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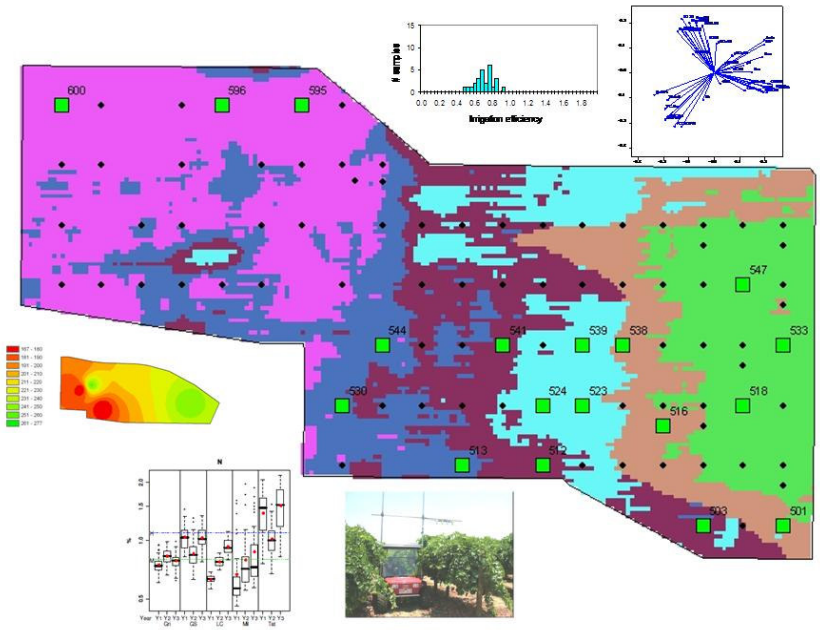
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Grape and Wine Research and Development Corporation

Managing Soil and Water to Target Quality and Reduce Environmental Impact



FINAL REPORT to

GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION

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Abstract

A comprehensive data set was compiled from measurements of soil properties, climate, management inputs and vine performance in 5 commercial vineyards across different climatic regions of Australia. Multivariate, spatial and temporal statistical techniques were applied to the data to (1) describe the variation in soil properties, vine performance and irrigation inputs; (2) explore the interaction of factors impacting on yield and quality of fruit and wine; (3) investigate resource use efficiency; and (4) determine the drivers of vine water use.

There was substantial variation in fruit and wine composition, yield and its components, vine size, soil physical and chemical properties and vine nutrition. The variation tended to be stable from year-to-year. Such variation is typical of vineyards and leads to inefficient resource use. There is opportunity to use this unique data set to highlight the extent of variation in resource use efficiency in vineyards (e.g. 10-fold difference in water use efficiency) and suggest new innovative approaches to overcome these inefficiencies.

The variation in wine composition within each of the 5-sites was correlated with vine size (measured by aerial imagery of normalised difference vegetative index, NDVI) but not soil electrical conductivity. This suggests that imagery data can be used more effectively than high density soil conductivity data (e.g. EM38) to differentiate wine quality, although care needs to be taken at sites with narrow hedgerows (i.e. VSP). Similarly, variation in berry composition (concentration of secondary metabolites and soluble solids) was negatively associated NDVI, crop load and berry size. The effects of soil physical and chemical properties (e.g. soil carbon and nitrogen) on wine and berry composition appeared to be expressed via their influences on NDVI and crop load. Irrigation emitter output varied substantially at some vineyards and was related to NDVI.

The variation in vine nutrition showed that there was frequent spatial autocorrelation and moderate-high temporal stability in N, K, Na, Ca, Mg and B suggesting that zonal management is an option to overcome deficiencies and toxicities and improve the efficiency of fertiliser use. Furthermore, positive linear relationships were found between N, K, Na and Mn concentrations in the petioles and fruit suggesting that the current practice of sampling leaf petiole provides a reliable estimate of nutrient levels in berries.

Vine water use was highly correlated with canopy light interception. A suitable tool was developed to estimate light interception by measuring the amount of shade cast by the vines (effective area of shade, EAS). Remote sensing of canopy temperature by thermography and infrared sensors provided a robust technique to measure variability in vine water stress. These and other methods were documented in a manual of technical protocols.

Spatial data collected during this project highlighted that future research needs to focus on optimising water and nutrient use efficiency in vineyards by matching irrigation to vine water requirement. Multivariate analysis of the data indicated that specific studies of soil C and N and berry Ca impacts on fruit and wine composition are needed. More detailed studies of harvest index and radiation use efficiency, particularly the effects of cool climates and the capacity to objectively set crop load are also needed.

Executive summary

There are many soil, climate and management factors that interact to determine vineyard yield and fruit composition. Traditional research has employed designed experiments to investigate the effects of a single factor on vine performance. This is achieved by varying the factor and observing the response. All other factors that influence vine performance are assumed to be constant thus avoiding confounding interactions. One or two additional factors may be incorporated into the experiment to observe the interaction between the factors but this is usually limited to a maximum of three factors. New knowledge generated from this approach has lead to significant improvement in wine grape production but there are still substantial gaps in understanding the drivers of yield and fruit composition.

An alternative approach was used in this project to improve our knowledge of the interaction of climate and soil characteristics with management and its impact on vine nutrition, growth, yield and fruit and wine composition. Multivariate, spatial and temporal statistical techniques were applied to a substantial and comprehensive data-set collected from 5 Shiraz vineyards (Langhorne Creek, Mildura, Griffith, Tatura and Great Southern). Data were collected over a 3-year period for the seasons 2005/06 (Y1), 2006/07 (Y2) and 2007/08 (Y3). At each site, data sets were compiled from: contiguous high resolution measurements of soil electrical conductivity and remotely sensed spectral properties; individual target vine measurements of yield, growth, berry composition, nutrition, soil physical and chemical properties, and irrigation inputs; zonal measurements of wine composition; block fertiliser and fungicide applications; and a single automatic weather station.

There was substantial spatial and temporal variation in fruit and wine composition, yield and its components, vine size, soil physical and chemical properties and vine nutrition. Variation in fruit secondary metabolites was consistently greater than 2-fold. Similar variation was observed in the wine. Yield was highly variable, exceeding 10-fold at most sites in each year. Variation in vine size was generally close to 2-fold, partially explaining some of the variation in yield. Variation in water use efficiency (t/Ml) and irrigation efficiency (water use per unit of applied irrigation) was greater than 4-fold. Such variation has large implications on drainage and fertiliser use efficiency.

Principle component analysis of vine vigour, soil physical and chemical properties and fruit composition showed that vigour, crop load and berry size were negatively associated with berry secondary metabolites, Brix and pH, and positively associated with berry acidity. The effects of soil physical and chemical properties (when present) appeared to be expressed via their influences on vigour and crop load. Often the soil physical and chemical properties had contrasting influences on vigour and berry composition.

Spectral and sensory analysis of wines showed that there was a negative relationship between NDVI and wine colour, phenolics and tannins across all sites except Tatura. There was a positive relationship between EM38 and wine colour, phenolics and tannins at Griffith and Langhorne Creek. These results suggest that imagery data can be used more effectively than high density soil conductivity data (e.g. EM38) to differentiate wine quality although care needs to be taken at sites with narrow hedgerows (i.e. VSP). During the project awareness increased with respect to the potential wine produced within a block at the sites and some growers considered differential harvesting or management. Future research needs to investigate how much variation is necessary before differential harvesting produces different wine potential and whether differential management can overcome variation in vine performance.

Wine colour and total red pigments were negatively related to soil nitrogen and soil carbon and positively related to soil salinity. This result, however, was only consistent across two of the five sites. Although the effect of soil carbon on wine properties is not consistent it potentially has significant implications for management practices that increase soil organic matter and for carbon sequestration in vineyard soils. Multi-variate analysis of the nutrition data showed that nutrients like Ca may impact on berry flavonoids. For example, berry Ca concentration accounted for a greater percentage of variance in tannins than berry weight and was a consistent model component in describing tannin and IRP concentrations. Future research needs to determine if this response is direct or indirect (through vine vigour).

Analysis of the nutrition data set showed that some nutrient levels in the vine remain relatively constant between years. The nutrients with frequent spatial autocorrelation and moderate-high temporal stability

were N, K, Na, Ca, Mg and B. Positive linear relationships were found between N, K, Na and Mn concentrations in the petioles and fruit suggesting that the current practice of sampling leaf petiole will provide an estimate of nutrient levels in berries.

Analysis of the components of soluble solids yield (Y_{SS}) from 3 years and across 5 sites showed that bunch number was the main determinant of yield. However, when the data was analysed for each site, berry number per bunch was the main determinant at Great Southern and Langhorne Creek. Furthermore, berry fresh weight contributed approximately 30 % to the variability in Y_{SS} at Griffith and Langhorne Creek but was negative at Tatura. The contribution of berry soluble solids concentration to Y_{SS} was negative at Great Southern and Tatura. At the hotter sites (Mil and Gri) crop load did not impact on berry soluble solids concentration whereas at Tat, GS and LC, berry soluble solids concentration decreased with increasing bunch number per vine.

Analysis of the yield data in terms of source and sink limitations was undertaken using an allometric model. The results suggest Y_{SS} was source limited at Tatura and Great Southern, and sink limited at Griffith and Langhorne Creek. Radiation use efficiency (RUE) was determined from the amount of radiation intercepted during the season and the soluble solids yield. There was considerable variation between sites and years, however, overall RUE approached 0.8 g/MJ solar radiation.

Detailed measurements of transpiration (using sap flow), canopy light interception, vine water stress and soil water content were made on a select subset of vines to develop simple approaches to estimate vine water requirements. A positive linear relationship was established between grapevine sap flow and the product of effective area of shade (EAS) and reference crop evapotranspiration (ETo). Such a relationship is fundamental for matching irrigation supply to vineyard water requirements. However, within-block variability in EAS and emitter rate, as clearly demonstrated by this project, limit the benefits of accurate irrigation scheduling. Further improvements in WUE would theoretically be made possible by appropriate irrigation system modification into smaller irrigation management units. Research regarding the actual benefits of such system modification is recommended.

Analysis of 15-minute air temperature data, soil physical and chemical properties, and fruit composition has not provided any clear effects of root zone constraints and transient periods of heat stress on fruit composition. The analysis of this data set is continuing. The limitation here is that the root zone constraints can not be well defined without a sound knowledge of root distribution which is not currently available.

The on-ground measurement of canopy temperature during this project by either infrared sensors or a thermal camera clearly identified that this technology can be used to assess spatial and temporal variation in vine water stress. A set of sensors mounted on a farm vehicle or an aerial thermal image taken from a blimp were both able to discriminate between grapevines supplied with different levels of irrigation. Such an approach provides a measure of the spatial variability in vine water stress. Results from Mildura clearly showed distinct areas within a vineyard that were water stressed.

There is some potential for using canopy temperature measurements to aid irrigation scheduling, however, this approach requires further development. A number of difficulties associated with temporal measurement of canopy temperature and with the chosen sensors were recognised during the project. These problems were systematically addressed, primarily through the adjustment of equipment set-up configurations and data processing.

Technical notes on EAS, spatial sampling for nutrition, and irrigation management were published during the project. The measurement techniques used to collect data at each site were compiled into a manual of technical protocols. The manual was used by technicians at each site to adhere to measurement guidelines so that there was consistency in the data. This approach proved particularly useful for a multi-agency and geographically distributed project.

Spatial data collected during this project highlighted that future research needs to focus on stabilising water and nutrient use efficiency in vineyards by matching irrigation to vine water requirement. Multivariate analysis of the data indicated that specific studies of soil C and N and berry Ca impacts on fruit and wine composition are needed. More detailed studies of harvest index and radiation use efficiency, particularly the effects of cool climates and the capacity to objectively set crop load are also needed.

The substantial and comprehensive data set collected during this project will continue to provide new innovative concepts for soil and water management to hit quality targets and reduce environmental impact were proposed. Project staff are continuing to process and communicate the results to scientific peers.

The '5-site' concept of collecting spatial and temporal data combined with a multi-agency approach provided a conduit for collaboration between personnel with different scientific expertise. Not only did this add a greater level of scientific rigour to investigation pathways but it also served as a means of developing a collaborative culture not normally available though a series of smaller projects.

Background

Soil and water management to hit quality targets and reduce environmental impact is critical for the Wine Industry to maintain its international competitiveness. Management needs to be economically justified, environmentally sustainable and potentially flexible for rapid adjustment to changing markets and weather conditions. Decision-makers must be confident that management changes will modify vine performance to meet specifications of yield and quality.

Growing wine grapes to meet market specification is complex. Each vineyard experiences its own unique set of soil and climatic conditions that shape its performance. Superimposed upon the inherent soil and climate conditions is management, where soils are modified and water and nutrients are applied to enhance or suppress the soil and climate factors that determine yield and fruit composition. Management intervention is based on many published research studies that have traditionally employed designed experiments to investigate the effects of one or two factors on vine performance. Factors were varied and the response was measured. All other factors that influence vine performance were kept constant to avoid confounding.

An alternative approach was used in this project to improve our knowledge of the interaction of climate and soil characteristics with management and its impact on vine nutrition, growth, yield and fruit and wine composition. Temporal and spatial data were collected from 5 Shiraz vineyards across Australia. Multi-variate statistical methods were used to explore relationships between soil chemical and physical properties, vine nutrient status, climate, management inputs, vine growth, yield and fruit and wine composition. Data collected to explore these interactions was also used to test specific hypotheses.

Project aims and performance targets

1. To better define the key drivers of vine performance by:
    a. Quantifying and describing the spatial and temporal variation in vine parameters (yield, growth, composition, water stress and nutrition), management inputs (irrigation, fertiliser, training system) and environment variables (climate, soil) in 5 vineyards in viticultural regions across Australia.
    b. Establishing relationships between vine parameters, management inputs and environmental variables using spatial statistical methods.
2. To use the spatially described sites to:
    a. Investigate the sensitivity of yield to variation in canopy radiation interception, crop load and water stress.
    b. Determine the relationship between vine water use, canopy light interception and water stress.
    c. Investigate the interaction of root zone constraints and transient periods of heat stress on fruit composition.
    d. Investigate the relationship between soil and vine nutrition and fruit composition
    e. Investigate and compare the potential of airborne thermal imagery and ground-based measures of foliage infra-red (IR) temperature to describe spatial patterns of water stress across grapevine canopies and whole vineyard blocks (PhD project)
3. To develop and provide information on improved soil and water management practices based on project results.
4. To capture innovative measurement techniques that may be used by the Winegrape Industry to improve vine performance.
5. To develop new project proposals to test hypotheses derived from the results of this project.
6. To provide the basis for development of a GWRDC Soil and Water Initiative nutrition project.

2004-05

Outputs	Performance Targets
1. Set up and manage sites for collaborative research	Negotiate and establish 3 vineyard sites. Discuss potential site/data sharing arrangements with other researchers.
2. Initial database of management inputs, weather data and spatial variability in yield and its	Collect and analyse. Contribute to data sharing arrangement on website.

components, EM38, elevation, NDVI, and fruit composition	
3. Investigate techniques to assess canopy temperature (water stress indicator) using remote IR technology	Purchase, set up and test instruments for spatial and temporal measurement of canopy temperature.
4. Investigate techniques to measure bunch and berry temperature	Establish protocol for spatial and temporal measurement of bunch and berry temperature.

2005-06

Outputs	**Performance Targets**
1. Data/site information exchange with collaborators	Meet with collaborators in other S&W projects to present baseline results, and discuss spatial and temporal analysis techniques and data sharing.
2. Data sets across 5 sites of management inputs, weather data and spatial variability in yield and its components, EM38, elevation, NDVI, light interception, canopy temperature (if technique successful) and fruit composition	Establish another 2 sites, collect and analyse data across all 5 sites
3. Data sets of spatial variability in vine nutrition (in particular nitrogen) at select site(s) determined with collaborators in Soil and Water Initiative (Dr Ben Robinson)	Collect and analyse (via commercial laboratory) veraison petiole samples
4. Data sets across 3 sites (04/05 sites) on spatial variability in soil characteristics	Intensive soil sample and analysis of EC (1:5), pH, physical and chemical properties (using MIR)
5. Wines made from zones within sites	Make wine from different zones that represent spatially different characteristics in environment and vine performance. Appropriate sites negotiated with wine companies.
6. Data sets on temporal variation in fruit temperature for select vines	Set up loggers and sensors to measure bunch and berry temperature
7. Determine calibration function for conversion of sap flow to vine transpiration	Purchase sap flow equipment and calibrate using the cut-tree method in collaboration with Dr Steve Green
8. Data set of vine water use, light interception and vine water stress for select vines	Establish initial relationship between vine water use and effective area of shade
9. Initial relationships established	Commence rigorous statistical analysis of data sets to test known and develop new relationships
10. Article in industry journal	One article published by June 2006
11. Soil nutrition data sets from the 5 regional sites	Intensive soil cores taken in the vine and mid row to 1 m depth and analysed (commercial laboratory) for C, N, P, K, S, cations, Cu, Fe, Mn and Zn
12. Vine nutrition data sets from the 5 regional sites	Collect and analyse (via commercial laboratory) petiole and leaf blade samples at flowering and veraison for macro and micro elements, and trunk samples in winter for %N and %C
13. Grape berry total phenolics and juice nitrogen data sets from the 5 regional sites	Collect berry samples at harvest for analysis of total phenolics (DPI laboratories) and juice nitrogen (via commercial laboratory)
14. Field experiments established (PhD)	Field site established and preliminary measurements taken in collaboration with project staff

2006-07

Outputs	**Performance Targets**
1. Data/site information exchange with collaborators	Meet with collaborators in other S&W projects to present relationships and their impact on soil and water management

2. Data sets continued across 5 sites of management inputs, weather data and spatial variability in yield and its components, NDVI, light interception, canopy temperature (if technique successful) and fruit composition	Collect and analyse data across all 5 sites
3. Data sets of spatial variability in vine nutrition (in particular nitrogen) at select site(s) determined with collaborators in Soil and Water Initiative (Dr Ben Robinson)	Collect and analyse (via commercial laboratory) veraison petiole samples
4. Complete data sets across 5 sites on spatial variability in soil characteristics.	Intensive soil sample and analysis of EC (1:5), pH, physical and chemical properties (using MIR)
5. Wines made from zones within sites	Make wine from different zones that represent spatially different characteristics in environment and vine performance. Appropriate sites negotiated with wine companies.
6. Data sets continued on temporal variation in fruit temperature for select vines	Collect and analyse data
7. Data sets continued on vine water use, light interception and vine water stress for select vines	Establish relationship between vine water use and effective area of shade
8. Workshop at 2 sites on improving irrigation scheduling from vine water use estimates	Run 2 workshops that encompass results from vine water use data
9. Vitinotes on techniques to measure factors that influence vine performance	Electronic publication of Vitinotes by June 2007
10. New knowledge on vine water use, light interception and water stress	Draft paper complete by June 2007
11. Vine nutrition data sets from the 5 regional sites	Collect and analyse (via commercial laboratory) petiole and leaf blade samples at flowering and veraison for macro and micro elements, and trunk samples in winter for %N and %C
12. Grape berry total phenolics and juice nitrogen data sets from the 5 regional sites	Collect berry samples at harvest for analysis of total phenolics (DPI laboratories) and juice nitrogen (via commercial laboratory)
13. Vine nutrition funding proposal developed with CSIRO Merbein	Proposal submitted to investors
14. Literature reviewed (PhD)	Draft literature review on techniques to measure foliage temperature and its relationship to plant function

2007-08

Outputs	**Performance Targets**
1. Data/site information exchange with collaborators	Meetings/interactions/trial set-ups.
2. Data sets continued across 5 sites of management inputs, weather data and spatial variability in yield and its components, NDVI, light interception, water stress and fruit composition	Collect and analyse data across all 5 sites
3. Data sets continued across 5 sites on temporal variation in fruit temperature for select vines	Collect and analyse data
4. Wines made from zones within sites	Make wine from different zones that represent spatially different characteristics in environment and vine performance. Appropriate sites negotiated with wine companies.
5. Funding proposals developed to test hypotheses using highly-replicated field experiments	Proposal submitted to investors
6. Vine nutrition data sets from the 5 regional sites	Collect and analyse (via commercial laboratory)

	petiole and leaf blade samples at flowering and veraison for macro and micro elements, and trunk samples in winter for %N and %C
7. Grape berry total phenolics and juice nitrogen data sets from the 5 regional sites	Collect berry samples at harvest for analysis of total phenolics (DPI laboratories) and juice nitrogen (via commercial laboratory)
8. Wine composition data from the 5 regional sites	Wine composition analysis for traits suspected of relating to vine nutrition

2008-09

Outputs	Performance Targets
1. Improved knowledge of soil and water management that allows winegrape growers to improve their ability to meet specifications	Published/upgrade booklet on soil and water management guidelines in collaboration with other projects in the Soil and Water Initiative
2. New knowledge on the effects of soil and water management on grape and wine composition	Publish results in scientific journals
3. Final Report	Final report submitted by June 2009
4. Improved knowledge of nutrition management that allows winegrape growers to improve their ability to meet specifications	Publish/upgrade Vitinotes on nutrition standards and sampling procedures in collaboration with other projects in the Soil and Water Initiative
5. Airborne thermal imagery, ground-based canopy temperature and leaf conductance data sets (PhD)	Simultaneously collect airborne thermal imagery and ground-based measures of canopy temperature and leaf conductance to assess spatial and temporal variation in water stress. Compile and analyse data using regression techniques
6. Soil water content; trunk, cordon and cane shrinkage; and leaf temperature data sets.	Collect continuous data of soil water content; trunk, cordon and cane shrinkage; and leaf temperature. Compile data and compare methods to measure water stress.
7. Draft chapters in thesis (PhD)	Complete 3 draft chapters in thesis using the data collected on thermal imagery and water stress
8. Draft scientific papers (PhD)	Complete 2 draft scientific papers

Materials and methods

Study sites

The study sites were commercial drip irrigated Shiraz (*Vitis vinifera*) vineyards in the Langhorne Creek (LC; 35.33° S 138.98° E), Mildura (Mil; 34.42° S 142.28° E), Griffith (Gri; 34.25° S 146.21°), Tatura (Tat; location confidential) and Great Southern (GS; 34.39° S 116.95° E) regions of southern Australia. Sites ranged in size from 6.4 to 16 ha (Table 1). Data were collected over a 3-year period for the seasons 2005/06 (Y1), 2006/07 (Y2) and 2007/08 (Y3).

At each site spatial and temporal data sets of vine performance, management inputs and environmental conditions were compiled from:

- individual target vine measurements of yield, growth, berry composition, nutrition, soil properties and irrigation inputs
- contiguous high resolution measurements of soil electrical conductivity and remotely sensed spectral properties
- zonal measurements of wine composition
- block fertiliser and fungicide applications
- a single automatic weather station

Table 1. Basic description of the vineyard sites.

Site	Size (ha)	Row spacing (m)	Vine spacing (m)	Row orientation	Pruning method	Training system
LC	6.8	3	1.8	N – S	Hand 2-bud spurs	VSP Bilateral cordons
Mil	6.4	3	2.4	E – W	Mechanical	Minimal pruned 2 bilateral cordons (vertically separated)
Gri	12.3	3.3	1.8	NE – SW	Mechanical + hand clean-up ~4-bud spurs	Minimal pruned 2 bilateral cordons (vertically separated)
Tat	16.0	3	1.8	N – S	Hand 2-bud spurs	VSP Bilateral cordon
GS	6.8	3.6	1.8	E – W	Hand 2-bud spurs	VSP Bilateral cordon

The selection of target vines required a unique process. Not only did the target vines need to capture the natural variation within each block but they also needed to allow for relationships to be tested. This required that extreme values be equally represented in the collected data as average values. To do this a statistical method was developed to select sampling locations. This method utilised k-means standardised clustering (SAS 2002) to summarise soil and plant variation concurrently from 10 m kriged soil (e.g. EM38) and vine (e.g. aerial imagery) data. Standardised *k*-means clustering is a non-hierarchical method of data aggregation that maximises the difference between cluster means and minimises the variation within each cluster. Table 2 summarises the data used for each site. These data were clustered into five zones. The number of vines selected within each cluster was determined by the standard deviation of the cluster and the size of the cluster. This standard deviation method resulted in a 24 % larger spread of data than using a coarse regular grid that would normally be applied. The extra spread increased the chance of quantifying relationships between soil characteristics, climate and management practises on crop quantity and quality.

Yield components, pruning weights, shoot number, bud number, butt circumference, berry composition, soil physical properties, phenology, and irrigation application rate were measured at 100 target vine locations. Light interception, and berry, vine and soil nutrient levels were measured at 40 target vine

locations. Soil moisture was measured at 4 target vine locations at all sites apart from Tatura where it was measured at 5 target vine locations. Sap flow was measured at 5 target vine locations at Tatura.

Table 2. Summary of the data used for target vine selection at each site. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Site	Soil	Vine
LC	EM38	Yield
Mil	EM38	Yield
Gri	EM38	Satellite imagery
Tat	EM38	Aerial imagery
GS	Gamma-ray spectrometry	Trunk diameter

Wine was made from fruit sampled within six zones determined by standardised k-means cluster analysis of apparent electrical conductivity using EM38 (LC, Mil, Gri, Tat) and gamma-ray spectrometry (GS), and plant cell density (PCD) derived from aerial imagery (LC, Mil, Gri, Tat, GS) (Fig. 1a). The k-means cluster technique maximises the difference between zones whilst minimising the variation within each zone for both soil and vine properties measured. The variation between zones and between sites is shown in Table 3. The magnitude of the variation are comparable for the Mildura site, whereas for the Langhorne Creek and the Frankland Valley sites the magnitudes of soil variation were considerably greater than those of the vine property. Three areas within each zone were selected for the collection of fruit at harvest in close proximity to target vines.

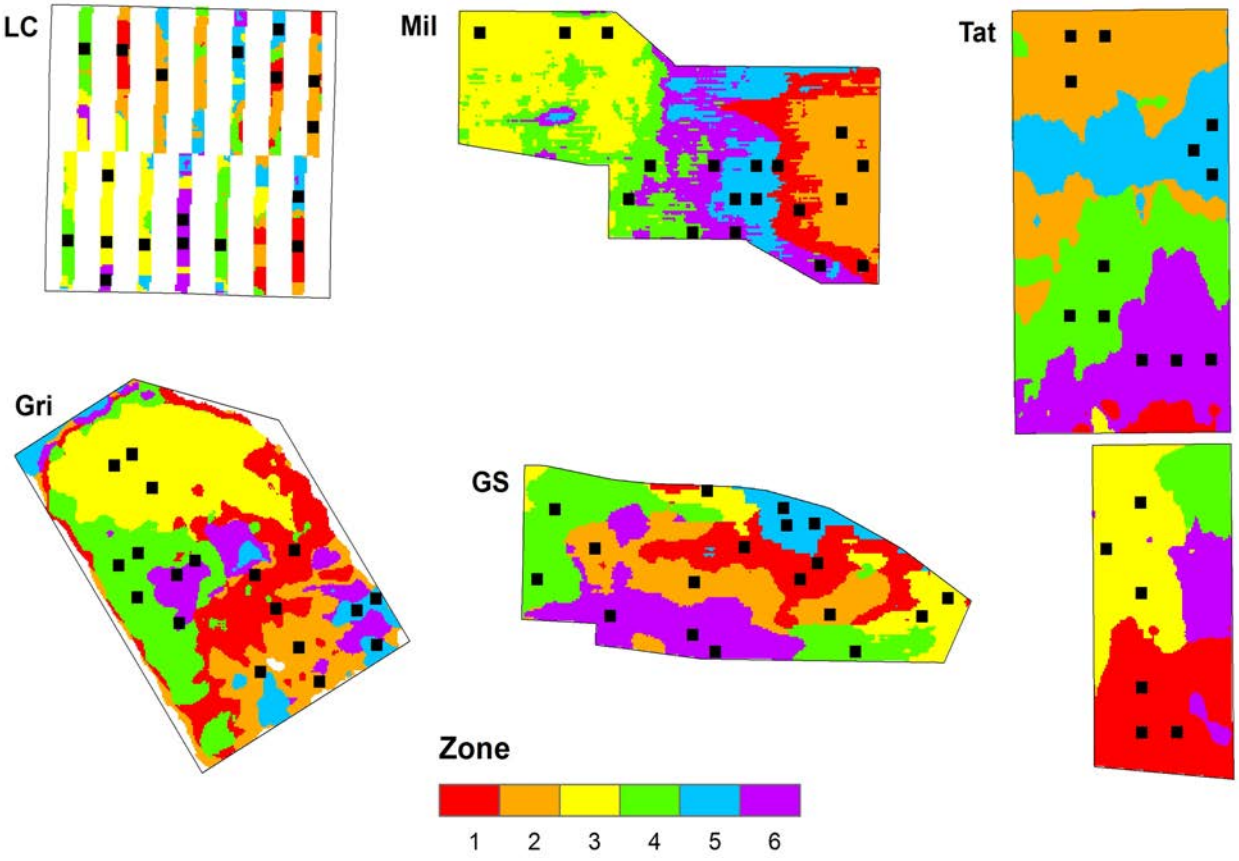


Fig. 1a. Resultant zones after standardised k-means clustering of soil and vine data for sites at Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS). Sampling locations within each zone are also shown.

