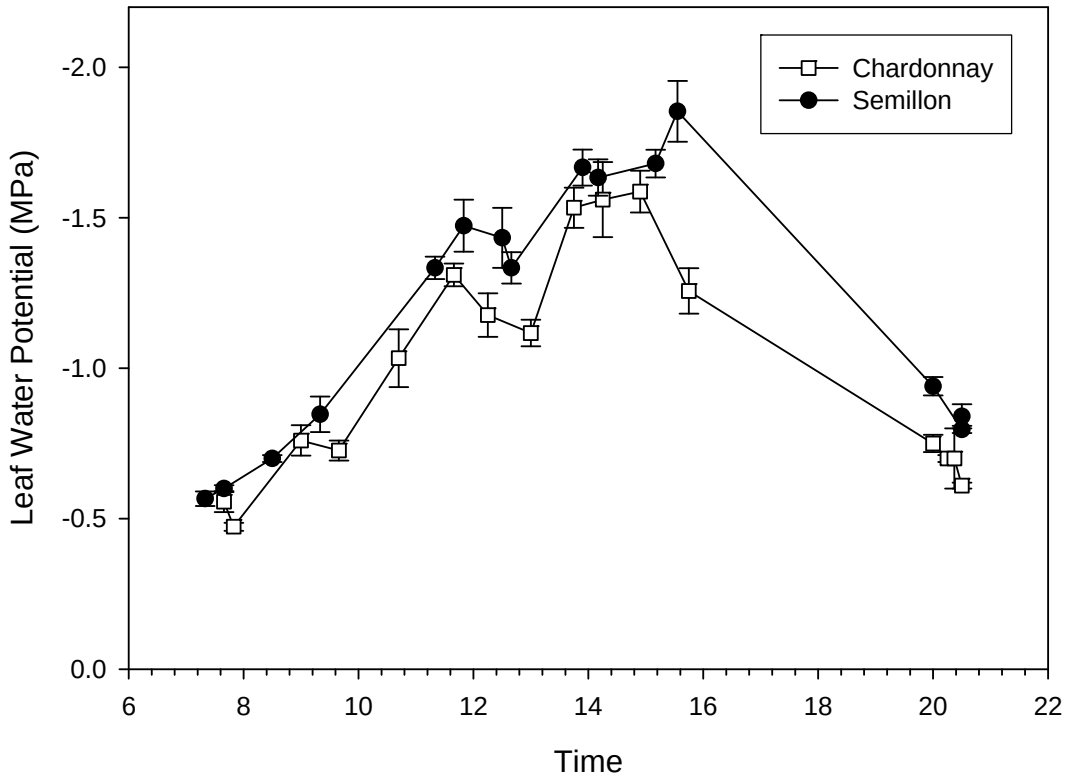


Figure 2. Diurnal leaf water potential of Chardonnay and Semillon vines grown in similar conditions in a replicated variety block.