Table 3. Relative variation in soil (either by EM38[+] or GRS[*]) and vine properties (PCD[^]) between each zone at Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Site	Property	Zone						%V[#]
		1	2	3	4	5	6	
LC	EM38	136	121	74	102	99	68	100
	PCD	89	102	97	90	108	115	29
Mil	EM38	107	113	93	93	100	95	22
	PCD	104	95	85	94	117	106	38
Gri	EM38	96	101	91	95	114	104	25
	PCD	101	88	117	107	87	101	34
Tat	EM38	111	91	107	97	91	102	23
	PCD	83	119	109	98	100	91	43
GS	GRS	91	124	68	97	71	149	119
	PCD	107	103	95	85	119	91	40

+ EM38 is electromagnetic induction
* GRS is gamma-ray spectrometry
^ PCD is plant cell density, a ratio of near infrared and red reflectance, calculated from aerial imagery
# %V is the percentage variation between the lowest and highest value between zones

Climate parameters

Short-wave solar radiation (Rs), air temperature (T_a), relative humidity (RH), wind speed and rainfall were measured in automatic weather stations located at LC, Tat and GS sites. Weather data from the Griffith CSIRO meteorological station was used for Gri and a combination of Bureau of Meteorology data from Carwarp (station number 76005) and the Lower Murray Water Group weather station at Nangiloc was obtained for Mil.

Technical details of the instruments and the sighting of the stations can be found in Appendix 5.

Soil sampling and analysis

Duplicate soil samples at each target vine location were taken 0.2 m from the irrigation emitter at 0-0.1, 0.15-0.25, 0.35-0.45 and 0.7-0.8 m depth increments. Duplicate samples were combined for analysis. Soil electrical conductivity (1:5), pH (in water and $CaCl_2$), chloride, clay/silt/sand, bulk density and the volumetric water content were determined for 100 target vine locations at each depth increment. Total C, total N, exchangeable Ca, exchangeable Mg, exchangeable K, exchangeable Na, cation exchange capacity, exchangeable sodium percentage, P, K, S, Cu, Fe, Mn, and Zn were determined for 40 target vine locations at 0-0.1, 0.15-0.25 m depth increments.

Samples were analysed by CSIRO Analytical Services, Adelaide Laboratories. Soil electrical conductivity, pH (in water and $CaCl_2$) and chloride were determined using a 1:5 soil:water extract following the procedure of Rayment and Higginson (1992), EC and pH of the extract were determined using a pH meter (Orion 940, Thermo Fisher Scientific Inc., Waltham, MA, USA) and an EC meter (CDM230, Radiometer Analytical SAS, Lyon, France). Chloride was determined using an automated colorimetric method (APHA, 2005 – method 4500-Cl^- E). Particle size analysis, bulk density and volumetric water release characteristics were determined by mid-infrared spectroscopy using the global calibration data set (Janik et al., 2007). Total N (%) and total C (%) were determined by high temperature combustion in an atmosphere of oxygen (CNS2000, LECO Corporation, St Joseph, Michigan, USA). Total N was measured as N_2 by thermal conductivity detection and total C was measured as CO_2 by a non-dispersive infrared detector (AOAC International, 1995; Matejovic, 1996). Exchangeable cations, cation exchange capacity, P (%), K (%), S (%), Al (mg/kg), B (mg/kg), Cu (mg/kg), Fe (mg/kg), Mn (mg/kg), and Zn (mg/kg) were determined using the methods detailed in Rayment and Higginson (1992). Specifically, exchangeable cations were determined using NH_4Cl solution at either pH 7.0 or pH 8.5 dependent on soil pH, Exchangeable cations Ca, Mg, Na and K were analysed by Flame Atomic Absorption Spectrometry (906AA, GBC Scientific Equipment Pty. Ltd., Melbourne, Australia) and cation exchange capacity ammonium and chloride were determined using segmented flow colorimetry. Soil P and K was extracted using Colwell 1 M $NaHCO_3$ at pH 8.5 and analysed by segmented flow colorimetry. Soil S was extracted using 0.1 M $Ca(H_2PO_4)_2$ at pH 4.0 and analysed by inductively coupled plasma optical emission spectrometry (SPECTRO ARCOS, SPECTRO Analytical Instruments, Kleve, Germany). Soil Cu,

Fe, Mn, and Zn were extracted using DTPA extracting solution [0.005 M DTPA (diethylenetriamine penta-acetic acid), 0.01 M $CaCl_2$ and 0.10M triethanolamine] in a soil solution ratio of 1:2. Cu, Fe, Mn and Zn were analysed by inductively coupled plasma optical emission spectrometry (SPECTRO ARCOS, SPECTRO Analytical Instruments, Kleve, Germany).

Soil electrical conductivity (EM38) and gamma radiometrics

Apparent soil electrical conductivity data were collected from four sites (LC, Gri, Mil and Tat) using an electromagnetic induction sensor (EM38, Geonics, Mississauga, Ontario, Canada). Spatial position and EM38 data in the vertical and horizontal dipoles were collected simultaneously. EM 38 surveys of each block were conducted on every other row travelling at approximately 2 m/s with data acquisition set at 1 Hz. Similarly, at the GS site, spatial position and gamma radiometric data were collected simultaneously. Gamma radiometric data was collected using a gamma spectrometer (MCA-2100R, Princeton Gamma-Tech Inc., Rocky Hill, NJ) by a commercial company (Baigent Geosciences, Banjup, WA, Australia). Data pre-processing, using in-house protocols, determined specific radiometric data for potassium, uranium, thorium and total counts. Both the EM38 and the gamma radiometric data were use to create maps of apparent soil electrical conductivity and radiometric properties.

Irrigation inputs

Irrigation input for each target vine was calculated from emitter flow rate and irrigation volume applied to a row of vines. Emitter flow rate within the immediate vicinity of each target vine was measured at least once at each site during the project. Irrigation volume was determined from electronic water meters installed in a lateral and a data logger recording flow at 15 minute intervals. Irrigation input per vine was determined by weighting irrigation volume by actual emitter flow rate divided by the average emitter flow rate. The irrigation system at the Mil and GS sites was set up to irrigate two separate blocks, and the Tat site was set up to irrigation three separate blocks. Water meters were installed in each of these blocks.

Emitter flow rate was measured by holding a collection vessel under a dripper and collecting water for a set time (e.g. 20 sec). The weight of the water collected in the vessel was measured to determine flow rate. Measurements were made at Gri in Y2 and Y3, Mil in Y3, LC in Y3, Tat in Y1-Y3 and GS in Y2. Calculation of irrigation input at Mil, LC and GS assumed emitter flow rate remained constant between years, and rates in Y1 at Gri were identical to Y2. Details of the method to measure emitter flow rate can be found in Appendix 5.

Irrigation efficiency (IE) was calculated from:

$$IE = \frac{I}{EAS \times ET_o} \quad (1)$$

where I was the irrigation amount (mm), EAS was the effective area of shade and ET_o was reference crop evapotranspiration (mm).

Water use efficiency (WUE) was calculated from:

$$WUE = \frac{Y}{I_{BB\text{-}H}} \times 100 \quad (2)$$

where Y was the yield per vine (t/ha) and $I_{BB\text{-}H}$ was the irrigation amount applied from bud burst to harvest (mm).

Soil matric potential

The measurement of soil matric potential was undertaken using gypsum blocks installed at 5 depths (10, 25, 45, 80 and 150 cm) in the soil profile. Four of the gypsum blocks at depths ranging from 10-80 cm were measured continuously with a GBug that was downloaded every 20 days using a MEA Retriever. A fifth gypsum block was installed at 150 cm depth at all sites apart from GS and measured manually every 20 days with a GBReader. Soil matric potential was measured at 4 target vine locations at all sites apart from Tatura where it was measured at 5 target vine locations. Details of the installation and measurement procedure can be found in Appendix 5.

Sap flow

Sap flow was measured using the Tmax method (Green et al., 2003). Sap flow sensors (Tranzflo, Palmerston North, New Zealand) were installed in four grapevines at each of five locations within the Tat site in Y1, Y2 and Y3. The sensor units consisted of two temperature sensor probes and one heater probe. Each temperature sensor probe contained three thermocouples embedded in plastic tube at depths of 5, 10 and 15 mm. The heater probe was installed in the vine trunk at approximately 0.7 m above the soil surface. The sensor probes were installed in the vine trunk at 125 and 400 mm above the heater probe. The heater probe was turned on for 2 s every 30 min and the time taken to reach the maximum temperature difference (Tmax) between each of the three thermocouple pairs was logged (CR10X logger, Campbell Scientific, Inc., North Logan, Utah, USA). Sap velocity was calculated using a wound diameter of 2.0 mm and a volumetric wood and water content of 0.35 and 0.50, respectively, according to Green et al. (2003). Sap velocity was converted to sap flow (L/h) using trunk circumference and sensor depth to determine the cross-sectional area of sapwood accounted for by each thermocouple. Sap flow for each location was calculated to be the average sap flow of the four instrumented vines. Daily total sap flow was calculated from midnight to midnight and converted to mm/day by adjusting for the planting area (5.4 m^2).

Effective area of shade (EAS) of vines instrumented with sap flow sensors was measured regularly in Y2 and Y3.

Plant tissue sampling and analysis

Plant nutrition data was collected for Y1, T2 and Y3 from 40 target vines at each site. Leaf petiole and blade samples were collected at flowering (approximately 50% cap fall) and veraison. Samples were analysed for total N, P, K, Ca, Mg, Na, S, Al, B, Cu, Fe, Mn, and Zn. Cane samples were taken at the end of season in Y2 and Y3 and analysed for total N and total C.

Samples were analysed by CSIRO Analytical Services, Adelaide Laboratories. Total N (%) and total C (%) were determined by high temperature combustion in an atmosphere of oxygen (CNS2000, LECO Corporation, St Joseph, Michigan, USA). Total N was measured as N_2 by thermal conductivity detection and total C was measured as CO_2 by a non-dispersive infrared detector (AOAC International, 1995; Matejovic, 1996). P (%), K (%), Ca (%), Mg (%), Na (%), S (%), Al (mg/kg), B (mg/kg), Cu (mg/kg), Fe (mg/kg), Mn (mg/kg), and Zn (mg/kg) were determined by inductively coupled plasma optical emission spectroscopy (SPECTRO ARCOS, SPECTRO Analytical Instruments, Kleve, Germany) following tube block sample digestion with nitric acid at 140°C for eight hours (Zarcinas and Cartwright, 1983; Zarcinas et al.,1983).

Details of the sampling, processing and analysis methods can be found in Appendix 5.

Phenology

Spatial variation in phenological development was determined at each site. The phenological stages of budburst, flowering, veraison and leaf-fall were assessed for every target vine on the same date at one site.

Evaluation of budburst involved classifying each bud on the target vines as burst or unburst and then calculating a percentage budburst. Evaluation of flowering and veraison involved assessing clusters (inflorescences at flowering and bunches at veraison) on randomly selected shoots on the target vines. Each tagged inflorescence (and bunch) was scored from 0 to 5. Leaf-fall was assessed prior to vines losing the majority of their leaves and involved a visual assessment of the entire vine using a score from 0 to 5. Details of the procedure can be found in Appendix 5.

Spectral data

Aerial spectral imagery data of each site were captured using a digital multi-spectral camera (High Resolution Airborne Multispectral System, SpecTerra Services Pty Ltd, Perth, WA, Australia) flown onboard a Cessna 206 at 1800 m (above ground level) provided by a commercial company (SpecTerra Services Pty Ltd, Perth, WA, Australia). The tracking and image capture timing was controlled using a global positioning system (296 Garmin, Olathe, KS, USA) with pre-planned flight lines. Spectra data were

captured simultaneously at four spectral bands of 20 nm bandwidth centred at 450 (Blue), 550 (Green), 675 (Red) and 780 (NIR) nm at a spatial resolution of 0.5 m resulting in an individual frame size of 1 km^2. Data pre-processing (band-to-band registration, radiometric correction for removal of vignetting and bi-directional reflectance distribution effects, and geo-referencing) was carried out by SpecTerra services using in-house software (Frank Honey, Pers. Comm.). The pre-processed data were used to create maps of several vine vigour indices: plant cell density (PCD, also called ratio vegetation index) calculated as NIR/Red; normalised difference vegetation index (NDVI) calculated as (NIR-Red)/(NIR+Red); and vigour (also called green red ratio) calculated as Green/Red. Vine and non-vine material were determined using SpecTerra services in-house software (Frank Honey, Pers. Comm.). Surfaces were created for both vine only data and using all data (vine plus non-vine). Map surfaces of high and low vigour areas were then ground-truthed against visual observation of vine size in each block.

Light interception

Canopy photosynthetically active radiation (PAR) interception was measured three times per day at regular intervals throughout Y2 and Y3 seasons on 40 target vines at each site. Measurements of PAR were taken over the planting square below the canopy, and in full sun using a ceptometer. The ratio of these two measures provides fractional canopy PAR interception (fPAR). Effective area of shade (EAS) was calculated as the average of fPAR measured at solar noon and solar noon ± 3 h. Effective canopy cover (ECC) is equivalent to fPAR at solar noon. Details of the method can be found in Appendix 5.

Shoot number, pruning weight, cordon length, bud number and butt circumference

The number of shoots greater than 10 cm was counted, pruned and then weighed on each of the 100 target vines. Shoot number and pruning weight corresponded to the same distance over which yield was determined by hand harvesting. For example, if vine bunches were picked, counted and weighed from 50 cm to the side of the vine trunk, then shoots were counted and pruned over the same distance.

Vines were pruned according to the directions of the vineyard managers. Machine pruned vineyards (Mildura and Griffith) were hedged by hand to the approximate dimensions of the machine. Wood removed later when the vines were cleaned-up was assumed to be negligible.

Cordon length, bud number and trunk circumference were determined after pruning on each of the 100 target vines. All viable buds (including obvious basal buds on spur-pruned vines) on one-year-old wood (spurs and canes) were counted. Trunk circumference was measured at the same position each year (by marking with paint) approximately 30 cm above ground level between two nodes and above the graft union. Loose bark was removed prior to making the measurement.

Yield components

Bunch number, total fresh weight and average berry weight were measured on each of the 100 target vines immediately prior to commercial harvest. Bunches were removed, counted and weighed. A 'bunch' included unripe fruit, desiccated bunches, and cluster of fruit with only a couple of berries. In the hot climate locations (Mil and Gri) a 50 cm section of the target vine was harvested. The 50 cm section was located to one side of the vine centred at the mid-point of the cordon (i.e. not straddling the trunk). In the warm climate areas (Tatura and Langhorne Creek) the entire target vine was harvested. At Great Southern, fruit was harvested from a 180 cm section (i.e. from midway between adjoining vines).

After weighing, a representative sample (30 bunches) of the harvested bunches was removed to determine average berry weight and fruit composition. From each bunch approximately ¼ of the berries were removed. The position in the bunch from which the berries were removed alternated between the top half and the bottom half of the bunch, removing all berries from the right portion of the top or bottom half. This was to ensure that a selection of berries was obtained from the top to the bottom, the inner and outer, and the sun exposed and shaded portion of the bunches. A random sub-sample of 150 berries was taken and weighed to determine average berry weight and was then frozen and kept for analysis of tannins, anthocyanins, phenolics, total N, total C, P, K, Ca, Mg, Na, S, Al, B, Cu, Fe, Mn, and Zn. The remaining berry sample was kept in cool-storage and used, as soon as possible, for measurement of total soluble solids, titrable acidity, pH, total N and chloride.

Details of the above harvest and sampling procedures can be found in Appendix 5.

Berry composition

Harvest berry juice total soluble solids (TSS), pH and titratable acidity (TA), and whole berry tannin, anthocyanin, phenolic, total N, total C, P, K, Ca, Mg, Na, S, Al, B, Cu, Fe, Mn, and Zn concentrations were measured at harvest in Y1, Y2 and Y3 on 100 target vines. Berry juice total N and Cl concentrations were measured at harvest in Y2 and Y3 on 40 target vines.

Berry juice TSS (°Brix i.e. g sucrose equivalents/g berry juice expressed as %), pH, TA (g tartaric acid equivalents/l berry juice), total N (mg/l) and Cl (mg/l) were measured after crushing and centrifuging the fresh berry sample from harvest. TSS was measured using a refractometer. pH and TA were measure using a pH electrode and titration with NaOH to pH=8.2. Total N was determined by high temperature catalytic combustion and chemiluminescence detection (Formacs^{TN}, Skalar Analytical Ltd., Breda, Netherlands). Total chloride was determined by an automated colorimetric method (APHA, 2005 – method 4500-Cl^- E) using an automated segmented.flow analyser (Alpkem Flow Solution 3, OI Analytical, Texas, USA).

Whole berries were homogenised and anthocyanin concentration (mg malvidin-3-glucoside equivalents/g berry fresh weight), tannin concentration (mg catechin equivalents/g berry fresh weight) and iron reactive phenolic concentration (mg catechin equivalents/g berry fresh weight) determined by spectrophotometry after extraction with ethanol (Skogerson et al., 2007). Details of this method are explained in Appendix 5.

The whole berry homogenates were freeze dried and total N (%) and C (%) determined by high temperature combustion in an atmosphere of oxygen (CNS2000, LECO Corporation, St Joseph, Michigan, USA) as described previously. Whole berry P (%), K (%), Ca (%), Mg (%), Na (%), S (%), Al (mg/kg), B (mg/kg), Cu (mg/kg), Fe (mg/kg), Mn (mg/kg), and Zn (mg/kg) were determined by inductively coupled plasma optical emission spectroscopy (SPECTRO ARCOS, SPECTRO Analytical Instruments, Kleve, Germany) following tube block sample digestion with nitric acid at 140°C for eight hours (Zarcinas and Cartwright, 1983; Zarcinas et al.,1983).

Details of sample preparation and analysis methods can be found in Appendix 5.

Canopy temperature

Spatial variation in canopy temperature (T_c) was measured using infrared sensors mounted on an ATV at the Tat and Mil sites. Initial testing and development of the method was undertaken in Y1 at Tatura. Subsequent measurement of vine rows containing target vines was done in Y2 at flowering (Tat and Mil), veraison (Tat and Mil) and harvest (Mil). Measurements were taken by driving slowly done rows and continuously recording T_c and air temperature (T_a) at 10 Hz and geographical location at approximately 1 Hz. Capturing target vine canopy temperature proved difficult using this method. In Y3, individual target vine T_c and T_a were measured at flowering (Tat), veraison (Tat and Mil) and harvest (Tat) using the same setup as Y2.

Temporal changes in T_c were measured in Y2 and Y3 using stationary infrared sensors at the Tat site on vines with sap flow sensors installed. Two methods were trialled. In Y2, sensors were mounted directly above the canopy. In Y3, sensors were positioned in the neighbouring row facing the western side of the canopy (at a distance of approximately 2.7 m). Data were recorded in field loggers at 15-min intervals.

Details of the installation and measurement procedure can be found in Appendix 5.

Thermal imagery

Additional and existing experiments were utilised to investigate the potential of thermal imagery to describe spatial patterns of water stress across grapevine canopies and whole vineyard blocks as part of a PhD study during this project. In addition to observations at the Tat site, deficit irrigation experiments were established on 8-year old Cabernet Sauvignon (101-14 rootstock) in 2007 and 14-year old Shiraz (Richter 99) in 2008 at Dookie College Estate vineyard (36.39°S 145.71°E). Data was also collected from an existing deficit irrigation experiment on Cabernet Sauvignon (Ramsey rootstock) at Oxford Landing, Waikerie (this site is described in GWRDC report on project GWT 07/02).

Thermal (PM570; FLIR Systems, Boston, USA) and optical images (Fuji Finepix S7000; FUJIFILM Corporation, Tokyo, Japan) were collected from the ground and the air. Ground-based images were taken from side-on and included reference surfaces of a) mat green cardboard, b) a non-transpiring grapevine leaf achieved by covering top and bottom with petroleum jelly, and c) a wet leaf, achieved by spraying with a low concentration of soapy water (Jones 1999). Airborne imagery was achieved using a 6 m long helium blimp with thermal and optical cameras attached via a gimbal arrangement (Fig. 1b). The helium balloon, tethered by a 90 m long rope, achieved thermal images with a field of view of approximately 45 m x 35 m. The thermal and optical cameras had 24° and 65° (max) lenses, respectively. Cameras were actuated by radio controlled remote. Real-time image viewing was achieved via video link to the thermal camera.



Fig. 1b. Thermal and optical cameras mounted on a gimbal attached to the 6 m long blimp. Thermal and optical images were actuated via a radio remote control.

Deficit irrigation experiment at Dookie

Two irrigation treatments, replicated 4 times, were implemented from veraison until harvest in a completely randomised design. One treatment (Wet_{CS}) irrigated grapevines according to estimated evapotranspiration (ET_c) and the other treatment (Dry_{CS}) withheld irrigation. ET_c was calculated from pan evaporation and a crop factor of 0.35. Each treatment plot contained 7 vines; the middle 3 vines were measured. The experiment commenced on 26 January and irrigation was withheld until 14 February. Veraison occurred from approximately January 20 to 30 and grapevines were harvested on February 28.

Vine rows were spaced at 3.4 m and orientated east-west containing vines spaced at 1.8 m. The grapevines were trained unilaterally and pruned to 15-20 two bud spurs. The grapevine canopy was support by one central and two outer foliage wires, to form a Smart-Dyson Ballerina canopy.

Ground-based thermal and optical images were taken between 1400 and 1600 h on 25, 29 January, and 1, 5, 9 and 12 February. Images were taken of both north and south sides of the canopy. Stem water potential was measured on 2 leaves per plot at the same time as thermal images were collected.

Deficit irrigation experiment at Waikerie

Aerial thermal and optical images were taken of an existing deficit irrigation experiment. Briefly, 5 irrigation levels, equivalent to seasonal rates to 6.7, 3.3, 2.3, 1.7 and 0.6 ML/ha, were maintained on 5 adjacent rows of 68 vines.

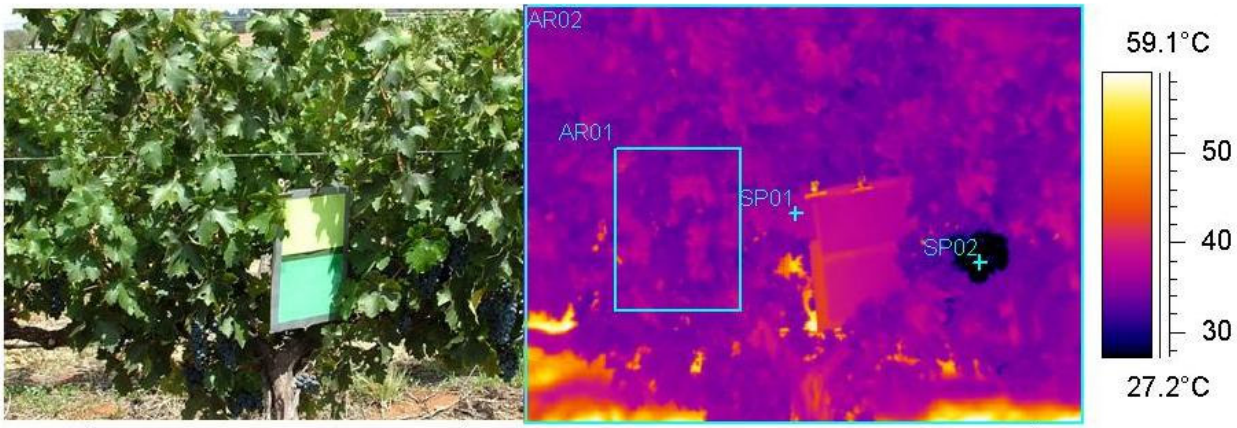
Aerial thermal and optical images were taken at this site on 9 January 2008. Concurrent ground-based measurements were made of leaf conductance using a porometer (model AP4; Delta-T Devices, Cambridge, UK).

Crop water stress index (CWSI)

Crop water stress was calculated using the following methods:
(1) Method 1 (Idso et al., 1981):

$$CWSI_{Idso} = \frac{(T_c - T_a) - (B.VPD + A)}{B(e_s - e_s') - B.VPD} \quad (3)$$

where T_c was the temperature of the area selected in thermal image to represent grapevine leaves (°C) (Fig. 2), T_a was air temperatures (°C), VPD was the vapour pressure deficit at T_a (kPa), e_s was the saturated vapour pressure at T_a (kPa), e_s' was the saturated vapour pressure at the equivalent temperature T_a+A, A and B were the intercept (°C) and slope (°C kPa^{-1}) coefficients, respectively, derived from the relationship between T_c-T_a and VPD (defined as the non-stressed baseline). T_a and VPD were determined from weather station data.



Label (vine 1)	Temperature [°C]				
	Spot	Min	Max	Avg	Stdev
Dry leaf (SP01)	36.9				
Wet leaf (SP02)	26.5				
Canopy select (AR01)		32.5	48.4	35.2	1.4
All image (AR02)		23.8	61.8	36.1	3.8

Fig. 2. Typical thermal and optical image of Cabernet Sauvignon grapevine canopy. Table contains temperature data associated with spots and areas selected in thermal image.

The non-water stress baseline was determined from thermal images taken 3.3m from the canopy surface on two separate days (6 and 15 February 2007). Diurnal measurements were taken on eight well watered Cabernet Sauvignon grapevines that were adjacent to the experimental plots. Measurements were taken every 60 to 90 minutes from 1430 to 1500 h. Stem water potential was measured and an infrared gas analyzer, Li-Cor 6400 (Li-Cor, Nebraska, USA) was used to measure net photosynthesis, stomata

conductance and transpiration on four leaves (2 northern side of canopy and 2 southern side of canopy) on each of the eight grapevines. The Li-Cor measurements were taken from 830 to 1400 h.

(2) Method 2 (Jones et al., 2002)

$$CWSI_{Jones} = \frac{(T_c - T_{wet})}{(T_{dry} - T_{wet})} \quad (4)$$

where T_{dry} was the dry non-transpiring reference leaf (covered with petroleum jelly) in the thermal image and T_{wet} was the wet reference leaf (covered with soapy water) in the thermal image (Fig. 2).

(3) Method 3 (Leinonen and Jones, 2004)

$$I_G = \frac{(T_{dry} - T_c)}{(T_c - T_{wet})} \quad (5)$$

Image analysis

Analysis of thermal and optical images was performed using ThermaCAM™ Researcher Pro 2.8 SR-1. A rectangular area of the image was selected to represent grapevine leaves (Fig. 2 and 3). The optical image of the canopy was used to guide selection of leaves.

For ground-based images, the area selected to represent T_c was approximately 5 and 10 % of the image area (Fig. 2). The selected area (where possible) did not contain foliage wires, the wet leaf, background sky or soil, or fruit. Where possible the selected canopy area was immediately above the cordon and fruiting zone. The average temperature and standard deviation of the selected area of the canopy was recorded.

For aerial images an area selected to represent T_c was taken of 3 vines between trellis posts to represent a treatment (Fig. 3). The area selected was central to the vine row to ensure exclusion of soil temperature. The average temperature and standard deviation of the selected area of the canopy was recorded.

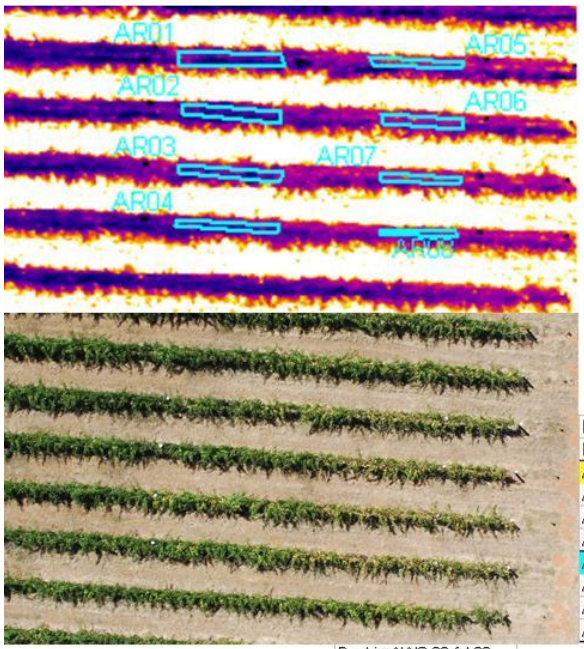


Fig. 3. Thermal and optical image taken from blimp 90 m above ground of irrigation experiment in Cabernet Sauvignon at Dookie. Data in tables refer to weather station and temperature of selected areas in the thermal image of irrigated and non-irrigated grapevines.

Label	Min	Max	Max - Min	Avg	Stdev
Image	-5.2	66.1	71.3		
AR01 Irrigated	27.8	44.1	16.3	31.1	1.7
AR02	28.3	33.7	5.4	30.7	0.9
AR03	28.8	43.2	14.4	32.3	1.6
AR04	27.3	36.5	9.2	31.4	1.2
AR05 not irrigated 35 days	31.2	40.6	9.4	34.9	1.7
AR06	30.3	43.5	13.2	33.7	1.6
AR07	30.8	43.1	12.3	34.7	2.1
AR08	30.9	42	11.1	34.2	1.8

Irrigated 25th Feb 08 – 26 l/vine

Dookie AWS 26 feb08

Datetime	time	Wind Dir. (Deg)	Wind Speed (m/sec)	Temperature	Rel Humidity (%)	BARP
26/02/2008	3:00:00 PM	297.3	2.7	27.1	25.9	993.5
26/02/2008	3:15:00 PM	270.0	2.0	26.9	26.4	993.4

Results and discussion

Descriptive analysis

Climate

Reference crop evapotranspiration (ETo) and degree days (base 10°C) for phenological periods at each site are shown in Figure 4. ETo was consistently highest at Mil and lowest at GS. ETo was noticeably high during the post harvest period at Mil and from bud burst to flowering at LC in Y2. Average seasonal ETo was 1209, 1511, 1324, 1267 and 1169 mm for LC, Mil, Gri, Tat and GS, respectively. Average daily ETo during the period from flowering to veraison was 5.5, 6.7, 6.3, 6.1 and 5.3 mm/day and for the period from veraison to harvest was 5.2, 6.8, 6.3, 5.5, 4.7 mm/day, respectively.

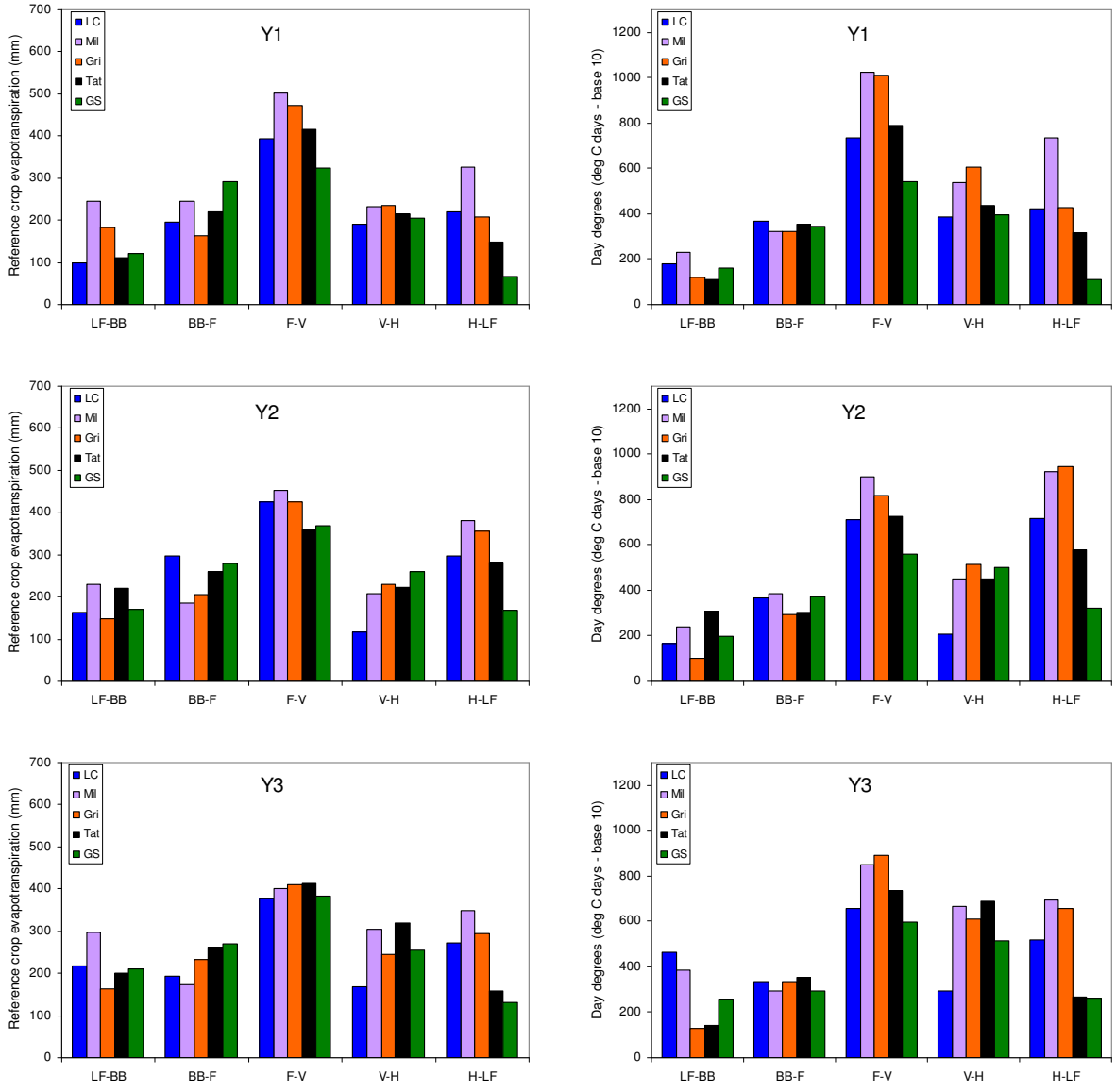


Fig. 4. Reference crop evapotranspiration and day degrees at the five sites during Y1, Y2 and Y3 for the periods from bud burst to flowering (BB-FL), flowering to veraison (FL-V), veraison to harvest (V-H) and harvest to leaf fall (H-LF). The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS). Error bars indicate standard deviation.

Day degrees was consistent for the period from bud burst to flowering across sites and between years despite the large difference in number of days between bud burst and flowering. Average day degrees from bud burst to flowering were 358, 333, 319, 336 and 336 day ℃ for LC, Mil, Gri, Tat and GS, respectively. Average seasonal day degrees was 2176, 2878, 2597, 2188 and 1812 day ℃ for LC, Mil, Gri, Tat and GS, respectively.

Rain was highly variable between sites and years (Table 3). Substantial rain occurred during the winter months at GS (i.e. from leaf fall to bud burst). There was particularly low rainfall at all sites from flowering to harvest in Y2. The period from veraison to harvest tended to be the driest. Total rainfall over the 3-year period was 961, 644, 927, 1001 and 1546 mm for LC, Mil, Gri, Tat and GS, respectively.

Topography

The topography increased in variability in the order Gri, Tat, LC, Mil and GS as shown in Table 4. Whilst three of the sites were relatively flat (Gri, Tat and LC) with height ranges falling within 1.4 m, the topography could still be linked to variability in data collected at high spatial density (more anon). Topography variation was more pronounced at Mil and GS with height ranges of 7.3 and 14.0 m. As expected, other data collected at high spatial density reflected this topography variation (more anon). The relative variation in surface topography is depicted in Fig. 5.

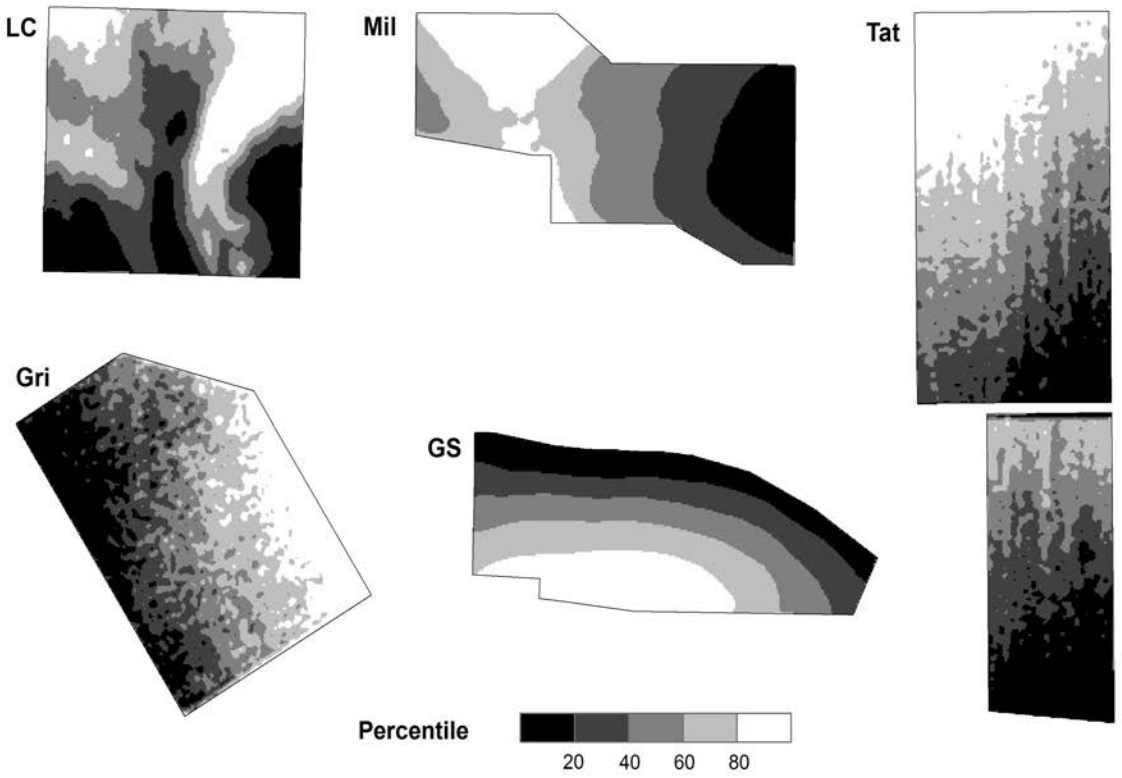


Fig. 5. Relative variation maps of soil elevation at Langhorne Creek (LC), Griffith (Gri), Tatura (Tat) and Mildura (Mil) and Great Southern (GS). High density elevation data were collected using a differential GPS with positional correction. Digital elevation modelling (ESRI, 2006) was used to derive this figure.

Table 4. Summary of the topography variation at each of the five sites. The sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS). Topography variation is expressed as height above mean sea level.

Site	Average height (m)	Range (m)
LC	14.8	1.4
Mil	46.0	7.3
Gri	129.4	0.3
Tat	123.6	0.6
GS	261.6	14.0

Soil Properties

The initial soil survey, using either electromagnetic induction (EM38) or a gamma spectrometer, was used to gain an integrated measure of soil variation across each of the 5 sites. The resultant variation in soil properties was greatest at LC and GS with the other sites showing much smaller levels of variation (Table 5). However, these soil surveys represent an integrated measure of soil properties whereby the response signal is dependant on a number of different soil variables. The EM38 signal responds predominantly to changes in soil salinity, soil moisture and clay (McNeil, 1980). Whilst some of these properties can change from day-to-day and season-to-season, the spatial structure of the EM38 data can remain consistent (Douaik et al., 2007). The gamma spectrometer signal, on the other hand, responds to changes in gamma radiation emitted from soil surface materials. This signal is only attenuated by changes in soil moisture but, like the EM38, the spatial structure remain consistent (Cook et al., 1996). The spatial pattern for each site is represented in Figure 6.

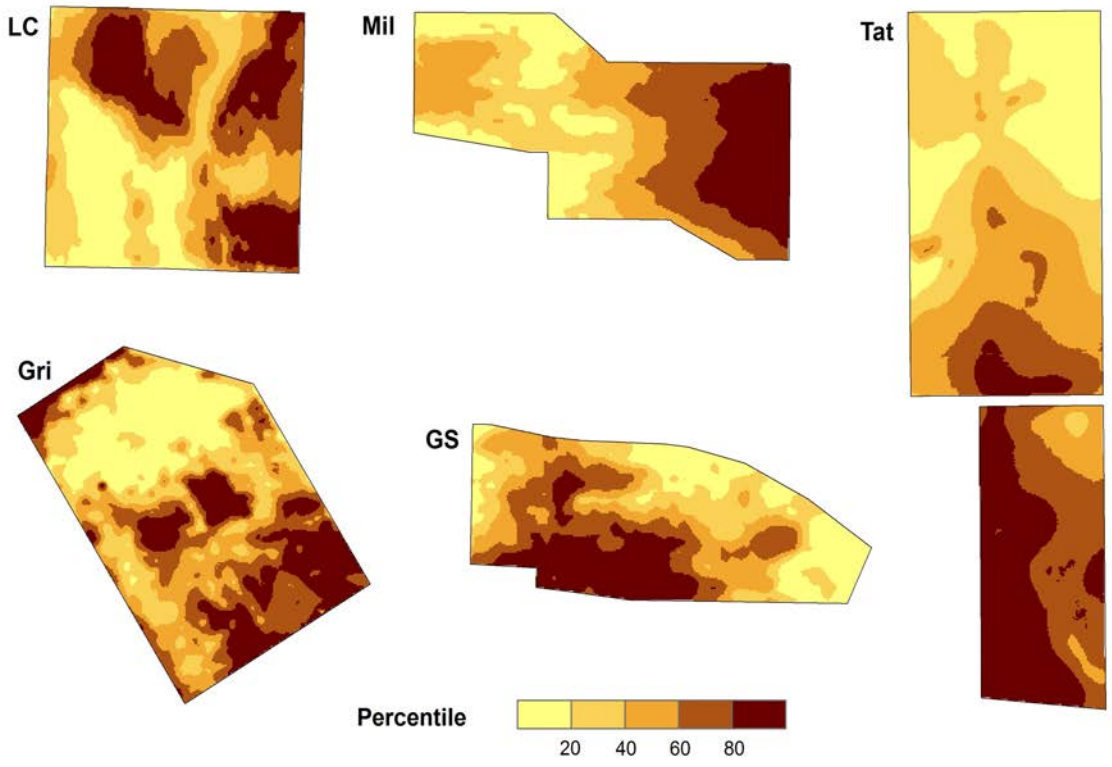


Fig. 6. Relative variation maps of apparent soil electrical conductivity at Langhorne Creek (LC), Griffith (Gri), Tatura (Tat) and Mildura (Mil) and total gamma radiometric counts at Great Southern (GS). High density data were collected using either an electromagnetic induction sensor (EM38) or gamma spectrometer. Ordinary kriging was used to derive this figure.

Table 5. Statistical summary of the initial soil survey data for the 5 sites. The apparent soil electrical conductivity was measured at Langhorne Creek (LC), Griffith (Gri), Tatura (Tat) and Mildura (Mil) and total gamma radiometric counts at Great Southern (GS),

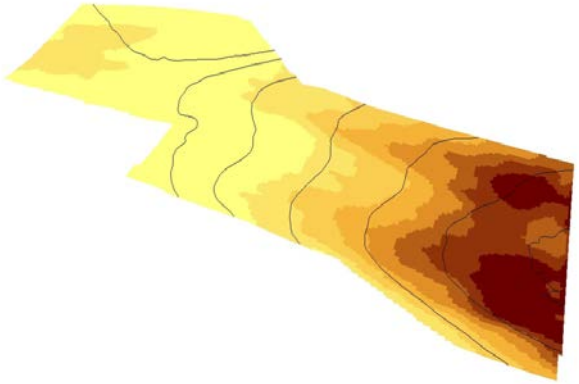
Statistic	Apparent soil electrical conductivity (dS/m) and total counts (cps)				
	LC	Mil	Gri	Tat	GS
Mean	0.90	1.52	2.23	1.80	270
Standard Deviation	0.22	0.12	0.15	0.13	75
Maximum	1.39	1.83	2.89	2.13	465
Minimum	0.38	1.40	1.96	1.42	97

The degree to which the spatial pattern of the EM38 data describes the spatial pattern of any soil property is determined by correlating the spatial data with point measurements of specific soil properties (Table 5). Soil salinity accounted for approximately 50 % and 70 % of the variation in the EM38 signal at LC and Mil sites, respectively. The spatial variation in the EM38 signal shows a strong similarity to the topography at Mil (Fig.7) suggesting that local drainage may be playing a role in the accumulation of salts at this site. Similarly, at the GS site the spatial pattern of the Gamma spectrometer signal shows a strong similarity to the topography yet the best correlation with soil properties only accounts for 19% of the variation (Table 6). This is most likely due to the use of total gamma counts rather than specific gamma energy bands associated with gamma emitting elements (e.g. potassium, uranium, thorium). The other two sites, Gri and Tat, did not show any correlation with soil properties that affect the EM38 signal. Whilst this may seem surprising it should be noted that the EM38 data was collected predominately in the mid-row, reducing the interference from irrigation and trellis wires, while the soil data was collected along the vine row at a specific distance from the drip emitter. Apart from the greater variation in soil salinity along the vine row that accompanies the use of drip irrigation, the mid-row soil conditions may not bear any connection to the irrigated situation along the vine row. This is most likely why there is a relatively poor correlation between soil salinity and EM38 readings at the LC site, a site with a high degree of soil salinity variation (Fig. 8).

Table 6. Pearson correlation coefficients between selected soil properties and apparent soil electrical conductivity, EM38 (LC, Gri, Tat and Mil) and total gamma radiometric counts, GRC (GS). The soil properties were depth weighted according to McNeil (1980) for comparison to the EM38 vertical dipole measurements and only the 0-10 cm soil properties were used to correlate with GRC,

Soil property	EM38				GRC
	LC	Mil	Gri	Tat	GS
$EC_{1:5}$	0.693	0.855	0.261	0.105	0.226
EC_{se}	0.533	0.832	0.276	-0.112	0.065
Clay %	0.324	0.679	0.229	0.575	0.436

Fig. 7. Map showing the variation in apparent soil electrical conductivity at the Mildura site overlayed on a digital elevation model. Contour lines are black and the relative apparent electrical conductivity is the various shaded areas. Note, the elevation has been exaggerated relative to the horizontal plane to enhance visual effectiveness.



Soil salinity

Sites showed considerable variation in level and spread of soil salinity (Fig. 8). Soil salinity was negligible at Gri and GS due to either good quality irrigation water (Gri) or very small volumes of water applied (GS). The Mil site showed moderate levels of soil salinity (i.e. 1.0 dS/m), despite the use of good quality irrigation water (< 0.2 dS/m) and was significantly higher than Gri and GS ($P < 0.0001$). Although irrigation water quality was good, the volume of water applied may have over time contribute to salinity presence in soil. At the Mil site it is believed that a localised rupture in a sub-surface irrigation main may have contributed to the increase in surface salinity levels.

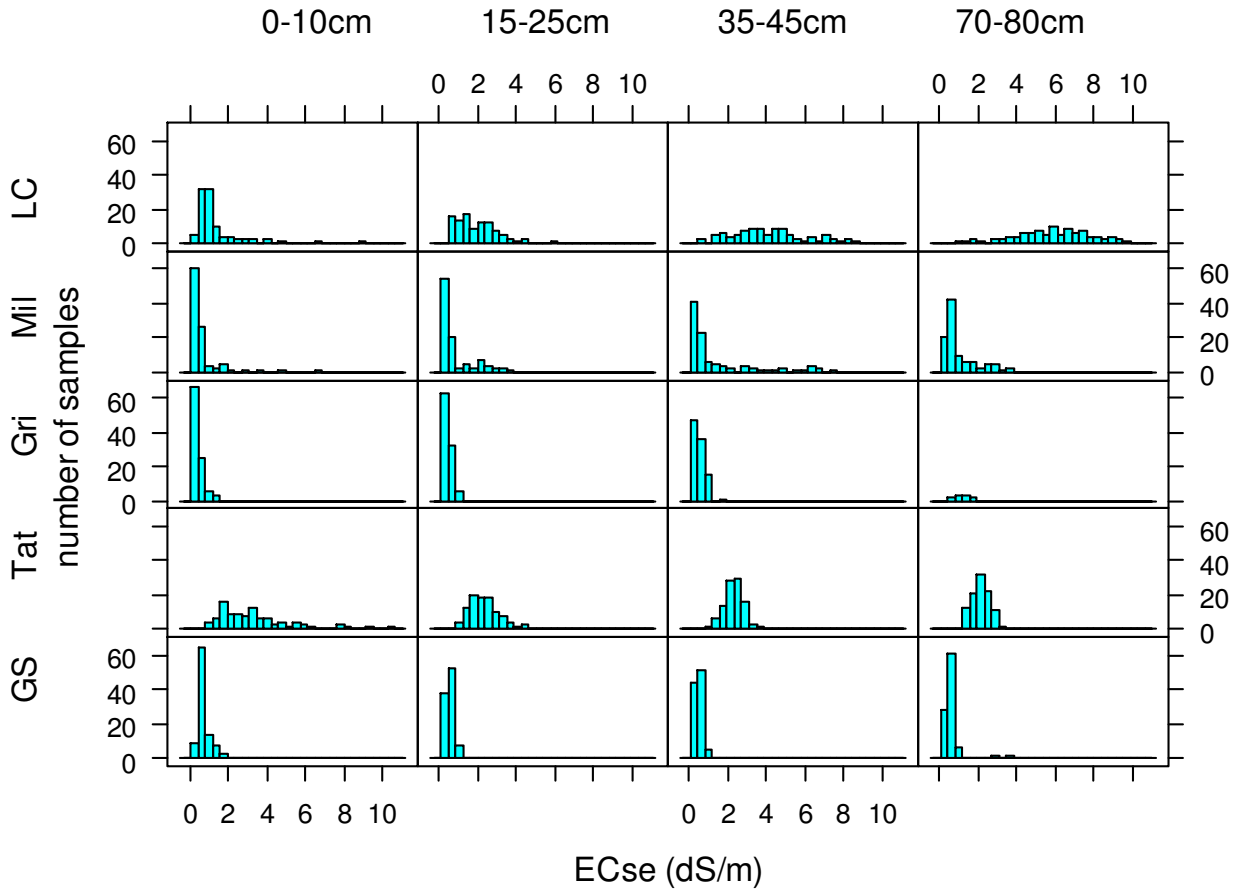


Fig. 8. Frequency distribution of soil extract electrical conductivity (EC_{se}) at Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS) determined at four soil depths (0-10, 15-25, 35-45, 70-80 cm). EC_{se} was derived from 1:5 soil:water extract electrical conductivity, % chloride, and % clay using the correction function of Shaw (1999).

The LC sites had the greatest degree of salinity ($P < 0.0001$) with average values greater than 1.5 dS/m, the threshold value for vines (Maas and Hoffman, 1977). Salinity values at LC increased with soil depth to 5.9 dS/m at 80 cm. These salinity levels were reflected in the vine with many visual signs of salt toxicity. Irrigation water salinity increased to 3.0 dS/m at LC in the Y3, a severe salinity risk rating according to Ayers (1977). Soil salinity levels were also high at Tatura, above the threshold value, but decreased with soil depth. Despite the large array of soil salinity at these two sites, yield, berry weight and pruning weight did not correlate with measured soil salinity with only 25 % of the variation in berry weight accounted for by variation in soil salinity at LC (data not shown). This observation has also been found in other studies (e.g. Prior et al., 1992) where yield and growth of grapevines were not affected at the critical salinity levels suggested by Maas and Hoffman (1977). This suggests that soil salinity measurements that are based on

limited soil profile measurements may not represent bulk soil salinity and therefore cannot be a reliable indicator of potential vine performance consequences.

Soil-water properties

Variation in soil texture and organic matter, and their corresponding affect on soil structure, determine the water holding properties of soil. Soil texture, indicated in Figure 9 by the amount of clay in each soil layer, was not uniform across each site. The Gri site had the heaviest (highest clay content) soil textural profile whereas the Mil site had the lightest. All sites, except for the Mil, showed an increase in clay content with an increase in soil depth. The Mil site showed a somewhat uniform soil profile. LC and GS sites displayed the largest range in clay content, which was also reflected in the total carbon content (Fig. 10).

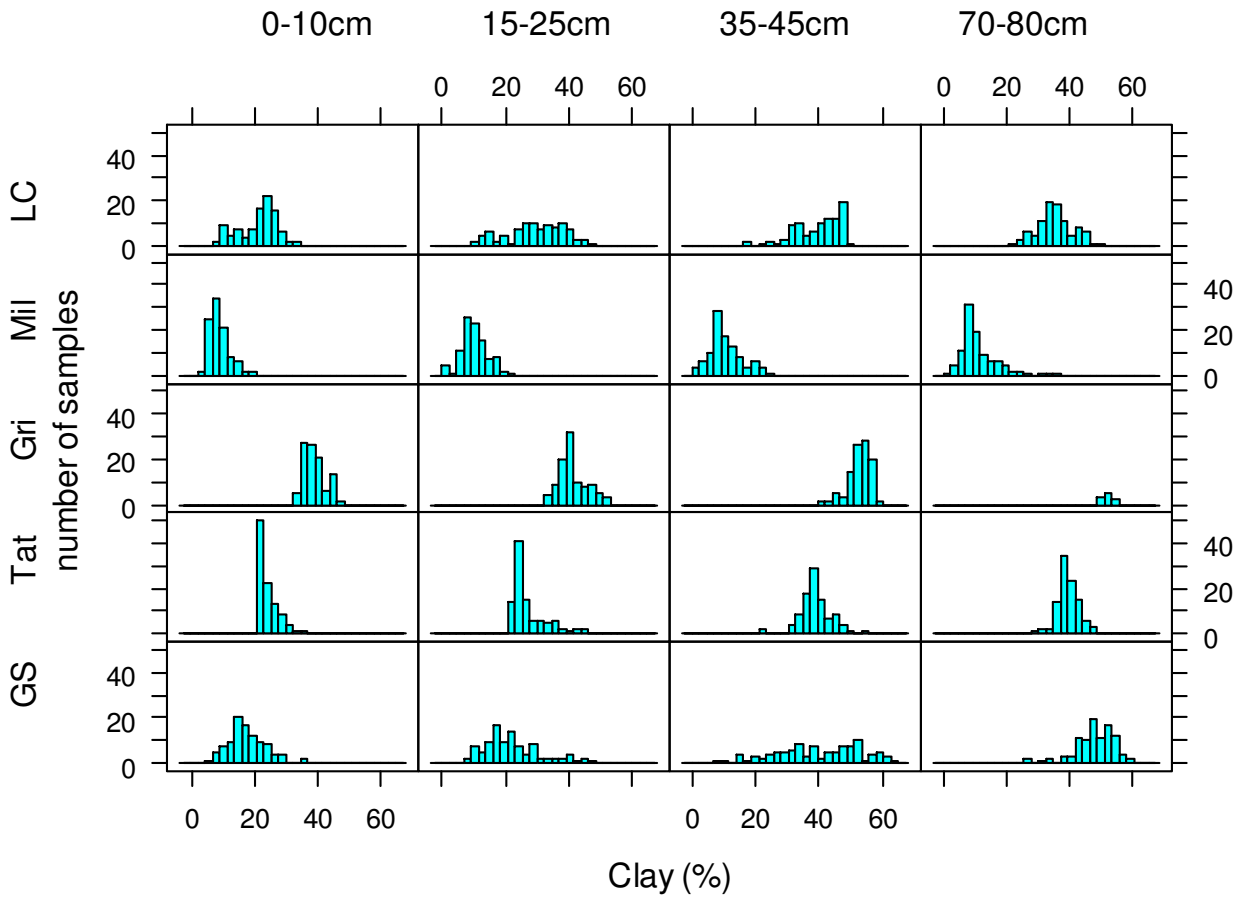


Fig. 9. Frequency distribution of clay (%) at Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS). Clay (%) was determined at four soil depths (0-10, 15-25, 35-45, 70-80 cm) using mid-infrared spectroscopy and a global calibration data set (Janik et al., 2007).