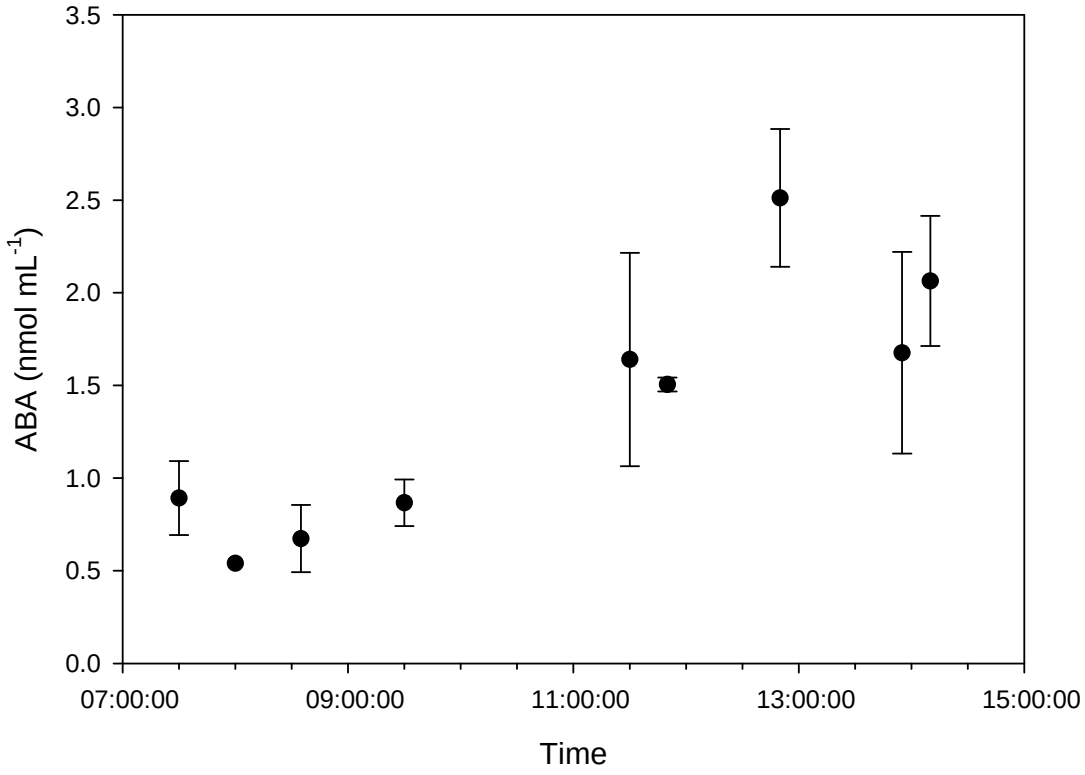


Figure 3. Diurnal ABA concentrations in xylem sap of Semillon vines grown in a replicated variety block.

Discussion

Early research on Semillon in NSW and other regions in Australia concentrated on varietal improvement and rootstock evaluation (Peterson et al. 1974; Scudamore et al. 1992; Cirami, 1993; Ewart et al. 1994). More recently, the impacts of nematodes (Rahman et al. 2001), root diseases (Highet and Nair, 1995) and trunk diseases (Castillo-Pando et al., 2001) have been investigated. The influence of the post-harvest period on vine productivity in Semillon was evaluated in the Riverina and Hilltops regions of NSW. It was concluded in this study that a key advantage of irrigated vineyards in warm/hot regions was the ability to accumulate greater amounts of root reserves for the following season (Holzapfel et al. 2006). It was also found that in the warm region where water application rates were less than adequate, vine growth and yield were compromised.

The topic of interest in the current study is Semillon vine water relations in the warm regions of NSW. The sensitivity of Semillon to water deficits and heat events, however, has been noted by viticulturists and grape growers across Australia. There is little understanding of the physiological causes that lead to leaf burn, and management techniques are required to overcome these stress symptoms. Currently there is a need for better estimates of vineyard water requirements and variety-specific vine water use under different irrigation strategies.

A survey of Semillon water relations was conducted in the Hunter Valley and the Riverina of NSW. Along with soil moisture and weather monitoring, vine growth, transpiration, sap flow, photosynthesis and water status was monitored during the season. Yield and berry composition were analysed. It was found that vine water status was determined by vapour pressure deficit, and superimposed on this was soil moisture levels. In the Hunter Valley leaf burn was evident after a 38°C episode despite heavy rains early in the season. Very little leaf burn was evident in any of the research sites of the Riverina which also attained similar temperatures. Careful soil moisture monitoring, and the conversion by the grower of one of our sites from flood to drip irrigation may have prevented the leaf burn that was evident in the previous two seasons. The benefits of soil moisture monitoring and drip irrigation were evident to this grower even before the completion of this project and we regard this as a positive change in practise by the industry.

A comparison of Semillon vine water relations to other varieties of the same age and size was carried out in a replicated variety block at CSU. This indicated that of the ten varieties monitored for leaf water potential, Semillon was consistently more water stressed. Semillon was the only variety exhibiting leaf burn despite similar soil and environmental conditions. A growth cabinet study comparing Semillon with two other varieties has indicated that Semillon is a high transpiring variety across a range of soil moisture levels and vapour pressure deficits. As such, Semillon can be labelled as an anisohydric or 'optimistic' variety.

A sequence of French studies (Regina and Carbonneau, 1996, 1997 and 1999) looked at the impact of water stress on several *V. vinifera* cultivars, one of which was Semillon. These studies also indicated that, of all the varieties tested, Semillon was the most sensitive to reduction in soil moisture content with an effect on stomatal conductance and rate of photosynthetic assimilation (Regina and Carbonneau, 1997).

Further studies of transpiration efficiency of eight *V. vinifera* varieties in South Australia have shown that Semillon produces the lowest amount of dry matter per litre of water than any other wine grape variety studied (Gibberd et al. 2001). These results agree with our findings and we have shown that the high transpiration rates characteristic of Semillon is likely the result of high stomatal conductance rather than greater number of stomata per unit of leaf area.

Predawn leaf water potentials of Semillon vines were consistently more negative than other varieties. The inability of Semillon vines to recover during the night is likely due to high rates of cuticular transpiration. It was found that warm and windy nights resulted in more negative leaf water potentials. Diurnal variation in leaf water potential of Semillon vines was also investigated under drought conditions at Domaine de Couhins. Similar to our results, measurements of pre-dawn water potential showed instability of leaf hydration (Carbonneau and Ollat, 1991). It is possible that xylem embolism formation during drought stress and highly evaporative conditions was not repaired during the night. The consistently high sap flow and transpiration rates, however, would indicate that emboli do not restrict flow. For this reason, further work on xylem cavitation was not pursued.

Abscisic acid (ABA) is a long-distance stress signal produced by the roots and induces stomatal closure (Stoll et al., 2000; Hartung et al., 2002). We hypothesised that low levels of this plant hormone may explain the high transpiration rates of this variety. ABA in the xylem sap of Semillon vines were within range of the other nine varieties examined, however, and there were diurnal increases in ABA concentrations following VPD trends. Others found that concentrations of ABA in fully irrigated plants of Semillon was lower than in other cultivars, under water stress, however, concentrations of ABA were higher than in Chardonnay (Regina and Carbonneau, 1997). We also found that Semillon had slightly higher ABA levels than Chardonnay but this did not seem to result in tight stomatal closure. Stomatal conductance did decline with increasing VPD and lower soil moistures, and the magnitude of the decline was greater than for other varieties such as Grenache and Shiraz. The actual rates of conductance, however, were still consistently higher. Stomatal size, and aperture diameter, varied tremendously across the surface of a leaf for many of the varieties. Further work characterising stomatal structure may provide insights into the reasons for such high conductance.

In the field trial, there were no overall effects of vine water status on berry composition. This is likely because clone, vine age, fertilisation, soil type, pruning and summer trimming were confounding any interactions. In the Dryland site, however, berries on vines with more negative leaf water potentials were lower in TSS, dry weight, pH and higher in TA. The role of water stress on berry composition was also highlighted in the pot trial. With only two days of deficit irrigation during the post-veraison period, berry fresh weigh and dry weight were smaller and ripening was slowed with resultant lower berry titratable acidity and total soluble solids. The field survey did highlight the importance of shoot number and leaf area on berry pH. Larger canopies resulted in higher pH levels probably because increased carbon assimilation hastened ripening. There were good correlations with berry pH and total soluble solids, and between berry fresh weight and dry weight.

Estimates of vine water use vary widely and are difficult to quantify. Vineyard water requirements are greater than the vines themselves because a large proportion of water is lost through soil evaporation, cover crop transpiration and drainage. The amount of water applied to a block was often difficult to estimate by vineyard managers. Sap flow sensors have allowed, however, a better estimate of actual vine water use. Automatic monitoring of vine water status itself, similar to that used for soil moisture monitoring, would allow the grower to fine tune watering to vine requirements. Variations in canopy size within a block may be revealed through remote sensing. This, along with accurate weather forecasting to predict impending heat events, will potentially reduce the water stress symptoms that Semillon currently experiences in vineyards of NSW.

The use of mulches to decrease soil evaporation was trialled by Semillon growers in the Hunter Valley. Volunteer species were slashed and placed directly underneath the vines. This seemed to be an effective method for ameliorating water stress, however the cost of applying mulch may not have made this practise economically sustainable. A study on the effect of mulches on berry composition has recently been carried out (Dr. I. Chen, NSW DPI) and an integration of the outcomes with the results of this study is warranted.