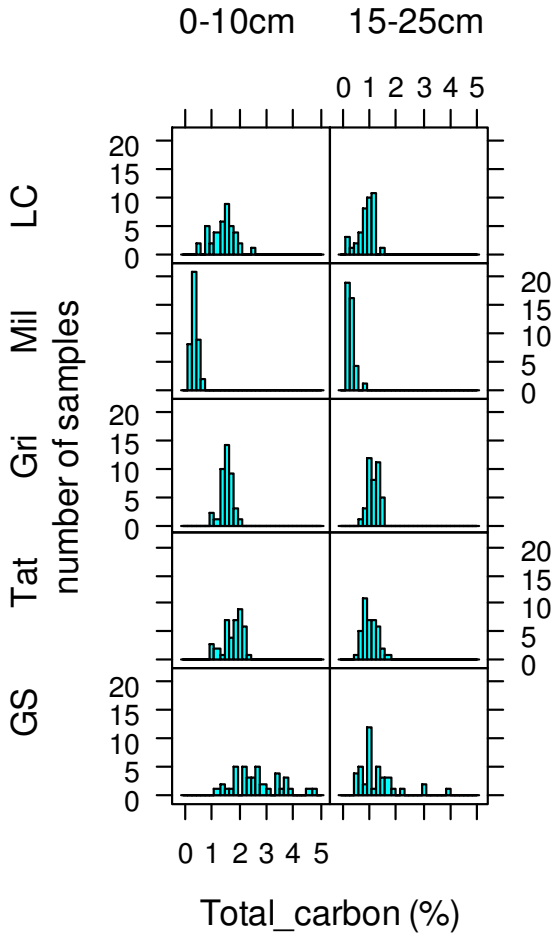


Fig. 10. Frequency distribution of soil total carbon (%) at Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS) determined at two soil depths (0-10, 15-25 cm).

Readily (RAW) and total available water (TAW) are shown in Figure 11. Calculating the RAW and TAW for the entire profile, the Mil site, a light textured soil, had the largest RAW while the Gri site, a heavy textured soil, had the lowest RAW ($P < 0.001$). Conversely, the Mil site had the lowest TAW while the Tat site had the highest TAW ($P < 0.001$). Both the RAW and TAW decreased with increasing soil depth across all sites, with the Mil site decreasing the least, given its more uniform profile, and the Gri site the most. It should be noted here that the predicted values of TAW and RAW have not been corrected against actual measured values, which is time consuming and expensive. The estimates of TAW and RAW are considered a little higher than the expected values for each soil textural range. However, the relative variation in TAW and RAW within and between sites can be considered more precise that the actual value. Previous work by Lanyon and Bramley (2004) demonstrated that while the predicted values require bias correction using subsets of measured soil properties, the spatial structure in the variation of soil properties is preserved.

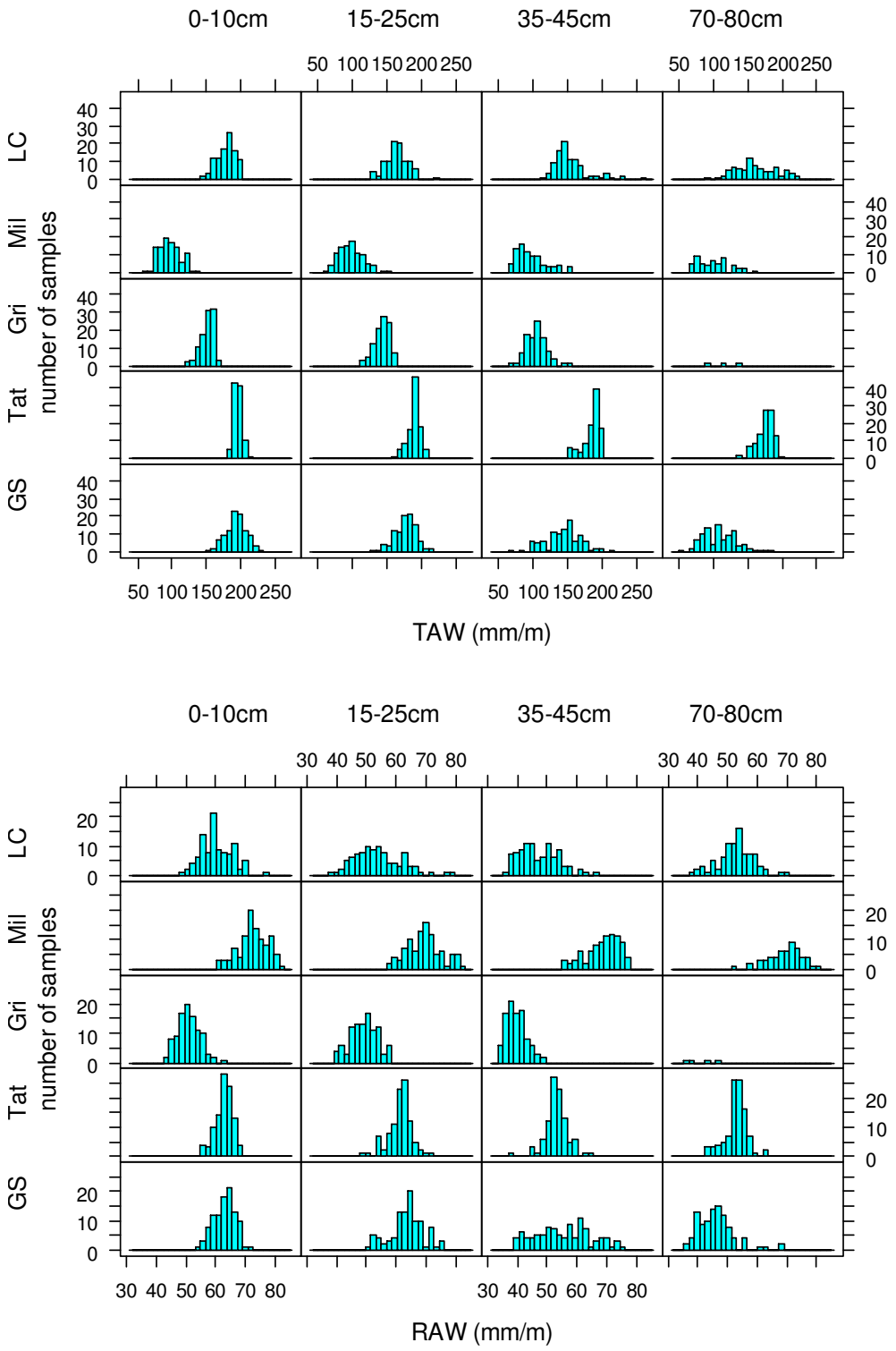


Fig. 11. Frequency distribution of readily available water (RAW) and total available water (TAW) at Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS). RAW and TAW were calculated at four soil depths (0-10, 15-25, 35-45, 70-80 cm) from the difference between volumetric water contents at -10 kPa soil matric potential and -60 kPa soil matric potential (RAW) and -1500 kPa soil

matric potential (TAW). Volumetric water contents at different matric potentials were derived from mid-infrared spectroscopy using a global calibration data set (Janik et al., 2007).

One significant shortcoming with this study was the inability to measure the effective rooting depth of vines at the spatial density other soil properties were measured. Whilst the measurement of effective rooting depth is considered important in determining the plant available water for irrigation design (McKenzie, 2000) it has been shown to have little correlation with vine performance (Lanyon and Bramley, 2004) due to variable root access to the mid-row soil volume. In contrast, root volume is directly related to vine performance.

Root exploration limitations are linked to soil structural problems. The potential for soil structural problems can be assessed by comparing the measured exchangeable cations and their ratios against the recommended levels (Lanyon et al., 2004). From Table 7 it is clear that many of the sites are within the recommended levels for the top two soil depths. However, at LC the exchangeable sodium percentage, ESP, is well above the recommended level of 6 %. The level of sodic condition varied considerably across the LC site (Fig. 12) which can cause soil structural problems and limit root exploration of deeper soil layers. The Tat site also had sodic conditions developed in the deeper soil layer although less severe than LC but just as variable. Both these soil profiles are duplex and can develop into restrictive horizons if soil structural stability becomes weak. Offsetting the high ESP is the high soil salinity levels which can maintain structural stability of these soils. However, the high salinity also comes with its potential effects on vine growth (see above).

Table 7. Comparison of exchangeable cations measured at Langhorne Creek (LC), Griffith (Gri), Tatura (Tat), Mildura (Mil) and Great Southern (GS) against recommended values (Lanyon et al., 2004) for two soil depths. Note that the Na % is the same as the exchangeable sodium percentage (ESP).

Site	Depth (cm)	Ca %	Mg %	Na %	K %	Ca:Mg	K:Mg
Recommended		*60-80*	*15-30*	*<6*	*5-10*	*2-10*	*0.1-0.4*
LC	0-10	62.1	24.6	8.0	5.2	2.5	0.2
	15-25	52.6	26.7	16.9	3.8	2.0	0.1
Mil	0-10	60.2	25.3	2.3	12.3	2.4	0.5
	15-25	64.3	25.0	4.4	6.3	2.6	0.3
Gri	0-10	69.1	22.4	1.1	7.3	3.1	0.3
	15-25	63.0	29.1	1.9	6.1	2.2	0.2
Tat	0-10	65.3	22.3	5.5	6.9	2.9	0.3
	15-25	59.0	28.4	8.9	3.7	2.1	0.1
GS	0-10	85.2	7.8	1.8	5.3	11.0	0.7
	15-25	78.8	12.5	3.3	5.4	6.3	0.4

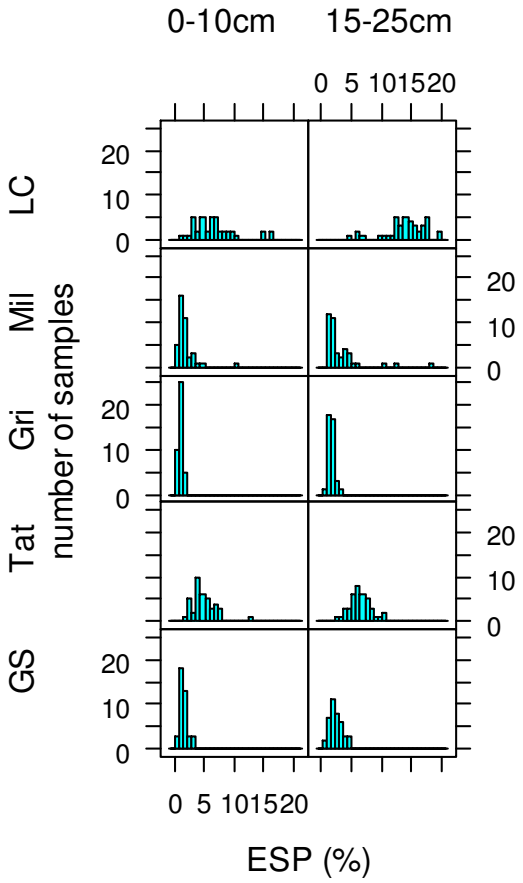


Fig. 12. Frequency distribution of exchangeable sodium percentage (ESP) at Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS) determined at two soil depths (0-10, 15-25 cm).

Soil nutrition

LC, Gri and Tat all had similar C:N ratios suggesting similar available nitrogen (Table 8). The Mil site had a higher average C:N ratio ($P < 0.05$) with the highest at GS ($P < 0.001$). Such a ratio gives a measure of potential nitrogen availability. Generally, the higher the ratio, the less available nitrogen for vine uptake.

Table 8. Statistical comparison of average soil carbon:nitrogen ratios at Langhorne Creek (LC), Griffith (Gri), Tatura (Tat), Mildura (Mil) and Great Southern (GS).

Site	0-10 cm		15-25 cm	
	Average	Standard Deviation	Average	Standard Deviation
LC	11.9	0.84	11.6	1.44
Mil	12.9	2.06	15.4	5.29
Gri	10.9	0.34	10.7	0.50
Tat	10.5	0.31	9.7	0.73
GS	17.8	1.95	21.3	3.59

The distribution of macro and minor nutrients at each site is shown in Figures 13 to 16. There are limited recommended values for soil nutrition to assess each site. Lanyon et al. (2004) summarised a number of recommended values for soil nutrition, along with extensions to deficiency and toxicity, which are used here to evaluate site nutrition.

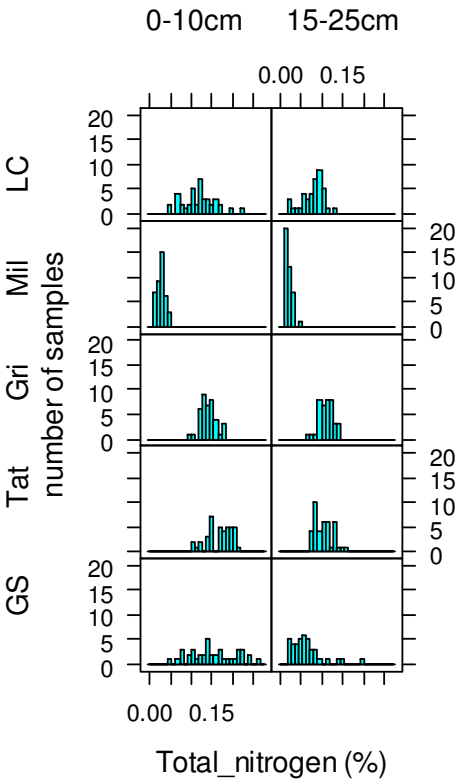
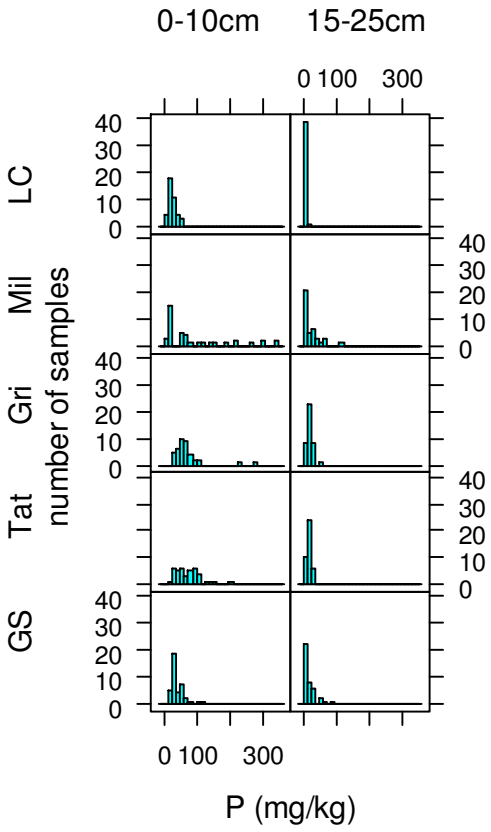


Fig. 13. Frequency distribution of total nitrogen (%) at Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS) determined at two soil depths (0-10, 15-25 cm).



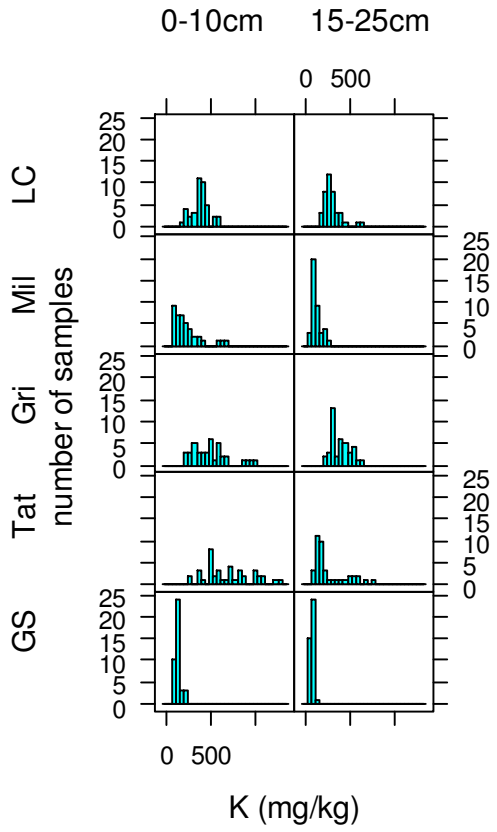


Fig. 14. Frequency distribution of soil extractable phosphorus (P) and extractable potassium (K) at Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS) determined at two soil depths (0-10, 15-25 cm).

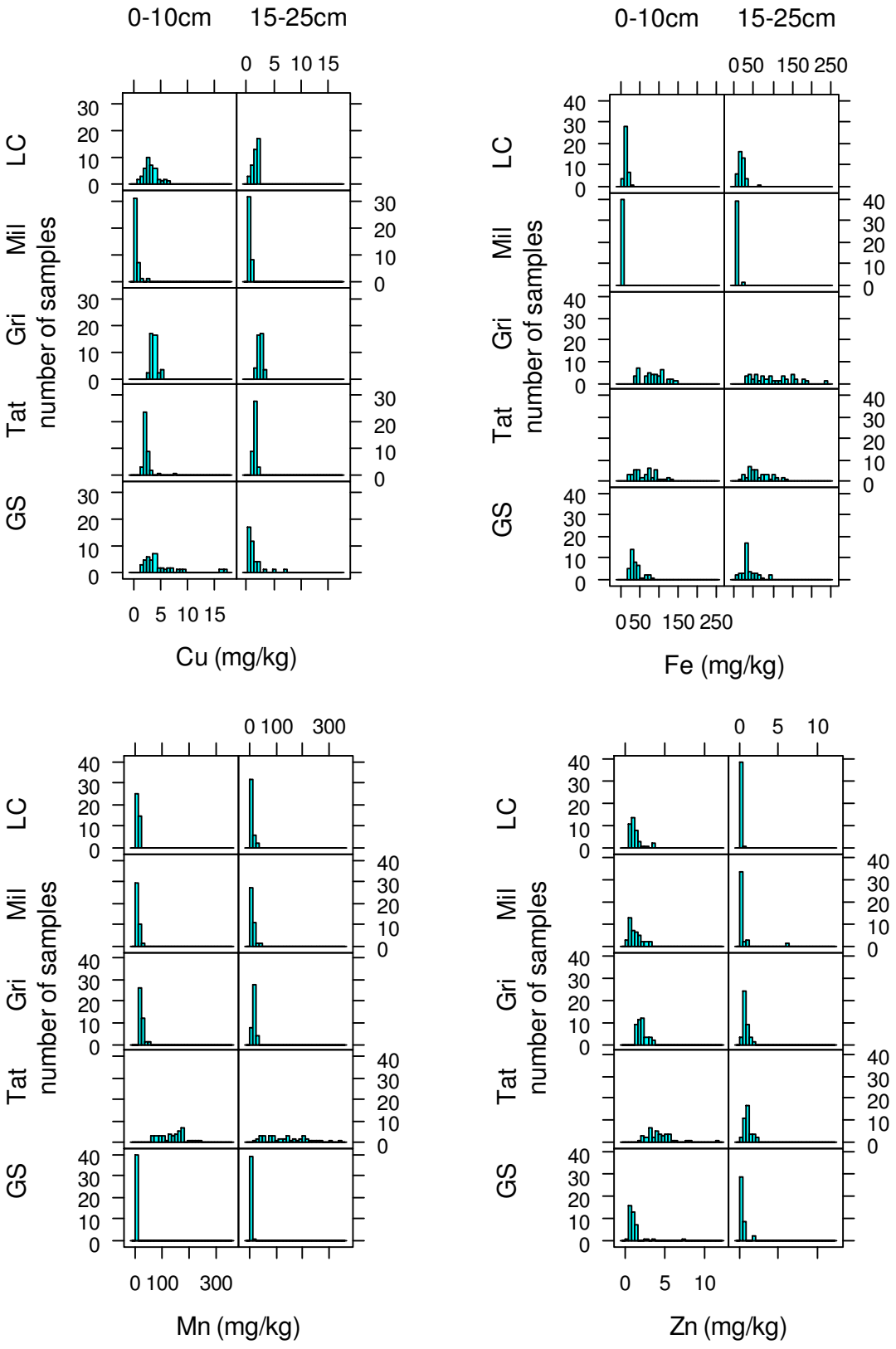


Fig. 15. Frequency distribution of soil copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) at Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS) determined at two soil depths (0-10, 15-25 cm).

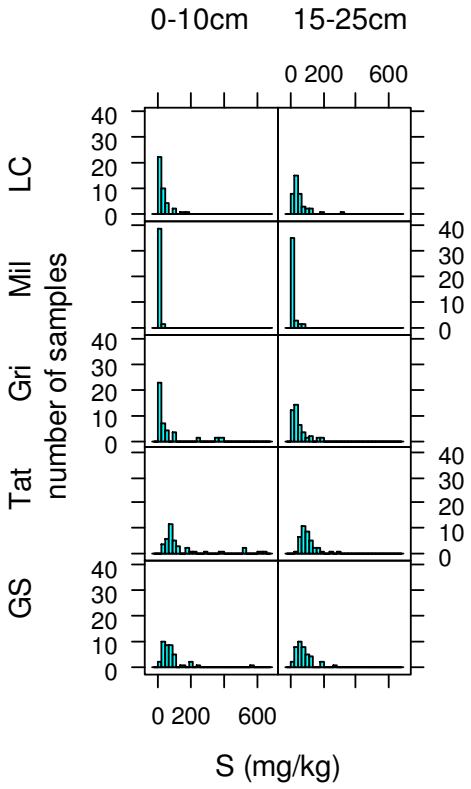


Fig. 16. Frequency distribution of soil extractable sulphur (S) at Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS) determined at two soil depths (0-10, 15-25 cm).

Phosphorus (P) showed significant variation between sites ($P < 0.001$). Deficient values of P were measured at LC, with marginal values recorded at GS. All other sites were deem adequate with the Mil site showing considerable variation in surface soil P. Potassium (K) on the other hand was consider high at Tat, Gri and LC, with Tat and Gri being the highest ($P < 0.05$) and showing the largest range. Both Mil and GS were considered to have adequate levels of K.

Copper (Cu) levels at Mil were considered adequate however all other sites were considered toxic with average levels exceeding the toxic level of 2 mg/kg. Similarly, adequate soil levels for manganese (Mn) are considered to be between 2 and 4 mg/kg yet Mil was the only site to fall within this range with all other sites far in excess, with the highest average level recorded at Tat (141 mg/kg). Without any clear negative growth and physiological signs on these vines that show Cu and Mn toxicity, the soil nutritional levels suggested by Lanyon et al (2004) need to be re-considered.

Zinc (Zn) levels for all sites were considered marginal at LC, GS and Mil sites. Higher levels were recorded at Gri and Tat ($P < 0.001$) with the highest level recorded at Tat which was considered 'High'.

Mil was the only site where the average iron (Fe) concentration was below the suggested 4.5 mg/kg adequate level. All other sites showed increasing levels of Fe in the order LC, GS, Tat and the highest at Gri with 92 mg/kg and the largest range. Mil was also the only site to fall below the suggested deficient level for sulphur (S) of 10 mg/kg. All other sites showed increasing levels of S in the order LC, Gri, GS with the highest at Tat with 130 mg/kg and the largest range.

Soil pH can control the availability of soil nutrients and vines are considered to grow adequately in a range of 5.5 to 8.0 measured in $CaCl_2$ (Lanyon et al., 2004). There were instances in all sites where soil pH_{CaCl2} was outside this range at both surface and deep soil layers (Fig. 17). This has consequence on the availability and toxicity of some nutritional elements.

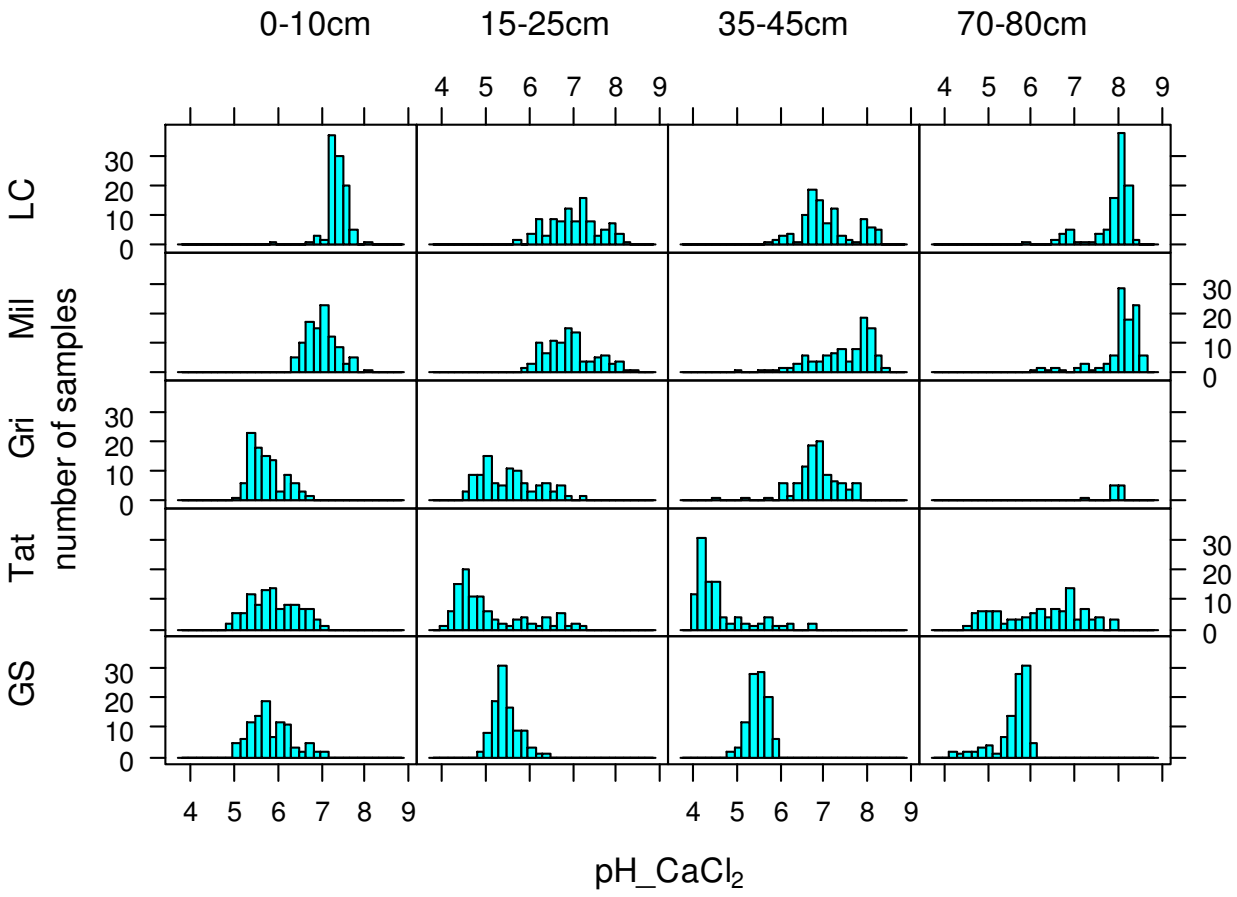


Fig. 17. Frequency distribution of soil pH ($CaCl_2$) at Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS) determined at four soil depths (0-10, 15-25, 35-45, 70-80 cm).

Irrigation

Irrigation varied from year-to-year, between sites and within sites. Mil and Gri received the most irrigation and GS the least (Table 9). Average irrigation applied at Mil ranged from 3.5 Ml/ha in Y2 to 5.6 Ml/ha in Y3. Irrigation at Gri declined from 5.8 Ml/ha in Y1 to 3.9 Ml/ha in Y3. The decrease in irrigation at Gri could be partly attributed to rainfall (1.5 Ml/ha fell from flowering to veraison in Y3). Average irrigation at GS varied from 0.1 to 0.5 Ml/ha in Y3 and Y1, respectively. The low level of irrigation at GS was offset by high rainfall, particularly during autumn, winter and spring.

Table 9. Rainfall (R) and irrigation (I) at each site during different periods of growth for Y1 to Y3. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Period (Y1)	LC		Mil				Gri		Tat						GS			
			Block 1		Block 2				Block 1		Block 2		Block 3		Block 1		Block 2	
	I	R	I	R	I	R	I	R	I	R	I	R	I	R	I	R	I	R
LF-BB	0	220	0	112	0	112		184	0	128	0	128	0	128	0	305		
BB-F	0	155	9	1	9	1		129	3	129	5	129	3	129	0	140		
F-V	73	40	230	36	227	36		36	131	37	141	37	107	37	39	26		
V-H	47	21	169	12	164	12		12	73	31	71	31	106	31	15	19		
H-LF	22	85	83	52	83	52		18	27	34	19	34	38	34	0	24		
TOTAL	142	521	491	213	483	213	580	379	234	359	236	359	254	359	54	514		

Period (Y2)	LC		Mil				Gri		Tat						GS			
			Block 1		Block 2				Block 1		Block 2		Block 3		Block 1		Block 2	
	I	R	I	R	I	R	I	R	I	R	I	R	I	R	I	R	I	R
LF-BB	0	47	0	50	0	50	15	91	0	89	0	89	0	89	0	257	0	257
BB-F	48	28	26	16	16	16	72	4	31	12	21	12	35	12	0	81	0	81
F-V	86	51	162	22	162	22	145	17	116	91	122	91	118	91	14	36	14	36
V-H	18	1	75	31	77	31	105	3	37	24	49	24	48	24	36	17	26	17
H-LF	40	73	100	82	95	82	103	72	51	89	44	89	47	89	0	87	0	87
TOTAL	192	200	363	201	350	201	440	187	235	305	236	305	248	305	50	478	40	478

Period (Y3)	LC		Mil				Gri		Tat						GS			
			Block 1		Block 2				Block 1		Block 2		Block 3		Block 1		Block 2	
	I	R	I	R	I	R	I	R	I	R	I	R	I	R	I	R	I	R
LF-BB	16	102	5	58	5	58	11	68	9	123	9	123	10	123	0	254	0	254
BB-F	22	73	21	79	21	79	60	75	218	27	70	27	63	27	0	116	0	116
F-V	61	34	196	44	161	44	110	148	81	62	83	62	86	62	9	54	12	54
V-H	42	4	143	23	145	23	105	59	65	64	71	64	76	64	2	5	9	5
H-LF	25	28	198	26	195	26	107	11	36	62	32	62	40	62	0	126	0	126
TOTAL	166	241	563	230	527	230	393	361	409	338	265	338	275	338	11	555	21	555

LF = leaf fall, BB = bud burst, FL = flowering, V = veraison, H = harvest.

Irrigation emitter rate variability is shown in Figure 18. Variation at each site was high, notably at Tat in Y1 and Y2, Gri in Y2 and GS as demonstrated by the distribution uniformity (DU) in Table 10. DU was less than 95% at all sites. There was no spatial pattern to the variation in emitter rate apart from Gri (particularly in Y2) and Tat in Y2. Flushing of laterals and a cleaning program substantially reduced the variation at Griffith in Y3. Variation at Tat in Y1 was due to blockages from iron precipitation. The drip lines were replaced at this site at the end of Y1. Variation across the site was reduced in Y2 and Y3 compared with Y1, however, the emitter rate in the southern portion of the site was considerably less than the northern block. This was attributed to low pressure when the emitter rates were measured.

Table 10. Irrigation distribution uniformity (DU) and nominal emitter flow rate (Q_n) at each site. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Year	LC		Mil		Gri		Tat		GS	
	DU (%)	Q_n (l/h/vine)	DU (%)	Q_n (l/h/vine)	DU (%)	Q_n (l/h/vine)	DU (%)	Q_n (l/h/vine)	DU (%)	Q_n (l/h/vine)
Y1							32	3.6		
Y2			93	9.4	85	3.6	71	5.5	72	5.5
Y3	91	3.6			92	3.6	92	5.5		

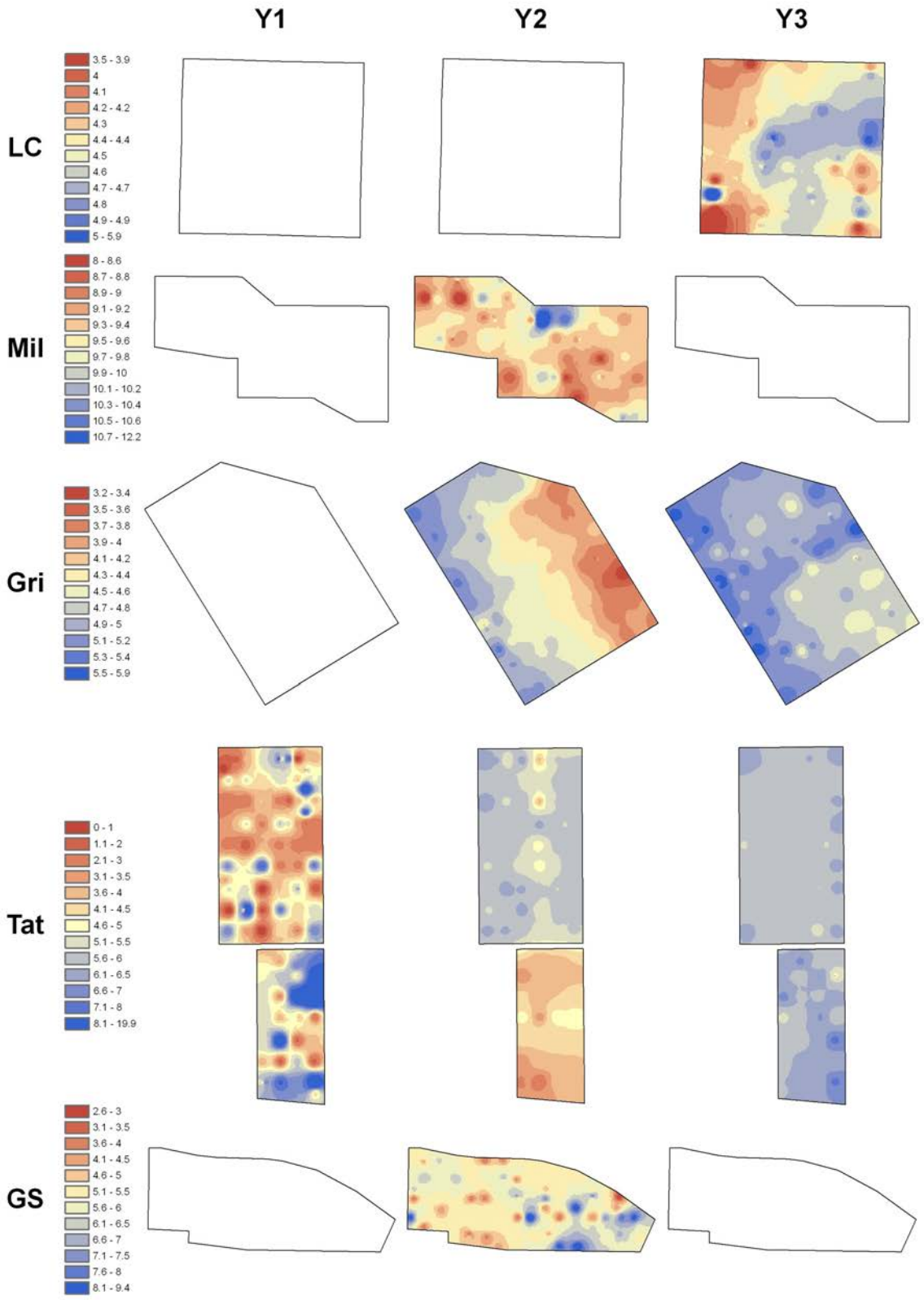


Fig. 18. Maps of irrigation application rate per vine (l/h/vine) at the five sites for Y1, Y2 and Y3. Application rate per vine were derived from measurements of emitter flow rate to 100 vines at Langhorne Creek (LC), Griffith (Gri), Tatura (Tat) and Great Southern (GS), and 65 vines at Mildura (Mil). Inverse distance weighting interpolation was used to derive this figure.

Within site variation in applied irrigation was greatest at Tatura in Y1 (Fig. 19). This was due to variation in emitter rate from iron blockages. The north western block at Tat (there were 3 separate irrigation control valves in the experimental area) received approximately 3-times more water than blocks 2 and 3 in Y3. Within site variation in applied irrigation was also notably high at Gri in Y1 and Y2 due to the variation in emitter flow rate.

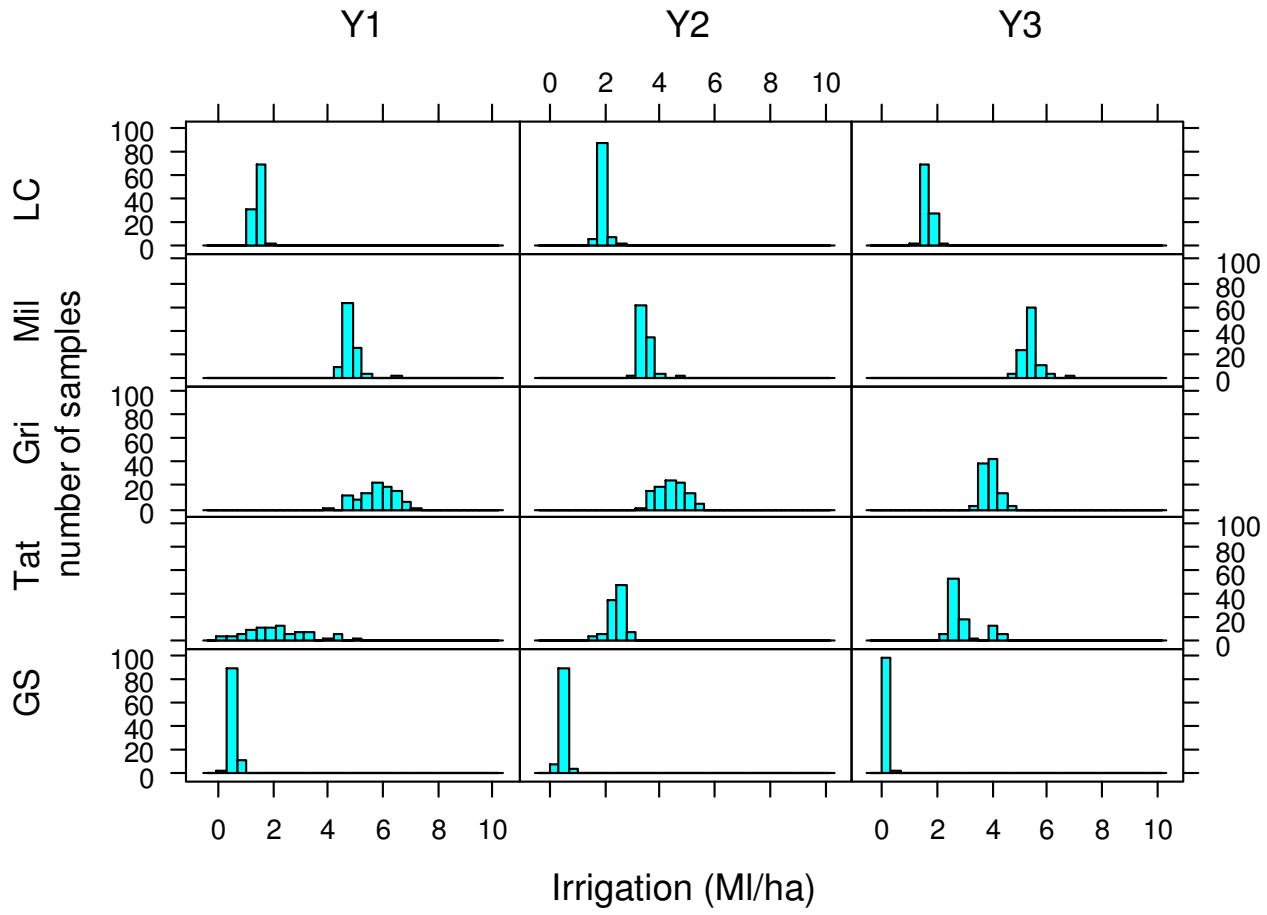


Fig. 19. Frequency distribution of seasonal irrigation per vine (Ml/ha) at the five sites for Y1, Y2 and Y3. Seasonal irrigation was based on measurements of application rate per vine and applied irrigation to a row within each block. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Within site variability in seasonal (bud burst to leaf fall) estimates of vine water use (i.e. EAS.ET_o) is presented in Figure 20. Mil had the highest site average vine water use and the greatest variability in vine water use. Vine water use at Mil ranged from 400 to 670 in both Y2 and Y3. Tat also had substantial variation in vine water use ranging from 210 to 330 mm in Y2 and 300 to 430 in Y3. Gri had the least variation in vine water use. LC and GS had the lowest site average vine water use. The spatial pattern was similar from Y2 to Y3 at all sites. LC appeared to be the only site that lacked spatial structure. A grower's ability to optimise water use efficiency by closely matching crop water requirements with supply was therefore compromised by within block variability in vine size.

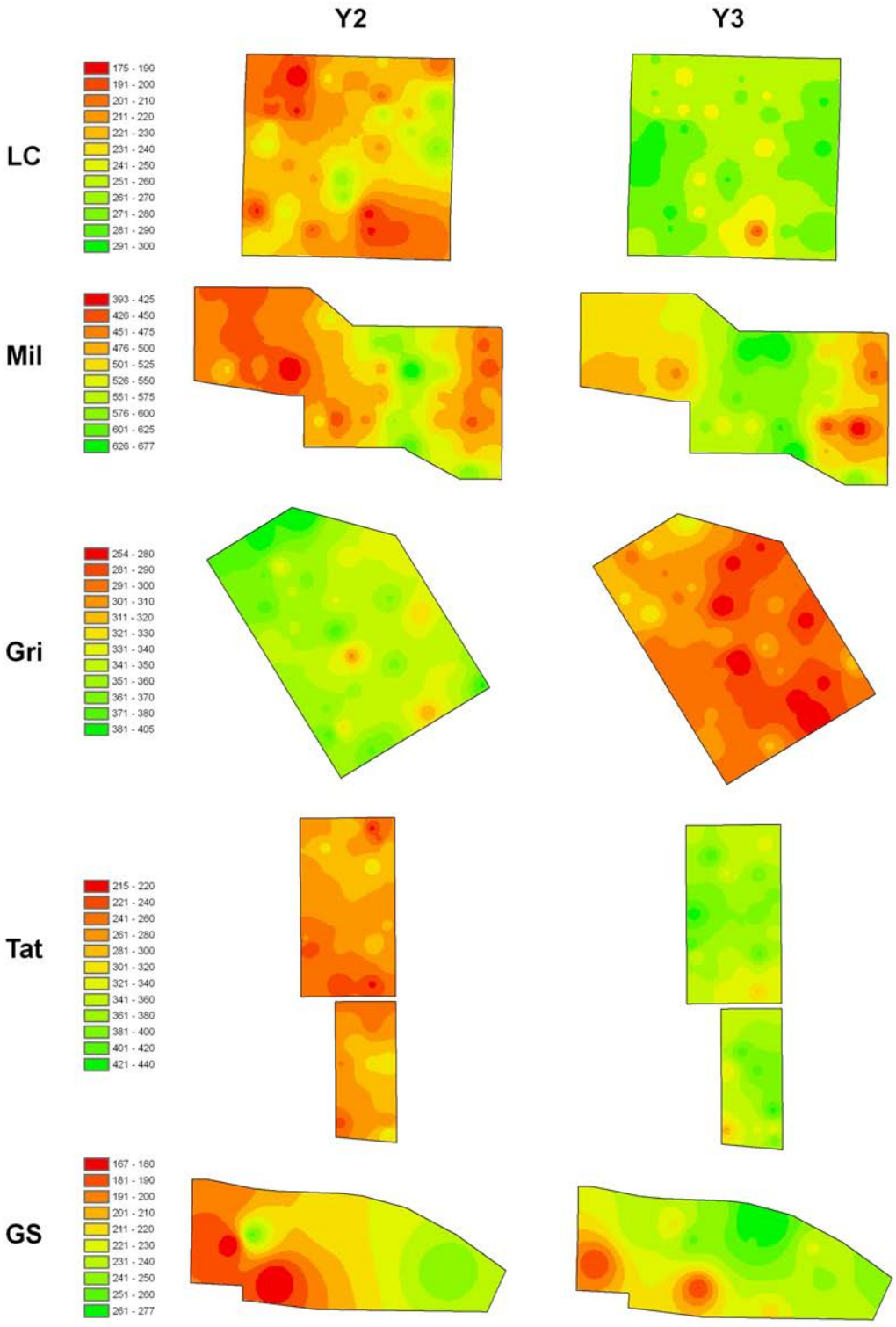


Fig. 20. Variation in estimated vine water use (mm) at the five sites for Y1, Y2 and Y3. Estimated vine water use was calculated from the sum of the product of effective area of shade (EAS) and reference crop evapotranspiration (ET_o) for the periods bud burst to flowering (BB-FL), flowering to veraison (FL-V), veraison to harvest (V-H) and harvest to leaf fall (H-LF). Each map was created using inverse distance weighted interpolation of 40 vines at all sites except Great Southern where number of vines measured varied from 8-40. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Irrigation efficiency (IE) varied between and within sites, between phenological stages and between years. Gri had the highest IE and was consistently greater than 1 indicating that it was well watered whereas GS had the lowest IE (Fig. 21). High rainfall from bud burst to flowering and from harvest to leaf fall at GS provided ample water to meet crop demand during these periods, however, from bud burst to harvest GS had very little rain suggesting the vines were severely water stressed. At LC, IE was consistently less than 1 (apart from bud burst to flowering in Y2). Rainfall from harvest to leaf fall in Y2 (73 mm) and bud burst to flowering in Y3 (73 mm) may have partly compensated for the low amount of irrigation during these periods but generally the vines at LC would have been water stressed. At Tat, IE exceeded 1 during the period from bud burst to flowering in Y2 and Y3 when there was very low rainfall. IE was less than 1 from veraison to harvest in Y2 and Y3 at Tat indicating vine water stress during this period. Rainfall at Tat from harvest to leaf fall in Y2 (89 mm) and Y3 (62 mm) may have partly compensated for the low amount of post harvest irrigation. IE was consistently less than 1 at Mil in Y2 suggesting vines may have been water stressed. Irrigation was increased in Y3 but IE was still less than 1 from bud burst to flowering and from veraison to harvest suggesting vines may have been water stressed during these periods although there was 79 mm rain from bud burst to flowering in Y3. Also, block 1 (at Mil there were 2 separate irrigation control valves in the experimental area) received approximately 30% less water than block 2 in Y2.

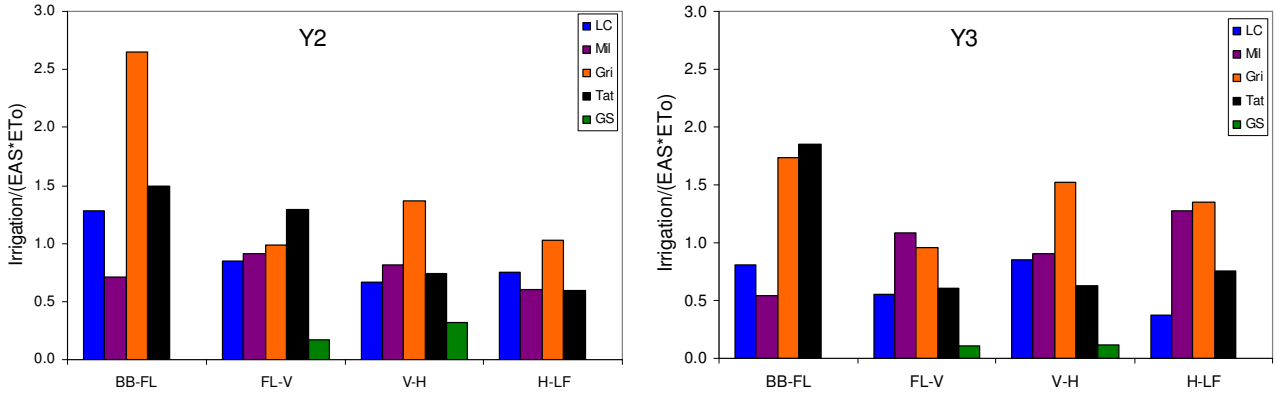


Fig. 21. Average irrigation efficiency (IE) at the five sites during Y2 and Y3 for the periods from bud burst to flowering (BB-FL), flowering to veraison (FL-V), veraison to harvest (V-H) and harvest to leaf fall (H-LF). IE was calculated as the ratio of irrigation to estimated vine water from measurements of irrigation inputs and EAS (see text for details). IE was calculated for 40 vines at all sites except Great Southern where number of vines measured varied from 8-40. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

There was consistent within site variation in seasonal (bud burst to leaf fall) IE at all sites (Fig. 22). Variation at most sites approached twofold. At Gri the IE ranged from 1.1 to 1.5 in Y3 suggesting some vines at this site may have been over-irrigated. At LC, the IE was consistently less than 1 and IE at Mil ranged from 0.5 to 0.9 in Y2. At both LC and Mil there would have been a substantial yield penalty. At Tat the range in IE was below and above 1 suggesting some vines were under-irrigated and some were over-irrigated.

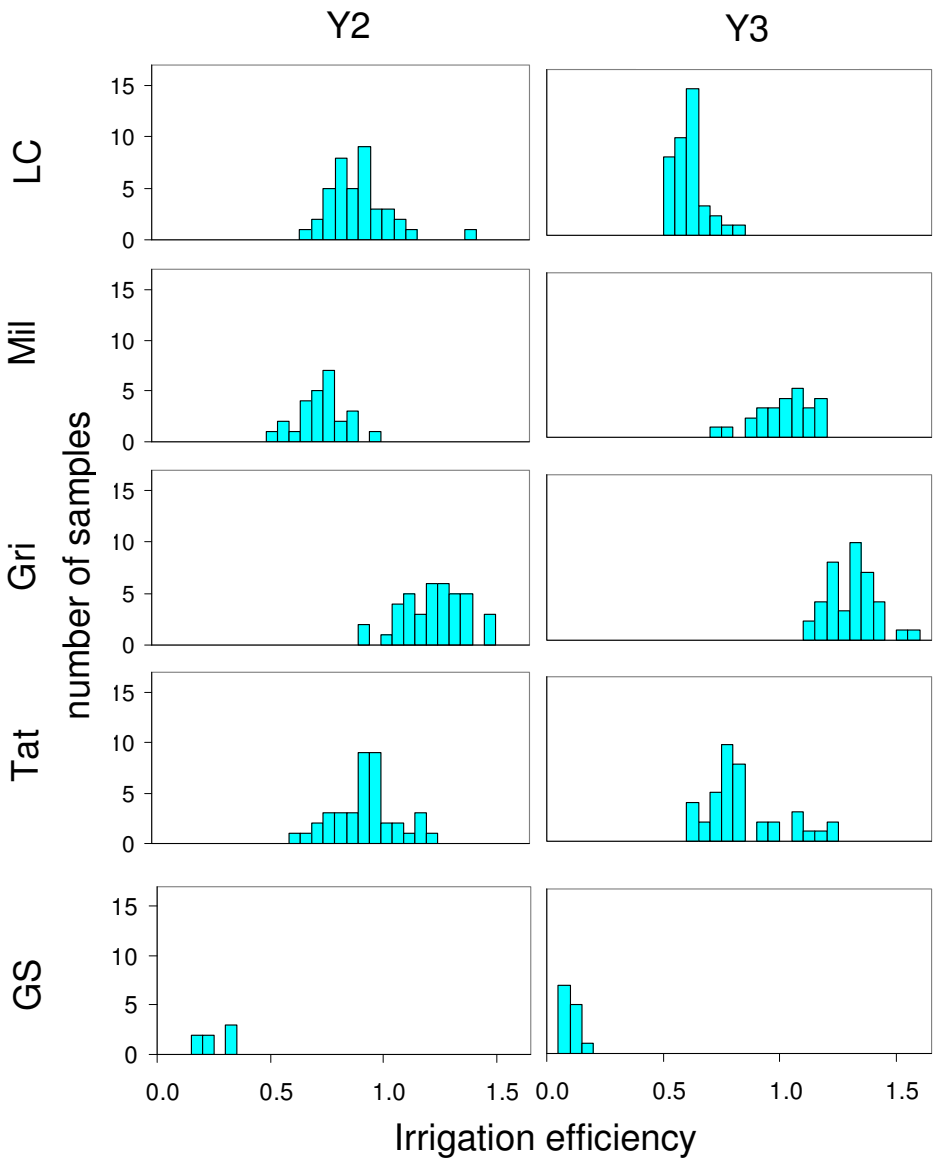


Fig. 22. Frequency distribution of seasonal irrigation efficiency (IE) per vine from bud burst to leaf fall at the five sites for Y2 and Y3. IE was calculated as the ratio of irrigation to estimated vine water use from measurements of irrigation inputs and EAS (see text for details). IE was calculated for 40 vines at all sites except Great Southern where number of vines measured varied from 8 – 40. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

WUE was highly variable with at least a four-fold difference at each site (Fig. 23). Variability in WUE was greatest at Mil, Tat (Y1) and GS. High variability in WUE at Mil was associated with yield variability, Tat was due to irrigation variability from blocked emitters and GS was due to a combination of yield and irrigation variability. High WUE at GS in Y3 was due to substantial rainfall in autumn, winter and spring (i.e. from harvest to the flowering).

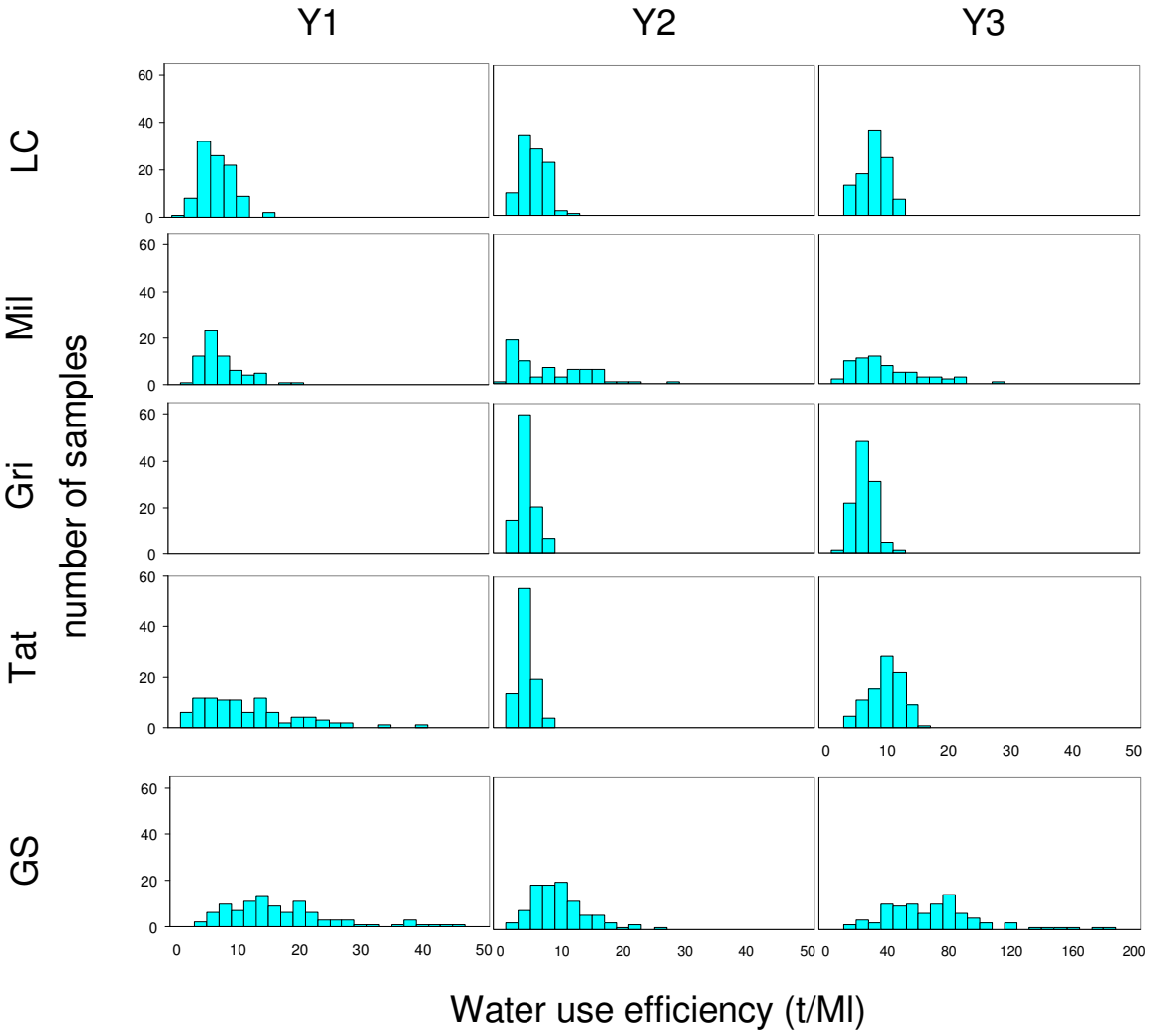


Fig. 23. Frequency distribution of water use efficiency per vine (t/Ml) at the five sites for Y1, Y2 and Y3. WUE was calculated as the ratio of yield to irrigation inputs for the period from bud burst to harvest. WUE was calculated for 100 vines at all sites except Griffith in Y1. Note the change in scale for Great Southern in Y3 compared to other sites and years.