7. Outcome/Conclusion

This work has increased awareness of the sensitivity of Semillon vines to irregular water supplies and heat events in the warm grape growing regions of Australia. Negative impacts include canopy damage and undesirable berry composition. In situations where high VPDs occur throughout the season, Semillon may not be an appropriate choice. The results of this study are not only applicable to NSW, but also to other regions in Australia experiencing drought and critical water shortages such as those from reduced Murray River flows.

The vineyard survey has increased awareness of the importance of appropriate irrigation to vine productivity. Irrigation was not of maximum benefit unless applied directly to the rootzone and with the least amount of evaporative loss from the soil surface. Continuous irrigation of vines grown on soils with low water holding capacity was costly and had negative environmental impacts such as soil salinification. High soil EC and Na also resulted in smaller canopies. Soil moisture monitoring allowed growers to apply water when required in the appropriate amounts.

The clonal/rootstock study indicated that there are clonal differences in susceptibility to water stress, and the rootstock used may aggravate or alleviate these symptoms. These pot-study results need to be extended to field trials to allow better informed decisions on appropriate combinations.

The adoption of farm technologies to improve irrigation scheduling, along with advances in weather forecasting, is providing the opportunity for irrigation responsive to daily changes in vineyard demands. Extreme heat events, for instance, can be predicted and irrigation can be appropriately adjusted if the water source is flexible. Similar fine tuning of irrigation to match to soil type, variety, vine age and canopy size is also achievable; but only if the water source is readily available.

Conclusions:

- Semillon was a high water user and did not have high transpiration efficiency
- High transpiration was a result of high stomatal conductance
- Transpiration efficiency was influenced by clone and the rootstock on which it was grafted
- Application of water to the principal root area was critical for maintaining vine water status
- Low soil moisture resulted in smaller canopies
- High salinity was an issue in some heavily irrigated field sites and resulted in smaller canopies
- Deficit irrigation resulted in smaller berries with negative impacts on berry composition

- ABA concentrations in the xylem sap were similar to other varieties and thus did not provide an obvious link to reasons for lack of tight stomatal closure

8. Recommendations

The following are recommended for Semillon growers:

- Precise soil moisture monitoring
- Frequent and flexible water source
- Apply water directly to the root zone
- Predict heat events
- Avoid regions with consistently high VPDs
- Avoid soils with low water holding capacity
- Avoid saline soils
- Avoid deficit irrigation strategies
- Use appropriate rootstocks
- Avoid N-S rows and exposure to Westerly sun
- Develop canopies that encourage leaf shading
- Reduce bunch exposure

It is recommended that the estimates for vine water use obtained in this research is incorporated into models such as VineLOGIC.

Appendix 1: Communication

Papers

Rogiers SY, Greer D, Hutton R, Somers T, and P Hutchinson. 2006. Managing Semillon's susceptibility to heat and drought. Australian and New Zealand GrapeGrower and Winemaker 515: 24-26.

Rogiers, SY, Hutton R, Greer DH, Somers T, and P Hutchinson. Xylem sap flow through Semillon grape vines grown under heat and water stress. Proceedings of the 6th international workshop on measuring xylem sap flow and its application to plant science. 27-30 November, 2006, Perth, WA

Rogiers, SY, Hutton R, Greer DH, Somers T. Water relations of Semillon vines. Grapevine Physiology and Biotechnology conference. November , 2008, Adelaide, SA.

Rogiers SY. Semillon water relations. Wagga Wagga Agricultural Institute, NSW Department of Primary Industries Annual update for 2007 and 2008.

Newsletters

Identifying Semillon's behaviour triggers. GWRDC 'R&D at Work' newsletter. January 2006.

The solution to Semillon stress. GWRDC 'R&D at Work' newsletter. Late 2008.

Radio

ABC radio, interview with Louise Fitzray, Mussel Brook. September 11, 2006.

Seminars

Greer DH, Rogiers, S.Y. Hutton R, Somers T. Existing and new research into Semillon vines. Riverina Wine Grape Marketing Board, Riverina Vineyard Field Day, September 7, 2006, Griffith, NSW.

Rogiers, S.Y. Hutton R, Greer DH, Somers T. The water relations of Semillon vines, a project update. Hunter Valley Vignerons Association, August 2007, Pokolbin, NSW.

Rogiers, S.Y. Hutton R, Greer DH, Somers T. Semillon, too optimistic for its own good. NSW Wine Industry Association and NWGIC Industry Advisory Board Meeting, November 12-13, 2007, Wagga Wagga, NSW.

Rogiers, S.Y. Hutton R, Greer DH, Somers T. Semillon, a variety from Bordeaux grown on the Riverina plains. National Wine & Grape Industry Centre, October 2008, Wagga Wagga, NSW.

Rogiers, S.Y. Hutton R, Greer DH, Somers T. Semillon vine water use: variety-specific water requirements. Riverina Wine Grape Marketing Board, VITT group, October 28, 2008, Griffith, NSW.

Appendix 2: Intellectual Property

Not Applicable

Appendix 3: References

Aasamaa, K, Sober, A & Rahi, M (2001) Leaf anatomical characteristics associated with shoot hydraulic conductance, stomatal conductance and stomatal sensitivity to changes of leaf water status in temperate deciduous trees. Aust. J. Plant Physiol. 28, 765–774.

Castillo Pando, M, Somers A, Green C, Priest M, Sriskanthades M (2001) Fungi associated with dieback of Semillon grapevines in the Hunter Valley of New South Wales. Australasian Plant Pathology 30: 59-63.

Carbonneau A and Ollat N. (1991) Instabilite de la rehydratation tardive des feuilles a l'amorce du regime de transpiration en situation de secheresse. Exemple de *Vitis vinifera* L. cv. Semillon. Journal International des Sciences de la Vigne et du vin. 25: 75-83.

Cirami R (1993) The Australian Grape Grower and Winemaker. Annual technical issue 1993, 150-151

Correia, M.J., Pereira, J.S., Chaves, M.M., Rodrigues, M.L. and Pacheco, C.A. 1995. ABA xylem concentrations determine maximum daily leaf conductance of field-grown *Vitis vinifera* L. plants. Plant, Cell and Environment. 18: 511-521.

Ewart A; Sitters J; and Cirami R (1994) The Australian Grape Grower and Winemaker. Annual technical issue, 76-80.

Gibberd M; Walker R; Blackmore D and Condon A (2001) Transpiration efficiency and carbon-isotope discrimination of grapevines grown under well-watered conditions in either glasshouse or vineyard. Australian Journal of Grape and Wine Research 7, 110-117.

Highet AS; Nair NG (1995) *Fusarium oxysporum* associated with grapevine decline in the Hunter Valley, NSW, Australia. Australian Journal of Grape and Wine Research 1: 1, 48-50.

Holzapfel, B., Smith, J., Mandel, R. and Keller, M. (2006): Manipulating the length and effectiveness of the post-harvest period and the impact on vine productivity of Semillon grapevines. Am. J. Enol. Vitic. 57, 148-157

Loveys, B.R. 1984. Diurnal changes in water relations and abscisic acid in field-grown *Vitis vinifera* cultivars III. The influence of xylem-derived abscisic acid on leaf gas exchange. The New Phytologist. 98: 563-573.

Loveys, B.R., Soar, C.J., Stoll, M. 2005. Root to shoot signalling and vine response to the environment. Proc. 12th Australian Wine Industry Technical Conference, Melbourne, Australia, 24-29 July 2004. p. 45-50.

Lovisolo C and Schubert A (1998) Effects of water stress on vessel size and xylem hydraulic conductivity in *Vitis vinifera* L. Journal of Experimental Botany 49: 693-700.

McCully ME, Huang CS, Ling LEC (1998) Daily embolism and refilling of xylem vessels in the roots of field-grown maize. New Phytologist 138: 327-342.

McGrath Kerr S. (2003) The National Winegrape Outlook Conference www.gwrdc.com.au/ downloads/ ResearchTopics/SMK%2099-1.pdf accessed 24/11/04

Mertens, R, Deus-Neumann and EW Weiler (1983) Monoclonal antibodies for the detection and quantification of the endogenous plant growth regulator, Abscisic acid. FEBS Lett. 160: 269-272.