Nutrition

This section provides a descriptive summary of plant nutrient data collected at the five sites in Y1, Y2 and Y3. Vegetative tissue data presented here focuses on nutrient concentrations in petioles at flowering due to the predominant use of this indicator by industry. Nutrient concentrations of petioles at veraison, blades at flowering and veraison, berry homogenate at harvest and N and Cl concentrations of free-run juice at harvest were also measured and are presented. Correlations between soil nutrient concentrations and vegetative tissue nutrient concentrations, and between vegetative tissue and berry homogenate (berry) and free-run juice (juice) nutrient concentrations are reported later.

Vegetative tissue nutrient status and range – petioles at flowering

Nutrient concentrations of macro-nutrients (Fig. 24) and micro-nutrients (Fig. 25) in petioles at flowering were compared to guidelines (Robinson et al., 1997).

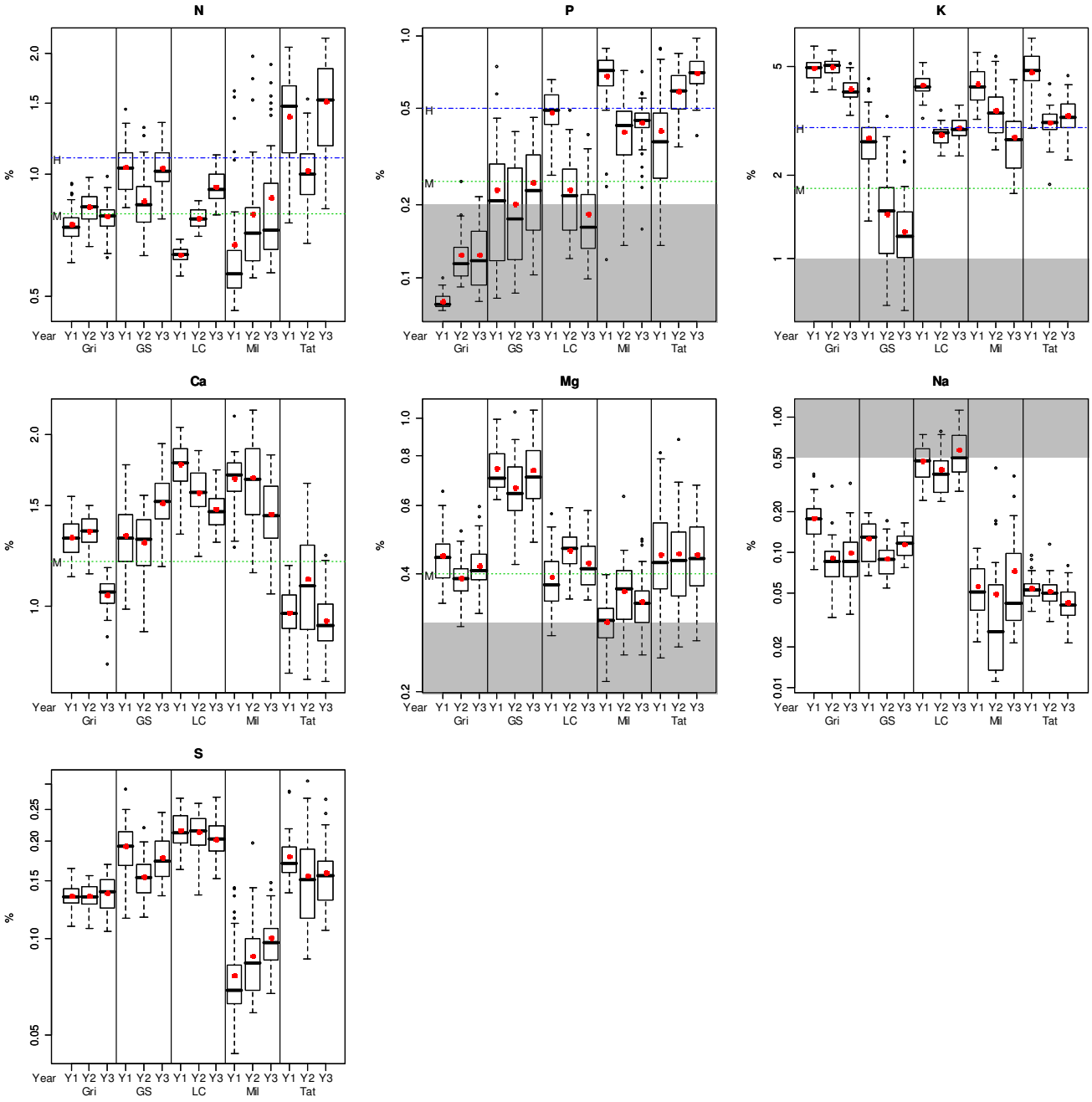


Fig. 24. Distribution of N, P, K, Ca, Mg, Na and S (%) in petiole samples collected at flowering across five sites for Y1, Y2 and Y3. The horizontal lines indicate boundaries between deficient (shaded), marginal (M), adequate, high (H) and toxic (shaded) classifications adopted from Robinson et al. (1997). Boxes extend from the 25th (Q1) to the 75th (Q3) percentile, the median is indicated by the central line and the mean is indicated by •. Whiskers are calculated as Q1 - 1.5*(Q3-Q1) and Q3 + 1.5*(Q3-Q1); values outside the whiskers are plotted individually. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

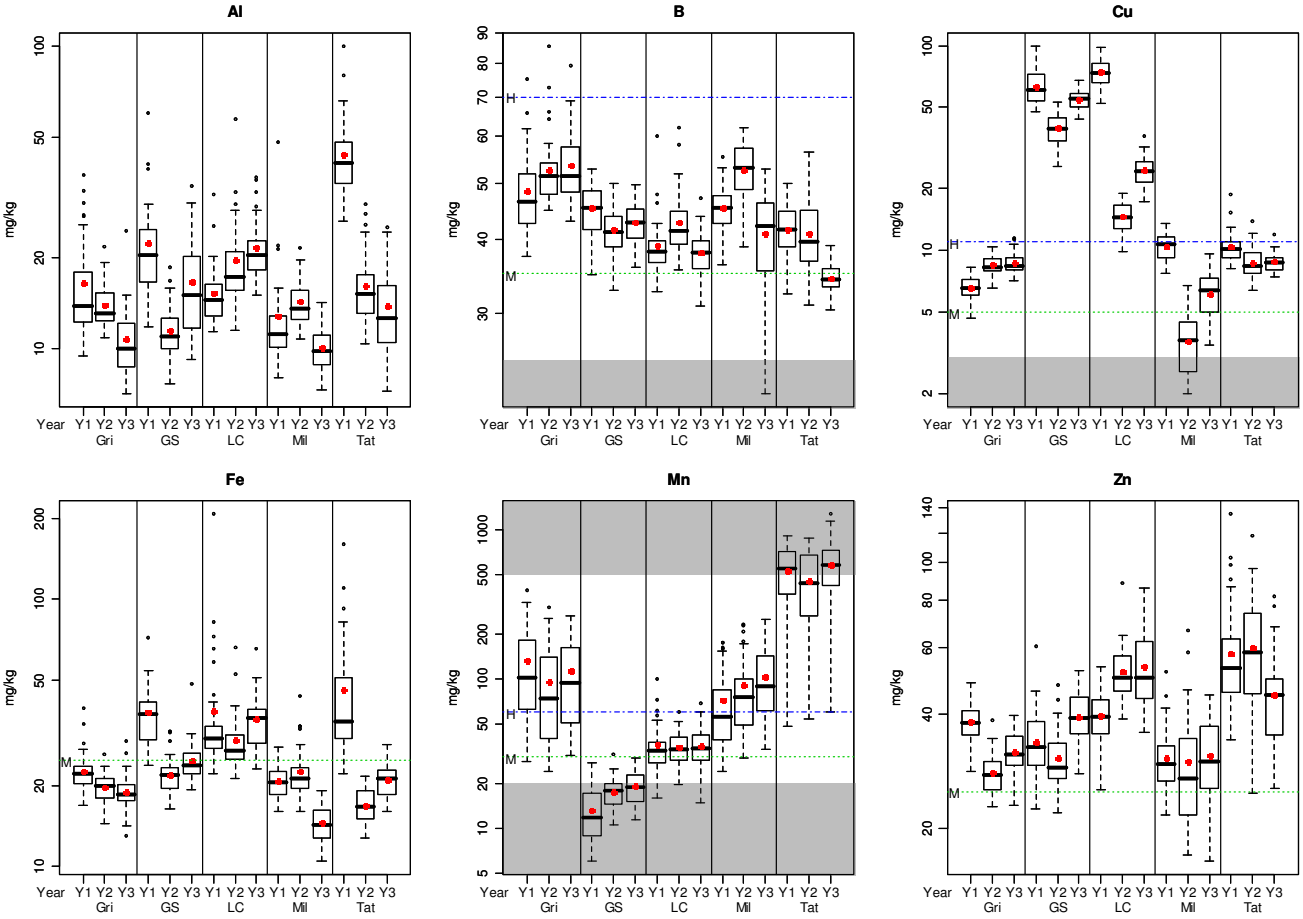


Fig. 25. Distribution of Al, B, Cu, Fe, Mn and Zn (mg/kg) in petiole samples collected at flowering across five sites for Y1, Y2 and Y3. The horizontal lines indicate boundaries between deficient (shaded), marginal (M), adequate, high (H) and toxic (shaded) classifications adopted from Robinson et al. (1997). Boxes extend from the 25th (Q1) to the 75th (Q3) percentile, the median is indicated by the central line and the mean is indicated by •. Whiskers are calculated as Q1 - 1.5*(Q3-Q1) and Q3 + 1.5*(Q3-Q1); values outside the whiskers are plotted individually. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Mean N concentrations in petioles at flowering indicated that N status ranged from predominantly marginal (Gri, LC and Mil) to high (Tat) and was adequate in all years at GS. P was deficient at Gri, marginal at GS, marginal or adequate at LC and adequate or high at Mil and Tat. K tended to be high at all sites except GS where concentrations fell from adequate (Y1) to marginal (Y2 and Y3). Ca was consistently below adequate at Tat. Mg was consistently marginal at Mil. Na status at LC was close to toxic in Y1 and Y2, and toxic in Y3. Mean S concentrations in petioles at flowering at LC, Gri, Tat and GS ranged between 0.13 and 0.22 %; mean S concentrations at Mil were noticeably lower, ranging from 0.08 to 0.10 %. Recommended levels are not suggested for S by Robinson et al. (1997).

Prior to plant nutrient testing for this study, Na toxicity at LC and Ca deficiency at Tat were recognised as problems by vineyard staff. Poor quality irrigation water and subsequent accumulation of salts in the soil profile and vines has been a concern in the LC region for a number of years. Regular applications of Ca are made at the Tat site. Vineyard staff attributed weak canes (that could be damaged by wire-lifting) to Ca deficiency. By contrast, P deficiency at Gri was not considered a problem and the vineyard owner cited the high vigour of the vines as a reason for not applying additional P. While P concentrations in petioles at flowering at Gri were consistently low in each season, soil P, blade P and homogenate P were generally not low compared to other sites (see Figs. 14, 26 and 30). It is unclear whether comparatively low P in petioles at flowering was caused by genetic or environmental differences between sites. Vines at the Gri

site were own-rooted and the clone was unknown. Regardless of the cause of comparatively low petiole P at flowering, the result supports the conclusion of Skinner et al. (1987) that petioles at flowering do not provide the best indication of vine P status.

There were distinct trends for increasing N concentrations at LC and increasing P concentrations at Tat over the three seasons. At LC, P had a distinctive decreasing trend, with the mean nutrient status of petioles at flowering being classed as adequate in Y1, marginal in Y2 and deficient in Y3. K concentrations at GS and Mil tended to decline over the three seasons. Temporal stability of relative nutrient concentrations within sites is presented and discussed in the paper 'Spatial patterns and temporal stability of grapevine nutrition: implications for sampling and management' (McClymont et al. submitted).

Typically, mean Al concentrations in petioles at flowering ranged from 10-22 mg/kg. Recommended levels are not suggested for Al by Robinson et al. (1997). Tat was the only site to record a below adequate B status of petioles at flowering (Y3). Cu status was high at GS and LC, while Mil recorded both adequate (Y1 and Y3) and marginal (Y2) Cu status. Fe status was found to be below the adequate range at all sites in most years, except LC. Mn status was high (Y2) to toxic (Y1 and Y3) at Tat, high at Gri (Y1, Y2 and Y3) and Mil (Y2 and Y3), and deficient at GS. Mean Zn concentration in petioles at flowering was considered to be adequate at all sites in all years.

Cu, S, Mn and Zn fungicides and foliar sprays were occasionally used prior to sample collection and surface contamination of samples by these sprays is possible despite thorough washing of samples. However, the highest Mn levels were found at the Tat site where Mn was applied only once three to four weeks prior to flowering each season. There was a high correlation between berry Mn and vegetative tissue Mn concentrations suggesting that the high concentrations at this site may be reflective of tissue concentrations rather than surface contamination alone. High correlations between vegetative tissue Mn and soil Mn concentrations also occurred. According to Clingleffer (pers. comm.), S contamination is unlikely to have occurred.

The range in nutrient status of individual vines within a site varied between nutrients, sites and years. As a general observation, Gri tended to have relatively low coefficients of variation (standard deviation/mean, data not presented). There were few examples of all sampled vines at a site falling within the same nutrient status classification. For example, individual vine P concentrations of petioles at flowering ranged from deficient to high on five occasions (Mil each season, GS Y1, and Tat Y1). At GS, mean P concentration was marginal or adequate each year but more than a quarter of the vines tested were deficient. Similarly, although the mean Na concentration at LC in Y2 was below the toxic level, nine of the 40 vines had levels that were classified as toxic. These results show that sampling procedures that pool material from across a site will potentially suggest 'adequate' levels of these nutrients when in fact large numbers of vines would be individually classed as deficient. The implications of within-site variation in nutrient requirements and the spatial patterns and temporal stability of this variation are examined in the paper 'Temporal and spatial patterns of grapevine nutrition: implications for sampling and management' (McClymont et al., 2009). Furthermore, grower sampling procedures to account for spatial variability in nutrition have been developed (McClymont and Goodwin, 2009).

Nutrient levels in blades and petioles at flowering and veraison

Nutrient concentrations were generally higher in petioles than blades for P, K, Mg and Na, and lower in petioles than blades for N, Ca, S, Al, B, Cu, Fe, Mn, and Zn. However, as can be seen in Figures 26 and 27 there were exceptions to these trends for certain sites and seasons. Likewise, general trends existed for nutrient concentrations to increase (Ca, Mg, Na, Fe, Mn) or decrease (N, P, K, S, Cu) between flowering and veraison (Fig. 28 and 29).

Relationships between nutrient concentrations in petioles and blades and between nutrient concentrations in samples taken at flowering and veraison were generally consistent with previously reported trends (Christensen 1969, 1984 and Pub.NG10-00; Atalay 1978; Robinson et al. 1978; Conradie 1980; Peacock et al. 1989; Skinner and Matthews 1990; Whiting 1990; Prior et al. 1992). However, continued analysis of this data offers opportunities to further improve understanding of nutrient partitioning within grapevines. For example, Atalay (1978) reported that when petioles and blades of Thompson Seedless grapevines (American R-99 rootstocks) had P concentrations greater than 0.215 % at fruit-set then petiole P was

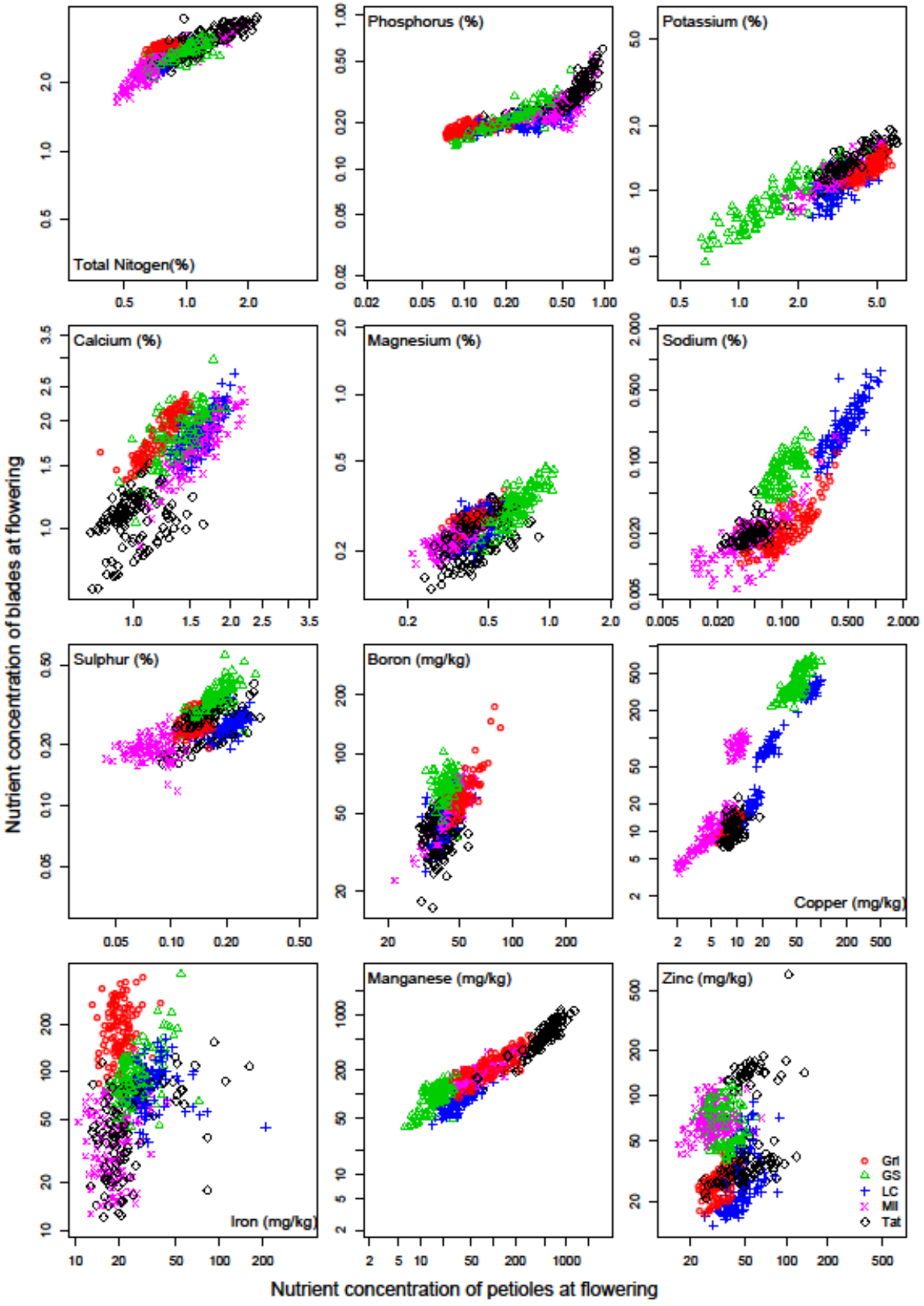


Fig. 26. Comparison of nutrient concentration in petioles and blades at flowering. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

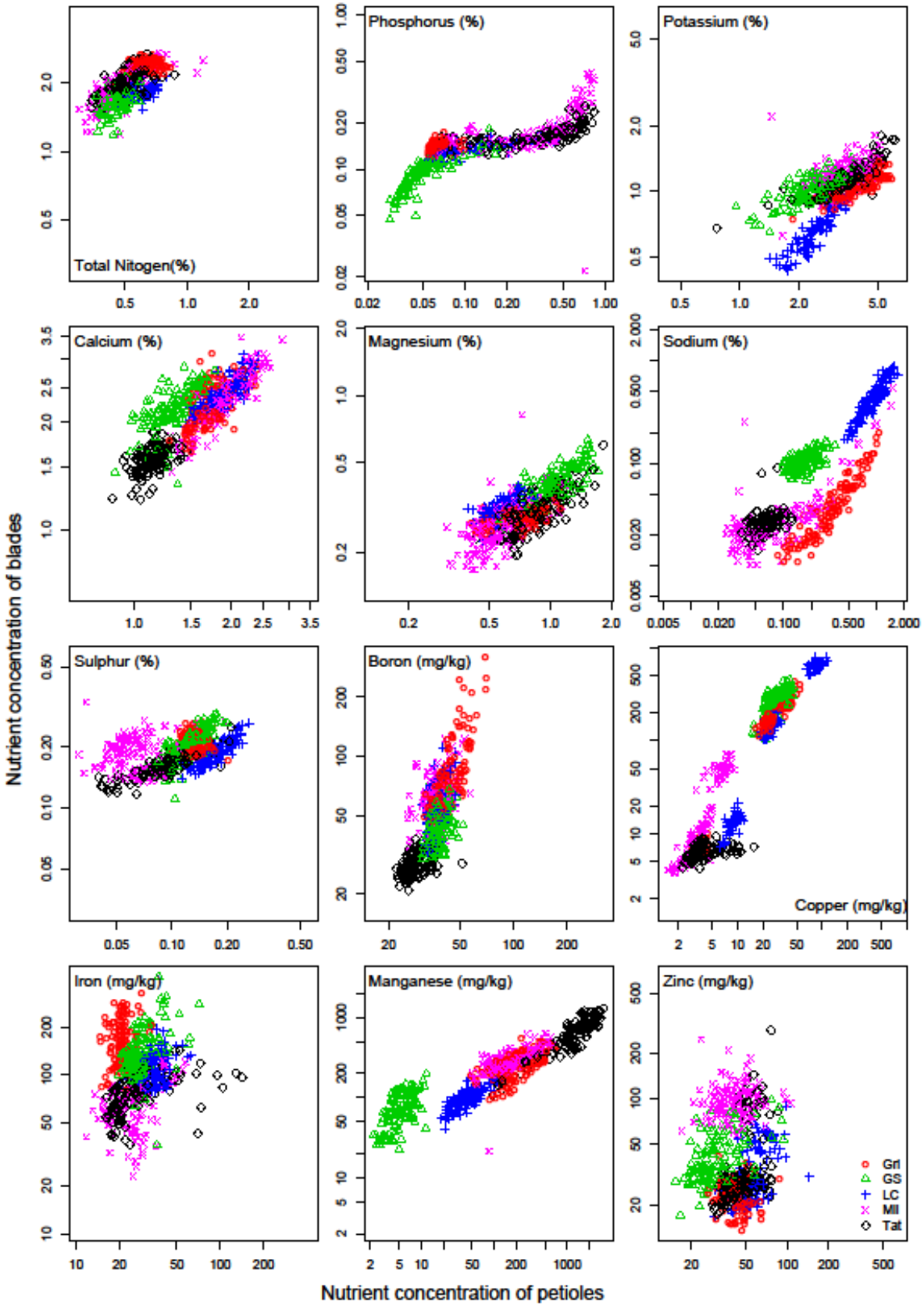


Fig. 27. Comparison of nutrient concentration in petioles and blades at veraison. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

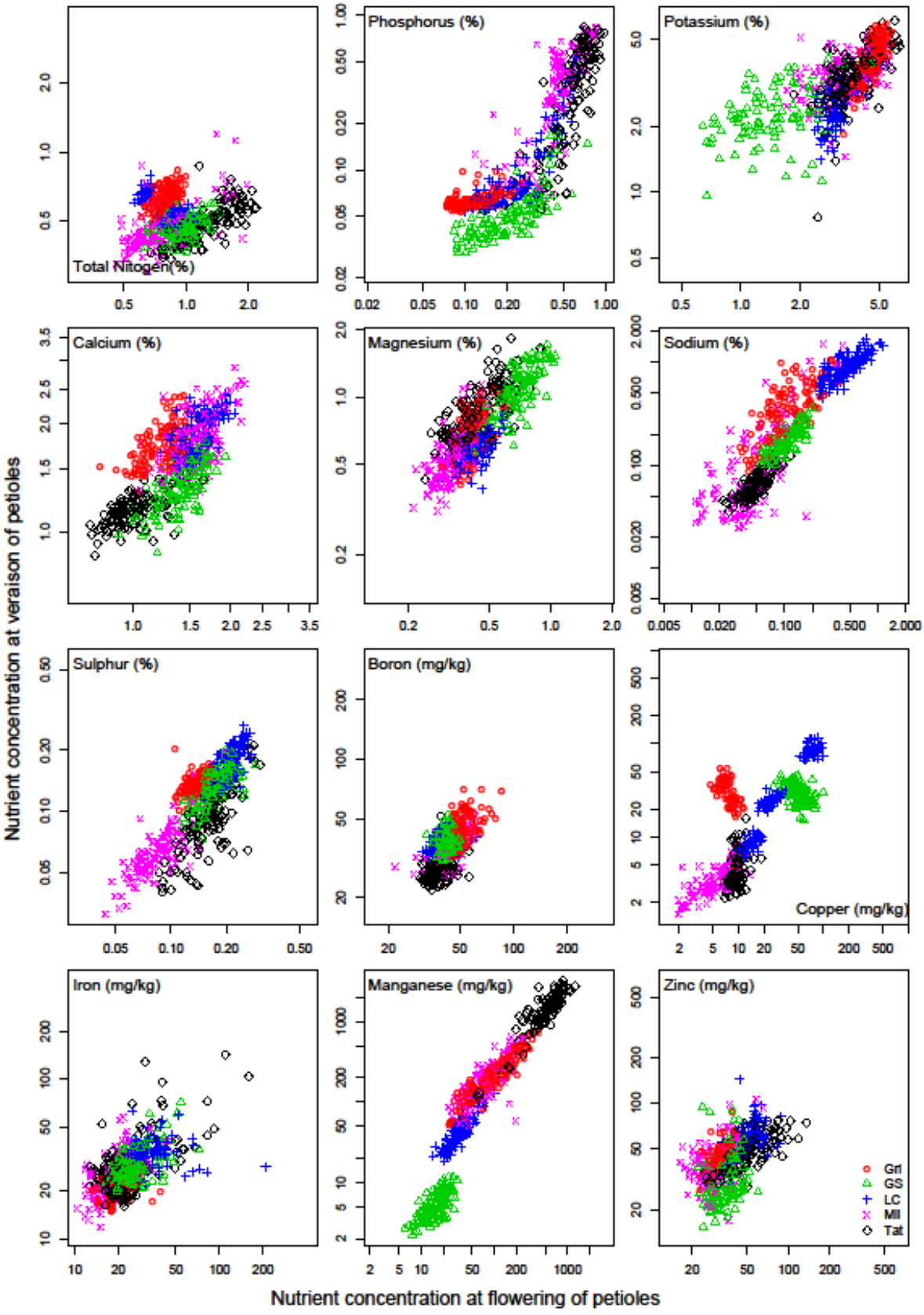


Fig. 28. Comparison of nutrient concentration at flowering and veraison in petioles. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

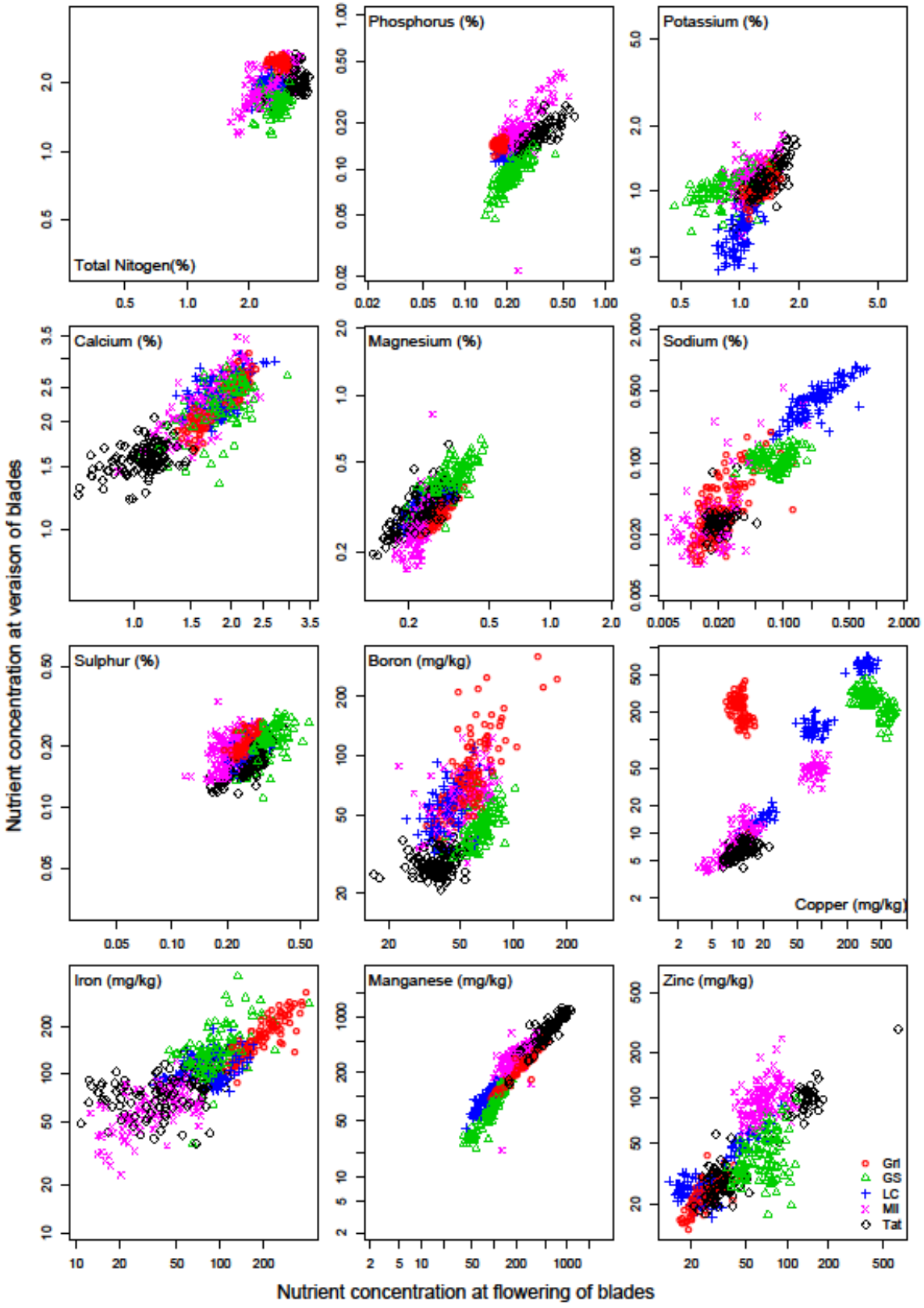


Fig. 29. Comparison of nutrient concentration at flowering and veraison in blades. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

greater than blade P, and that when P concentrations were less than 0.215 % then blade P was greater than petiole P. A similar balance point was found at flowering in this study (Fig. 26), however the range of P values (0.074-0.975 % and 0.140 – 0.605 % for petioles and blades, respectively, at flowering) was greater than in Atalay's study (0.074 – 0.759 % and 0.157 – 0.389 % for petioles and blades, respectively, at fruit set). Atalay (1978) reported a linear relationship between petiole and blade P, whereas a non-linear relationship could be suggested from our data.