Munsell book of color. 1976. Macbeth, a Division of Kollmorgen Corp., Baltimore, MD.

Peterson JR; Turkington CR; Evans JC (1974) Pruning and trellising trials with the Vitis vinifera cultivars Shiraz and Semillon under irrigated conditions. Australian Journal of Experimental Agriculture and Animal Husbandry. 14: 68, 418-424.

Rahman L, Sheare D, Somers T (2001) Australian Grapegrower and Winemaker 453: 22-25.

Regina M de- A; Carbonneau A (1996). Gas exchange in *Vitis vinifera* under water stress regime; 1: characterization of the variety behaviour. Pesquisa-Agropecuaria-Brasileira. 31: 12, 869-876.

Regina M de A; Carbonneau A (1997). Gas exchanges in *Vitis vinifera* under water stress regime; 3: abscisic acid and varietal behaviour. Pesquisa-Agropecuaria-Brasileira. 32: 6, 579-584.

Regina M de A; Carbonneau A (1999) Gas exchanges in grapevines under water stress regime; 2: photorespiration and varietal behaviour. Pesquisa-Agropecuaria-Brasileira. 34: 1, 37-43.

Regina M de A;Carbonneau A (1992) Giornate Piemontesi del IV Simposio Internazionale di Fisiologia della Vite, 14-15 Maggio 1992, Torino, Italy.

Schultz HR (2003) Differences in hydraulic architecture account for near-isohydric and anisohydric behaviour of two field-grown *Vitis vinifera* L. cultivars during drought. Plant, Cell and Environment 26, 1393-1405.

Schultz HR and Matthews MA (1992) Xylem development and hydraulic conductance in sun and shade shoots of grapevine (*Vitis vinifera* L.): evidence that low light uncouples water transport capacity from leaf area. Planta. 190: 393-406.

Scudamore Smith P, Oag D, Annard C and Zeppa A (1992) Australian and New Zealand Wine Industry Journal, 7: 99–103.

Stoll M, Loveys B and Dry P (2000) Hormonal changes induced by partial rootzone drying of irrigated grapevine. Journal of Experimental Botany 51: 1627-1634.

Tardieu, F. and Simonneau, T. 1998. Variability among species of stomatal control under fluctuating soil water status and evaporative demand: modelling isohydric and anisohydric behaviours. J. of Experimental Botany. 49: 419-432.

Tyree MT; Sperry JS (1988) Do Woody Plants Operate Near the Point of Catastrophic Xylem Dysfunction Caused by Dynamic Water Stress? Plant Physiology. 88, 574-580.

Zimmerman MH (1983) Xylem structure and the ascent of sap. Springer-Verlag, New York.

Appendix 4: Staff

The following group of people were instrumental in making this project run. I very much appreciate all their effort and enthusiasm!! Each component has been critical to the overall understanding of Semillon water relations.

Dr. Ron Hutton, Deputy Director, NWGIC – Sap flow analyses
Dr. Dennis Greer, Sr. Lecturer, Charles Sturt University- Gas exchange analyses
Paul Hutchinson (HUSSAT)- Soil moisture monitoring and weather stations
Tony Somers, Extension Officer, NSW Dept Primary Industries-Project initiation and extension activities

Simon Clarke- Stem hydraulic conductance, canopy area studies, leaf water potential, soil analyses and field work
Jo Hatfield- ABA method development and analyses
Sylvie Sicard-Equipment maintenance and all manner of laboratory and field analyses
Michael Lee-leaf water potential, gas exchange, harvest
Robert Lamont- Vine and soil sampling and analyses, vine maintenance
Gurlie Nielson- Stomatal density, membrane integrity and berry composition analyses
Helen Pan- Vine sampling
Angela Whitton- Berry composition analyses
Chris Haywood-Field harvests
Barbara Matthes-Accounts
Yvonne Elliott-Administration
Peter Carey-vine sampling and maintenance
Ned Sharkey-vine and root sampling
Campbell Meeks- soil moisture probe calibration, root sampling and berry composition
Brian Drechsler-vine maintenance