Berry homogenate and free-run juice nutrient concentrations

Mean nutrient concentrations in berry homogenate at harvest (Fig. 30 and Fig. 31) were highest for K (0.84 – 1.23 %), followed by N (0.42 – 0.69 %), Ca (0.08 – 0.18 %), P (0.07 – 0.14 %), Mg (0.05 – 0.07 %), S (0.04 – 0.07 %), and Na (0.01 – 0.06 %). Mean concentrations of N in free-run juice ranged from 133 – 618 mg/l while mean Cl concentrations ranged from 19-367 mg/l (Fig. 32). The range in nutrient concentrations within a site varied between nutrients, sites and years. As a general observation, Gri tended to have relatively low coefficients of variation while Mil tended to have the greatest coefficient of variation for a given nutrient (data not presented).

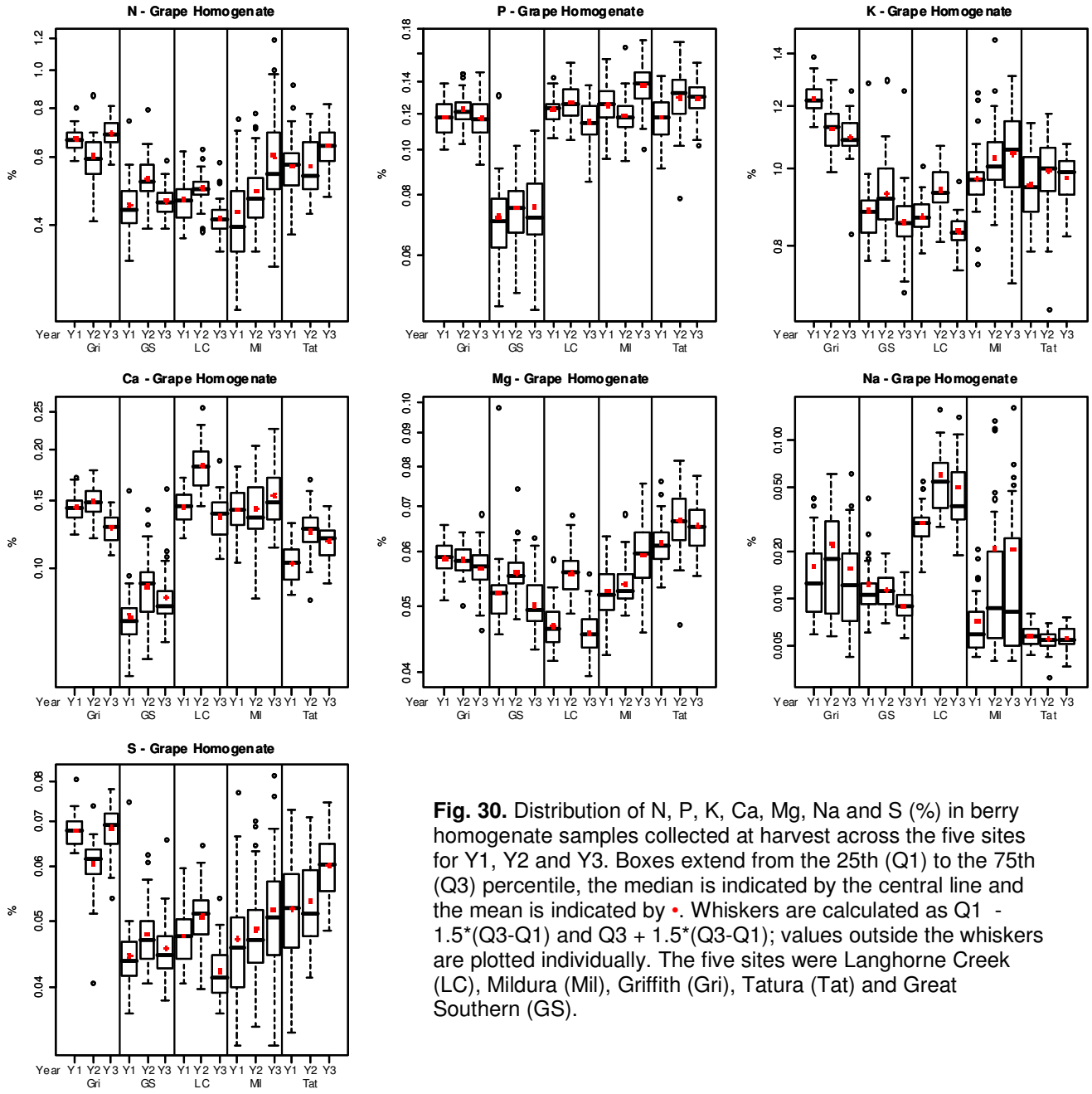


Fig. 30. Distribution of N, P, K, Ca, Mg, Na and S (%) in berry homogenate samples collected at harvest across the five sites for Y1, Y2 and Y3. Boxes extend from the 25th (Q1) to the 75th (Q3) percentile, the median is indicated by the central line and the mean is indicated by •. Whiskers are calculated as Q1 - 1.5*(Q3-Q1) and Q3 + 1.5*(Q3-Q1); values outside the whiskers are plotted individually. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

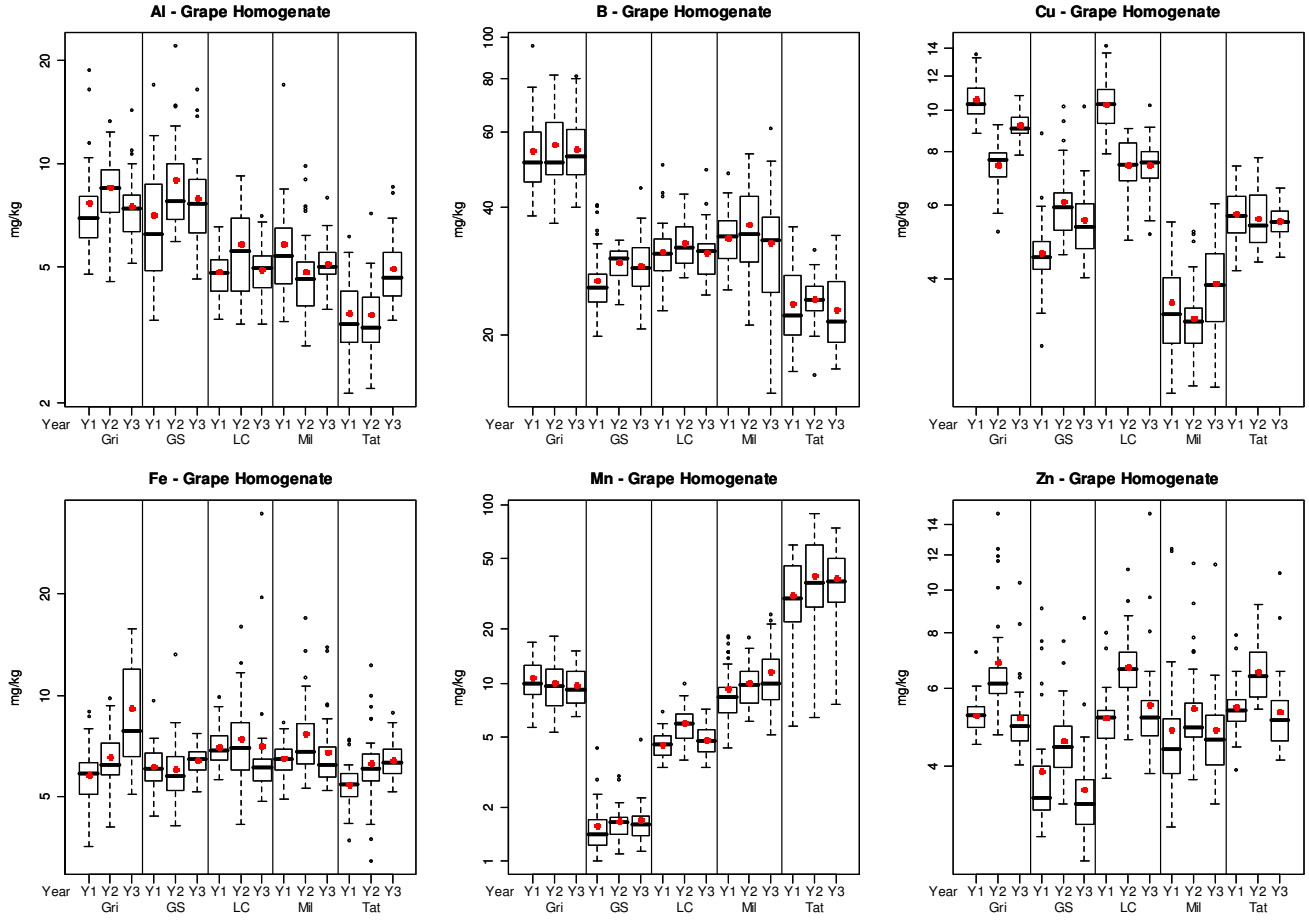


Fig. 31. Distribution of Al, B, Cu, Fe, Mn, and Zn (mg/kg) in berry homogenate samples collected at harvest across five sites for Y1, Y2 and Y3. Boxes extend from the 25th (Q1) to the 75th (Q3) percentile, the median is indicated by the central line and the mean is indicated by •. Whiskers are calculated as Q1 - 1.5*(Q3-Q1) and Q3 + 1.5*(Q3-Q1); values outside the whiskers are plotted individually. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

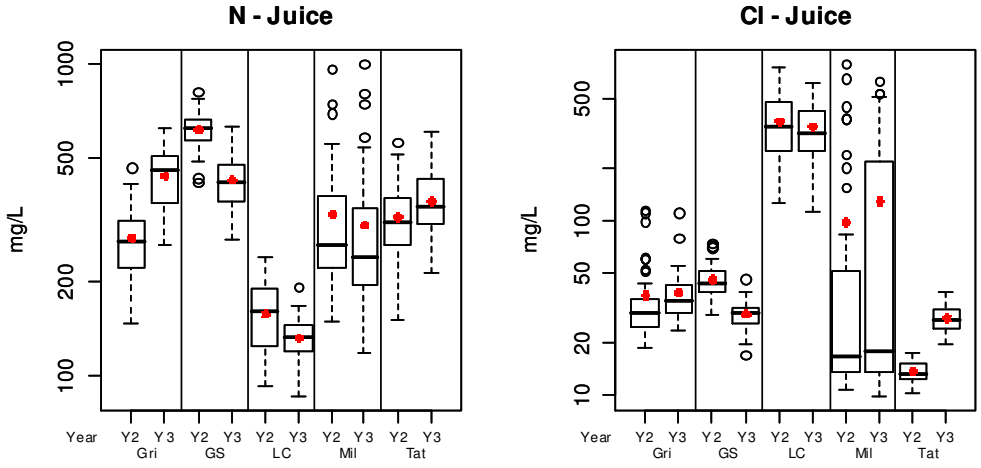


Fig. 32. Distribution of N and Cl (mg/l) in free-run juice samples collected at harvest across five sites for Y1, Y2 and Y3. Boxes extend from the 25th (Q1) to the 75th (Q3) percentile, the median is indicated by the central line and the mean is indicated by •. Whiskers are calculated as Q1 - 1.5*(Q3-Q1) and Q3 + 1.5*(Q3-Q1); values outside the whiskers are plotted individually. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Phenology

Phenological dates for each site and year are shown in Table 11. Earliest bud burst date occurred at GS and LC (5 September). Flowering date was reasonably consistent at each site varying by a maximum of seven days at Griffith. The number of days between flowering and veraison was consistent between years and across sites, ranging from 59 to 76.

Table 11. Phenological dates at each site. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

	Bud burst			Flowering			Veraison			Harvest			Leaf fall		
Site	Y1	Y2	Y3	Y1	Y2	Y3	Y1	Y2	Y3	Y1	Y2	Y3	Y1	Y2	Y3
LC	5/9*	29/8	12/9	8/11*	8/11	7/11	23/1	23/1	16/1	6/3	14/2	18/2	31/5	2/5	24/4
Mil	20/9*	14/9	26/9	2/11	2/11	5/11	18/1	11/1	4/1	21/2	12/2	20/2	19/5	10/5	10/5
Gri	23/9	19/9	11/9	10/11	3/11	2/11	25/1	10/1	8/1	6/3	12/2	20/2	5/6	22/5	1/6*
Tat	19/9*	19/9	19/9	22/11	14/11	16/11	1/2	22/1	15/1	17/3	27/2	17/3	17/5	29/5	21/5
GS	23/9	8/9	5/9	20/12	20/11	20/11	26/2	25/1	1/2	25/4	14/3	25/3	1/6*	9/5	13/5

* dates were estimated

Vine size

Spectral data – NDVI, PCD, Vigour

A similar outcome was observed when looking at the spatial variation of the aerial imagery data, in this case normalised difference vegetation index (NDVI) (Fig. 33). NDVI, in the main, did not resemble the spatial pattern of elevation and EM38 and gamma spectrometer data (Figs. 5 and 6). Some similarity can be seen between the topography variation at Tat and NDVI, which could be contributed to the variation in topsoil depth caused by land forming practices. NDVI spatial patterns were similar from year-to-year at each site although there are some areas within the some sites showing marked differences between years (e.g. Gri Y2 and Y3).

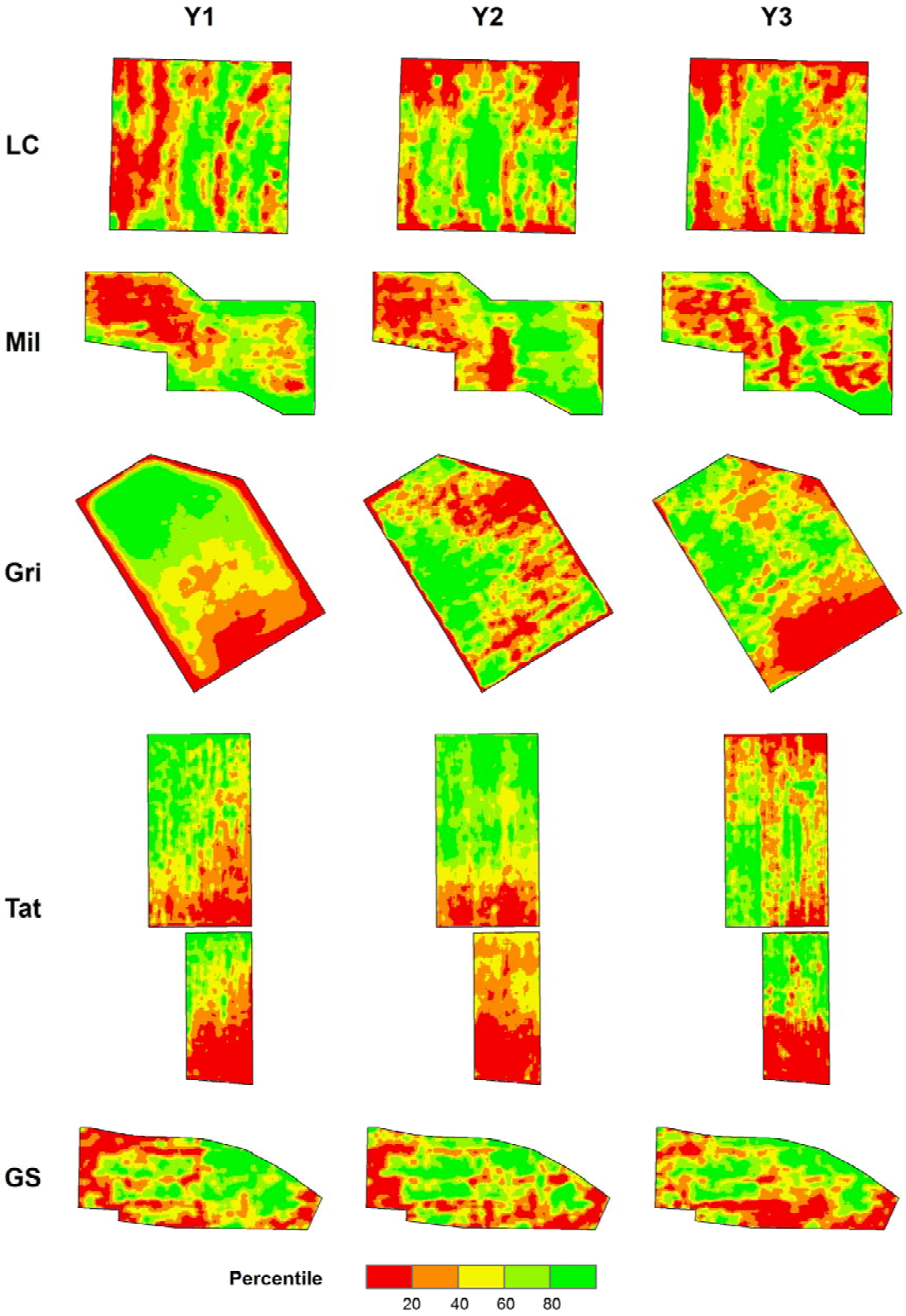


Fig. 33. Relative variation maps of normalised difference vegetation index (NDVI) at Langhorne Creek (LC), Griffith (Gri), Tatura (Tat), Mildura (Mil) and Great Southern (GS) for Y1, Y2 and Y3, NDVI was derived from aerial imagery date collected at veraison for each site. A neighbourhood statistical procedure was used to derive this figure without the removal of non-vine data points.

Light interception

In each season, EAS at the Griffith and Langhorne Creek sites increased rapidly from budburst to flowering and then plateaued from flowering to veraison (Fig. 34). At other sites, EAS continued to increase between flowering and veraison, albeit at a slower rate. A late season increase in EAS was observed at Great Southern. The effects of cultural practices, such as wire-lifting and shoot trimming, on EAS were evident. For example, in Y2, wires were lifted at the Great Southern site in early-December and shoots were trimmed at the Griffith site in January resulting in decreases in EAS.

Seasonal patterns of canopy radiation interception differed between sites but were similar from season to season. Lower EAS in Y2 at Tatura compared to Y3 was most likely due to a severe frost event shortly after budburst in Y2 that killed many shoots. Growers wishing to utilise EAS assessments for irrigation (Goodwin et al., 2009) or yield management could, therefore, rely on as few as one or two assessments of EAS each year, once the general seasonal pattern was established for a site and provided severe environmental conditions (e.g. frosts or hail) did not occur.

Linear relationships between EAS and water use have been demonstrated for a number of crops, including grapevines (McClymont 2006). It is, therefore, reasonable to suggest that crop water requirements could vary by more than 2-fold at certain sites during veraison, concomitant with EAS variability. In effect, a low vigour area could have a potential crop water use of 1 mm/day, while a high vigour area within the same irrigation unit would have a potential crop water use of 2 mm/day. The grower must then consider how to schedule irrigation to simultaneously avoid over-stressing high vigour areas and over-irrigating low vigour areas.

Vine size is a major determinant of potential yield and capacity to adequately mature fruit. EAS is a rapid, non-destructive, measure of vine size and could be used to guide management decisions regarding crop load. For example, selective thinning of certain areas within a block could be employed to allow for variation in grapevine capacity to mature fruit, whilst other areas may be identified as being able to carry higher than average crop loads.

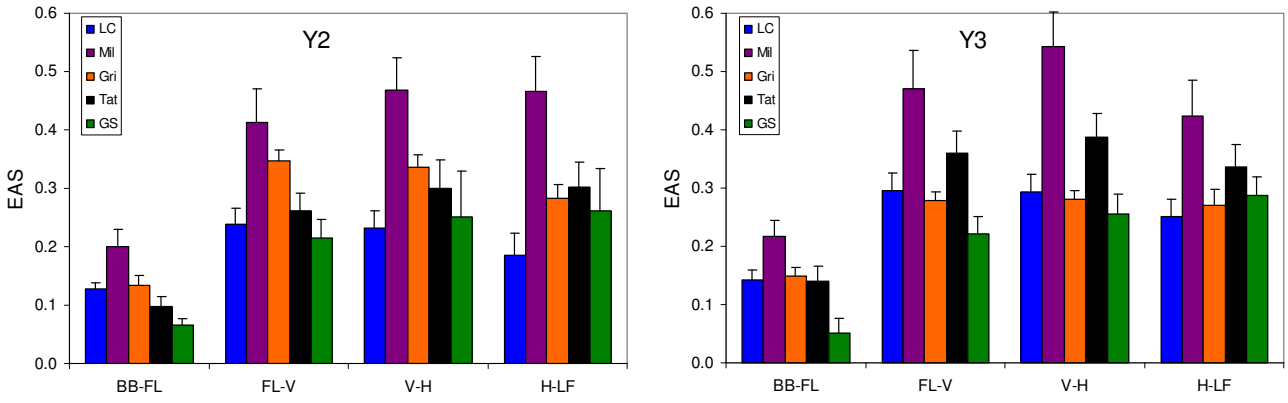


Fig. 34. Average effective area of shade (EAS) at the five sites during Y2 and Y3 for the periods from bud burst to flowering (BB-FL), flowering to veraison (FL-V), veraison to harvest (V-H) and harvest to leaf fall (H-LF). Measurements were made on 40 vines at all sites except Great Southern where number of vines measured varied from 8-40. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS). Error bars indicate standard deviation.

Yield

Vine yield varied within each site (Fig. 35) and between years (Table 12). Mil was the highest yielding site followed by Gri and Tat with similar yields, with the lowest yields coming from GS and LC. Y2 was a significantly lower yielding year than Y1 and Y3 ($P<0.001$). In particular, the yield at Tat was severely reduced in Y2 due to frost damage. This can be seen by the change in the spatial structure in yield when comparing Y1 and Y3 to Y2 in Figure 35.

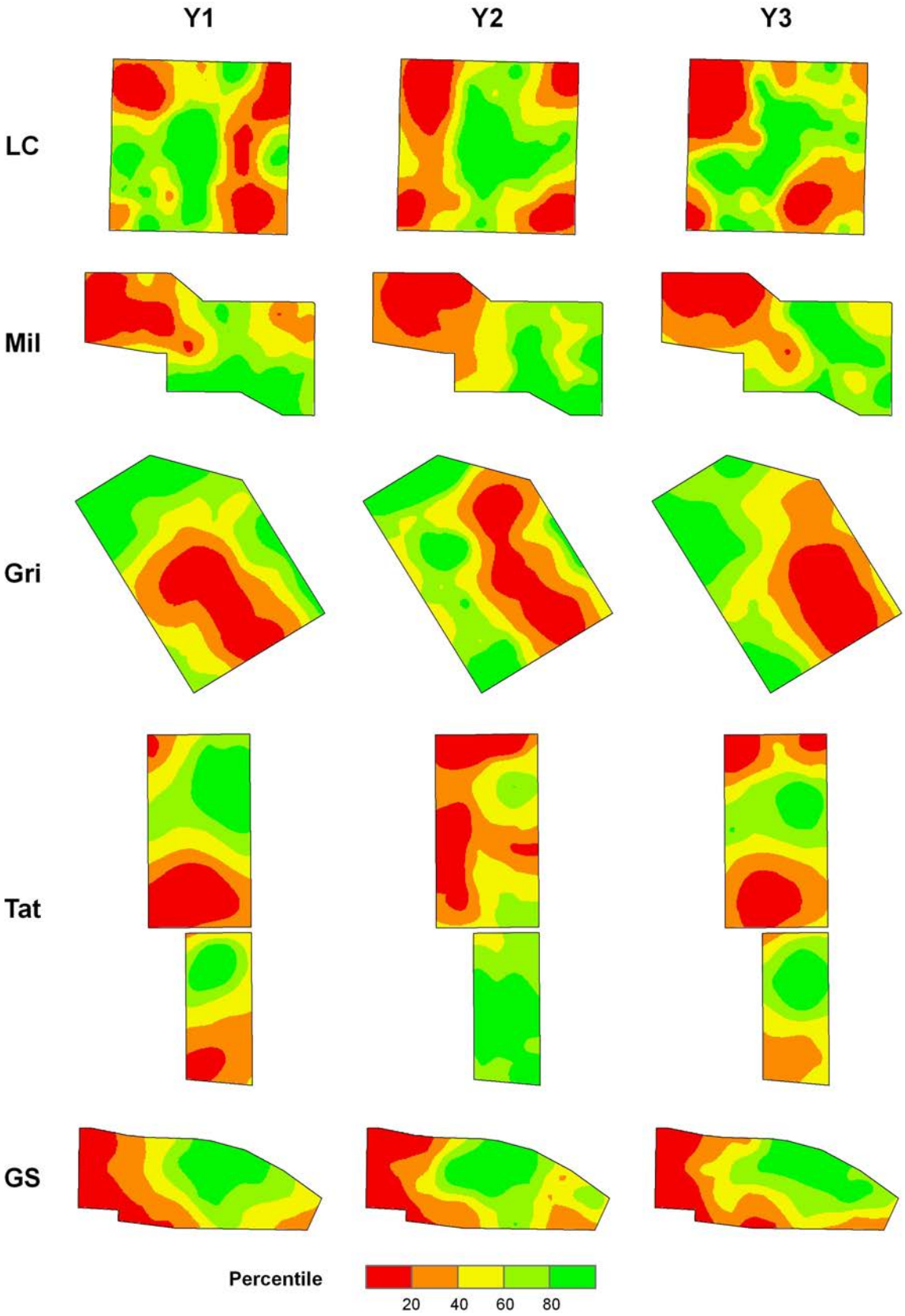


Fig. 35. Relative variation maps of vine yield at Langhorne Creek (LC), Griffith (Gri), Tatura (Tat), Mildura (Mil) and Great Southern (GS) for Y1, Y2 and Y3, Vine yield data were collected from 100 vines and expressed in t/ha before ordinary kriging was used to derive this figure.

Table 12. Statistical comparison of average yield at Langhorne Creek (LC), Griffith (Gri), Tatura (Tat), Mildura (Mil) and Great Southern (GS) for Y1, Y2 and Y3.

Site	Yield (kg/m^2)					
	Y1		Y2		Y3	
	Average	STD	Average	STD	Average	STD
LC	0.95	0.31	0.83	0.32	0.98	0.28
Mil	3.32	1.73	2.32	1.49	3.61	1.66
Gri	2.45	0.52	1.41	0.43	1.77	0.49
Tat	1.88	0.80	0.82	0.26	2.37	0.42
GS	0.89	0.40	0.42	0.18	0.90	0.33

STD – standard deviation

The variation in yield within each block varied in both magnitude and spatial consistency. The lowest average range as a percentage of average yield was Gri, 145 %, followed by Tat, LC, GS, then Mil at 299 % and are similar to that found by Bramley and Hamilton (2004). The spatial pattern of yield was relatively persistent between years across all sites. The Mil and GS sites show strong persistence in their spatial patterns whereas LC and Gri are somewhat less persistent. Further, the spatial patterns do not compare to the spatial patterns produced from the EM38 or elevation data. Some similarity in spatial structure can be seen between the gamma radiometric data and yield data at the GS site.

The yield components also showed a wide range of values: bunch number per m^2 varied from 4.6-fold at GS and LC to 17.6-fold at Mil; the number of berries per bunch variation ranged from 3.6-fold at Tat to 6.3-fold at Mil; and mass per berry exhibited a range of 2.4-fold at Gri and a 4.7-fold at Mil. Generally, the ranges of variation in yield and its components were: yield >> bunch number > berry number per bunch >> mass per berry but at some of the sites the bunch number and number of berries per bunch exhibited equivalent fold differences. These ranges are modestly inflated due to the merging of data across years, nonetheless, the results for a given year and site were of comparable magnitude.

Fruit composition

Whole berry total anthocyanin concentration

Berry anthocyanin concentration showed considerable variation between sites (Fig. 36). LC had the highest berry anthocyanin concentration followed by GS. The warmer high-volume irrigated sites (Gri, Mil and Tat) had lower ($P < 0.0001$) berry anthocyanin concentrations. The year-year variation in berry anthocyanin levels when average across sites was significant ($P < 0.0001$) with highest concentrations in Y3. There was a strong season by site interaction ($P < 0.0001$).

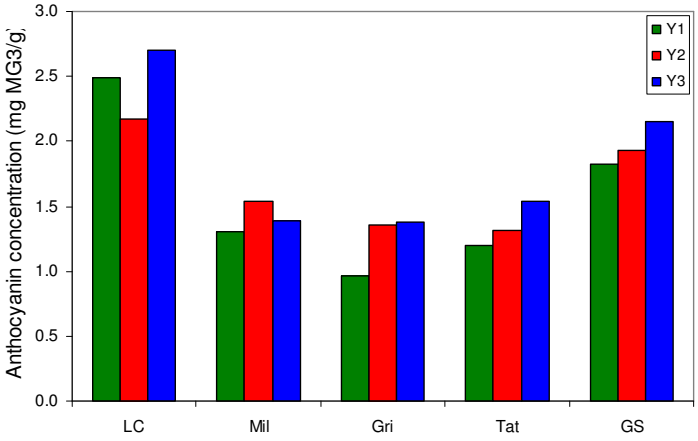


Fig. 36. Average whole berry total anthocyanin concentration (mg malvidin-3-glucoside equivalents/g berry fresh weight) at the five sites for Y1, Y2 and Y3. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Within site variation in berry anthocyanin concentration was large (Fig. 37). Variation was generally twofold. Mil had the greatest variation. For example, berry anthocyanin concentration ranged from 0.6 to 2.4 mg/g in Y2 at Mil. The least variation occurred at Gri ranging from 0.5 to 1.2 mg/g in Y1.

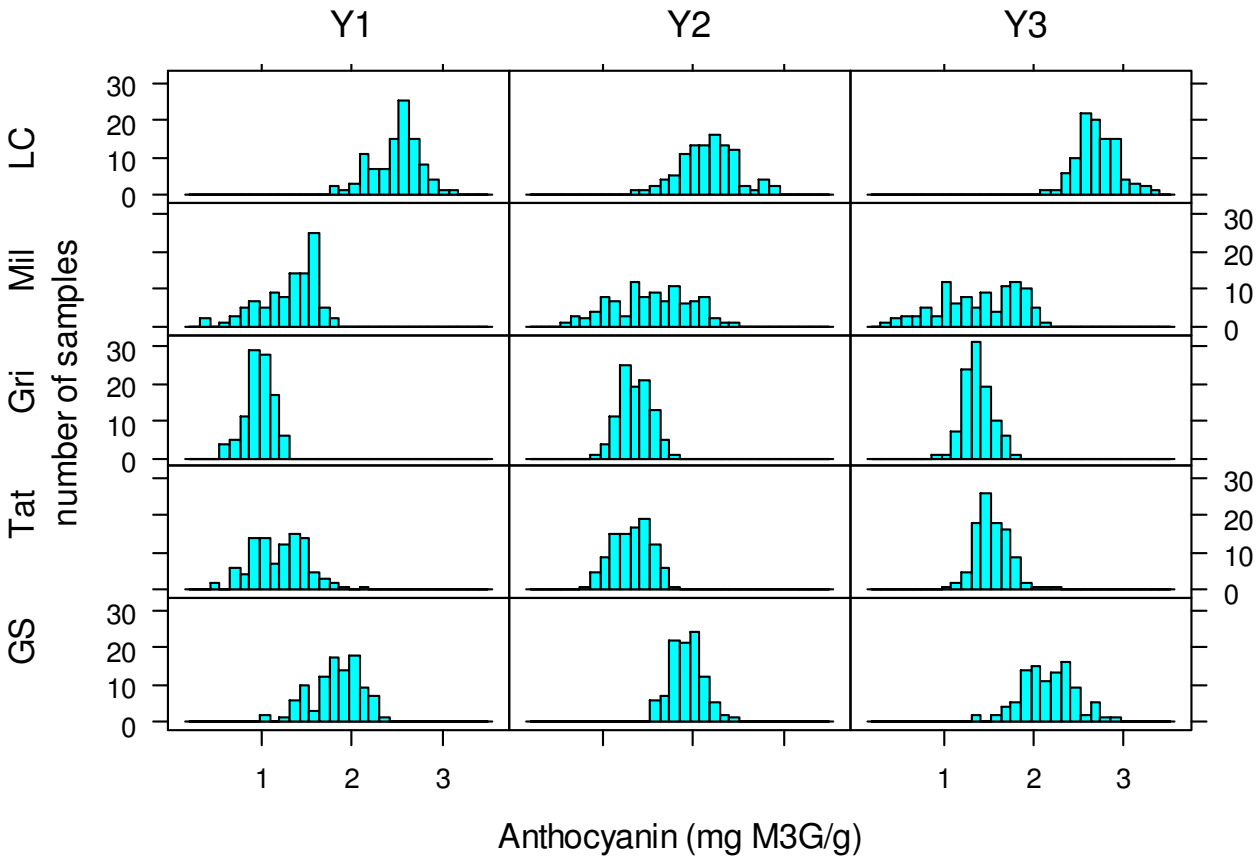


Fig. 37. Frequency distribution of whole berry total anthocyanin concentration (mg malvidin-3-glucoside equivalents/g berry fresh weight) at the five sites for Y1, Y2 and Y3. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

The strong correlation between years for individual vine data from all 5 sites suggests that the factors impacting on anthocyanin concentration remained reasonably consistent from year-to-year (Fig. 38). However, within a site there was a poor relationship between years.

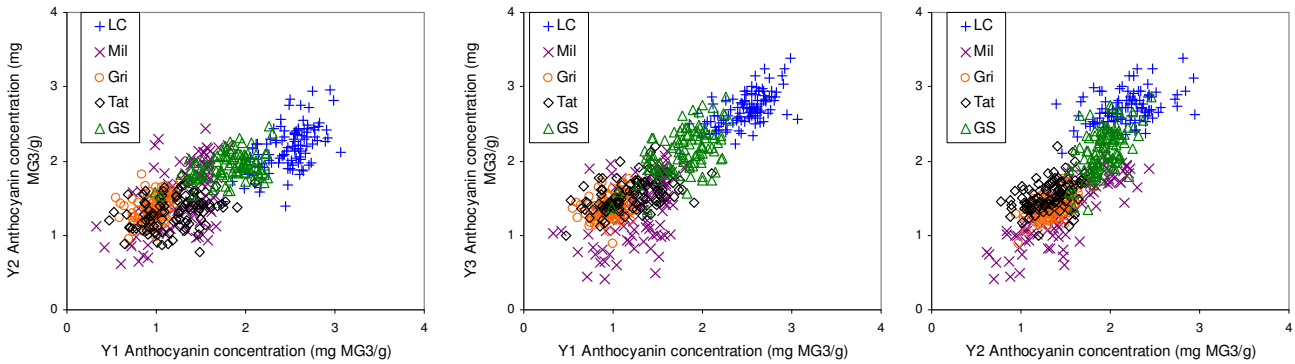


Fig. 38. Comparison between years of whole berry total anthocyanin concentration (mg malvidin-3-glucoside equivalents/g berry fresh weight) for individual vines at the five sites. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Whole berry total tannin concentration

Berry tannin concentration varied across sites ($P < 0.00001$) as well as from year-to-year ($P < 0.00001$) (Fig. 39). LC had the highest berry total tannin concentration but unlike anthocyanin concentration, the next highest tannin concentration was at Mil. Y2 consistently had the highest berry total tannin concentration. There was also a site x season interaction, i.e., the magnitudes of regional differences in berry tannin concentration were season dependent ($P < 0.00001$).

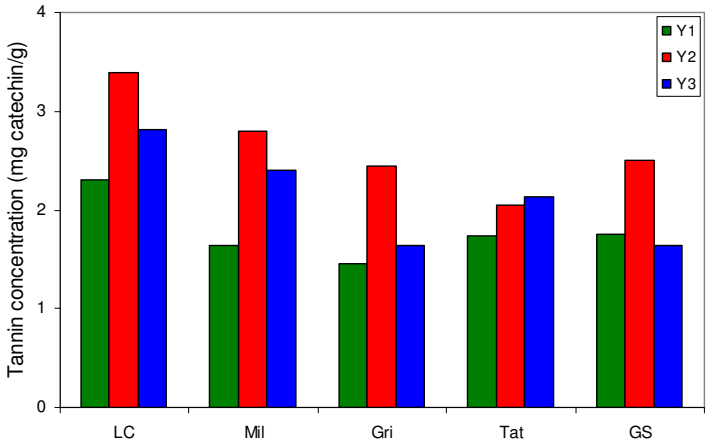


Fig. 39. Average whole berry total tannin concentration (mg catechin equivalents/g berry fresh weight) at the five sites for Y1, Y2 and Y3. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Within site variation in berry tannin concentration was high (Fig. 40). Variation was greater than twofold at LC and Mil (in both Y2 and Y3) and at Tat in Y1 and Y2. For example, berry tannin ranged from 1.3 – 4.6 mg/g in Y2 at Mil. The least variation occurred at Gri and GS.

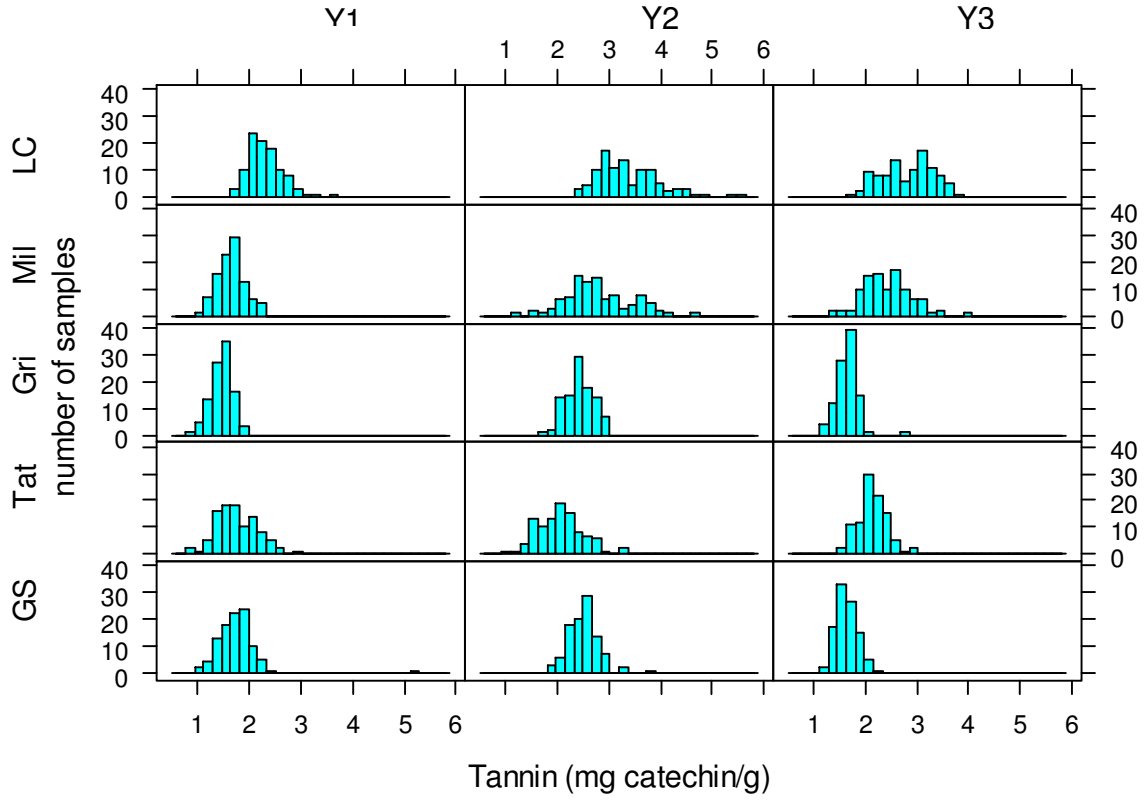


Fig. 40. Frequency distribution of whole berry total tannin concentration (mg catechin equivalents/g berry fresh weight) at the five sites for Y1, Y2 and Y3. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Whole berry total iron reactive phenolic concentration

As with berry tannin levels, the levels of iron reactive phenolic (IRP) concentration showed significant regional ($P < 0.0001$) as well as year-to-year differences (Fig. 41). More importantly, the regional differences were highly season dependent ($P < 0.0001$). One stark example of this is that in Y1, grapes harvested from the Gri site had the lowest concentration of IRP's, whereas in the following year, Y2, grapes from this site on average contained the highest IRP concentration. Across all sites, the IRP levels were the highest in Y2; but this was distinctly so in grapes harvested from the Gri site. This deviation is clearly seen in the plot of tannin against IRP for all sites and season (Fig. 42). Interestingly, the aberrantly high IRP in grapes from Gri Y2 samples were strongly and negatively associated with average berry weight.

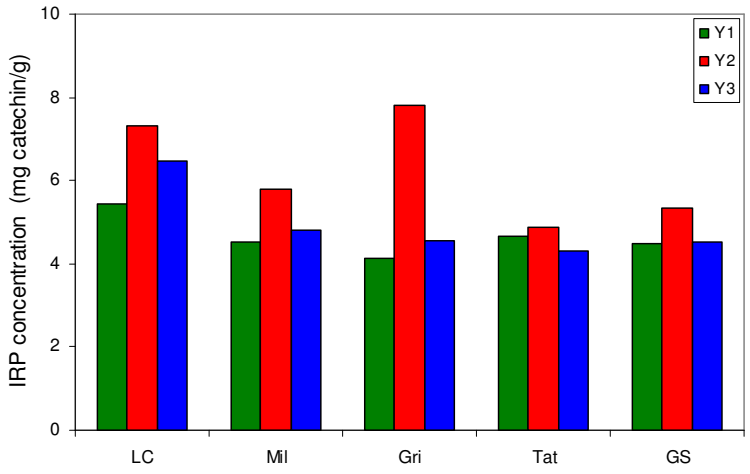


Fig. 41. Average whole berry total iron reactive phenolic concentration (mg catechin equivalents/g berry fresh weight) at the five sites for Y1, Y2 and Y3. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

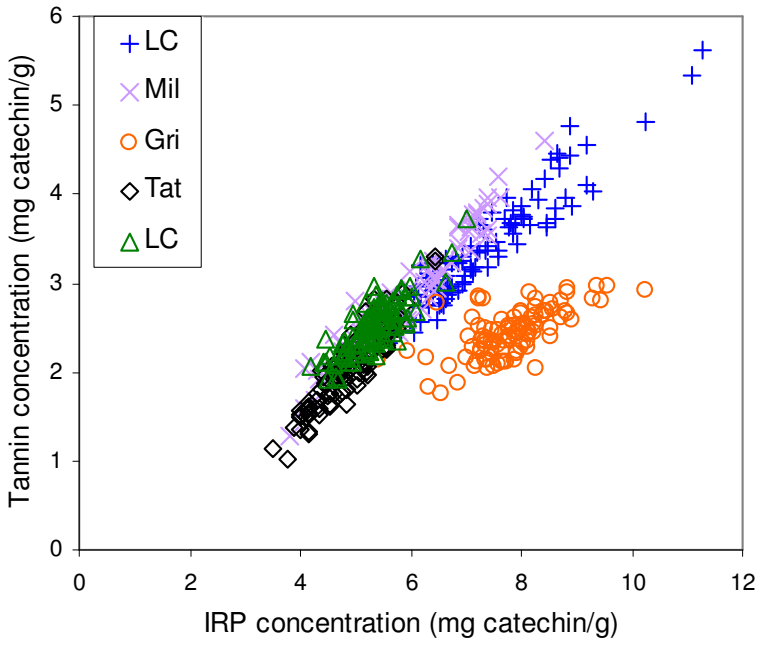


Fig. 42. Comparison of whole berry total tannin (mg catechin equivalents/g berry fresh weight) and whole berry total iron reactive phenolics (mg catechin equivalents/g berry fresh weight) at the five sites for Y2. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Within site variation in berry iron reactive phenolic (IRP) concentration was high (Fig. 43). Variation was greatest at LC, Mil (in Y2 and Y3) and at Gri in Y2. The least variation occurred at GS.

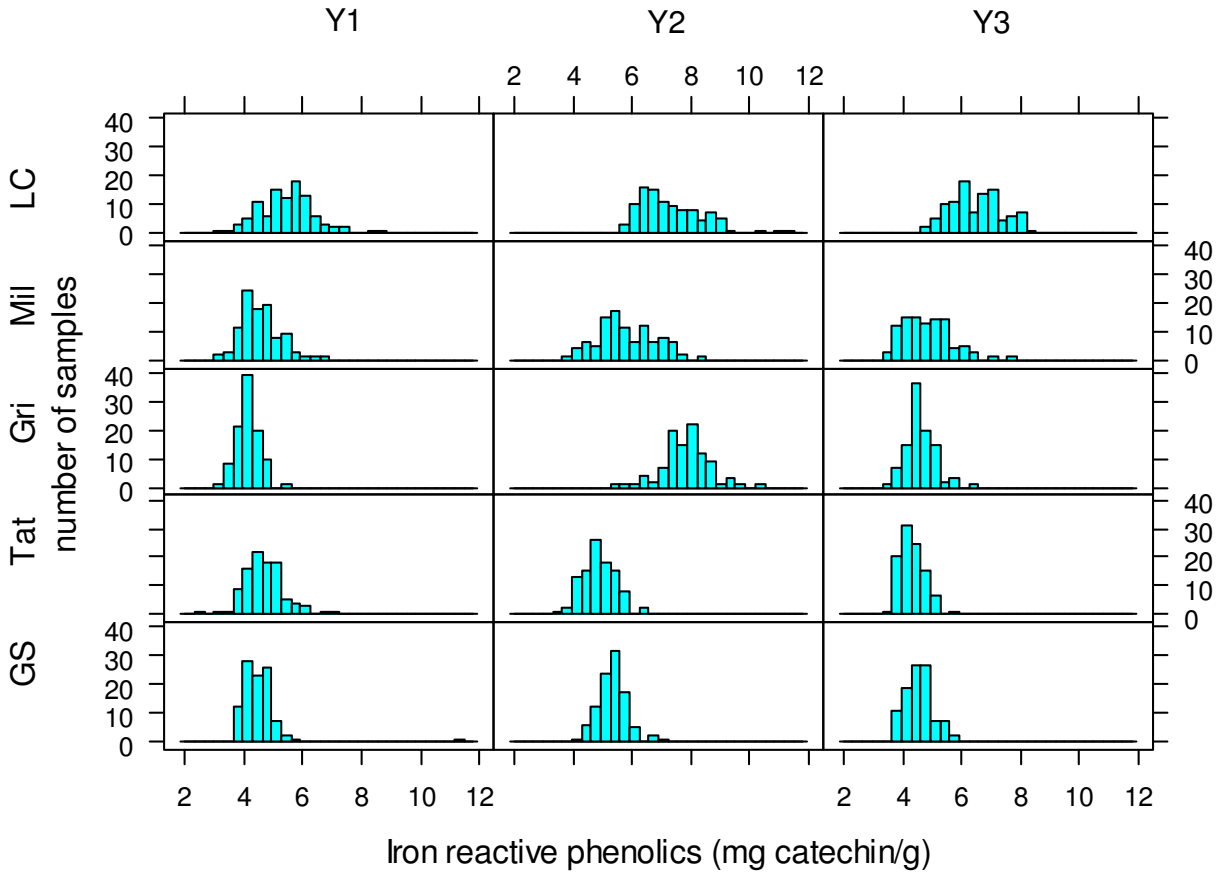


Fig. 43. Frequency distribution of whole berry total iron reactive phenolic concentration (mg catechin equivalents/g berry fresh weight) at the five sites for Y1, Y2 and Y3. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Berry juice total soluble solids concentration

TSS in berry juice at harvest showed considerable variation across sites and years ($p < 0.0001$) as well as significant interactions between years and sites ($P < 0.00001$) (Fig. 41). TSS was lowest at Mil, Gri and Tat, and highest at LC and GS. The large year-to-year mean difference at LC and GS (e.g. ~4.4 Brix) was surprising given the effort made to harvest grapes at the similar levels of "maturity".

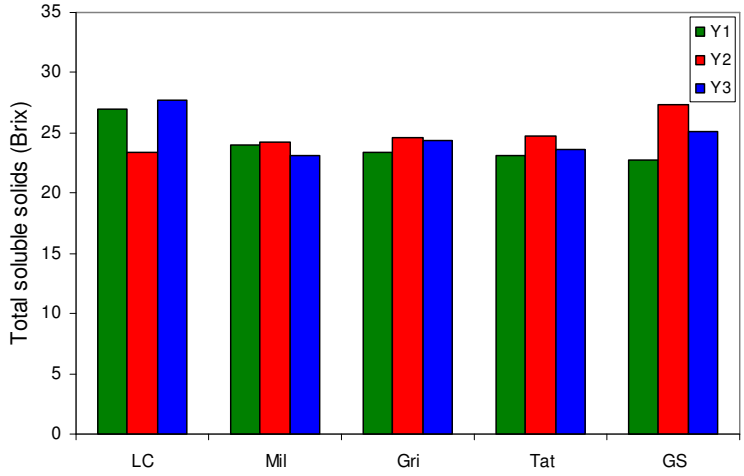


Fig. 44. Average juice total soluble solids (Brix) at the five sites for Y1, Y2 and Y3. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Variation in TSS within each site was high (Fig. 45). Variation was greatest at Tat in Y1 (ranged from 17.3 to 30.5 Brix), and Mil in Y2 (ranged from 18.6 to 28.3 Brix) and Y3 (ranged from 17.0 to 26.2 Brix).

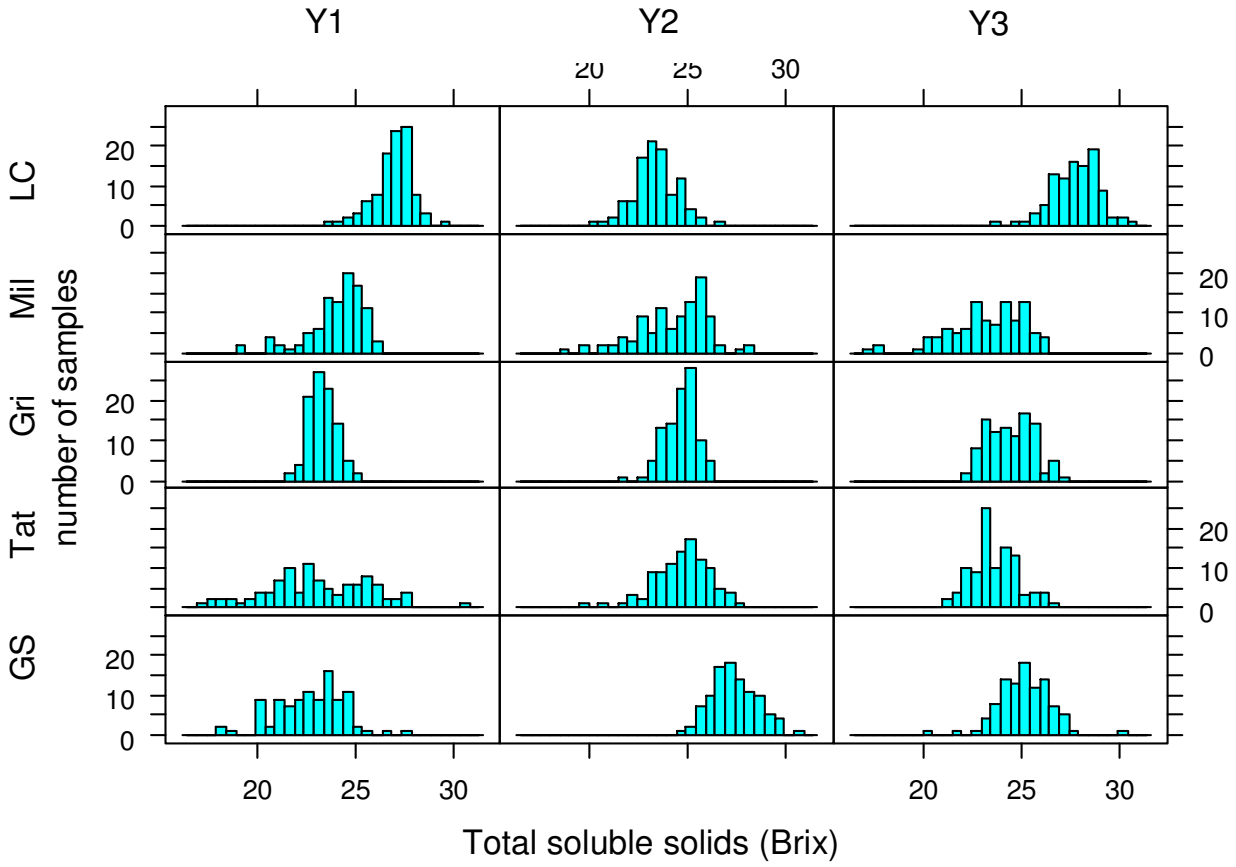


Fig. 45. Frequency distribution of juice total soluble solids (Brix) at the five sites for Y1, Y2 and Y3. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Berry juice pH

Berry juice pH levels at harvest showed strong year-to-year variation and considerable differences between sites ($P < 0.00001$) (Fig. 46). The lowest pH was at LC followed by GS. The highest pH occurred at Gri. Mil and Tat had similar pH. Like all of the other berry attributes examined so far, berry pH levels showed highly significant site x year interaction ($P < 0.00001$).

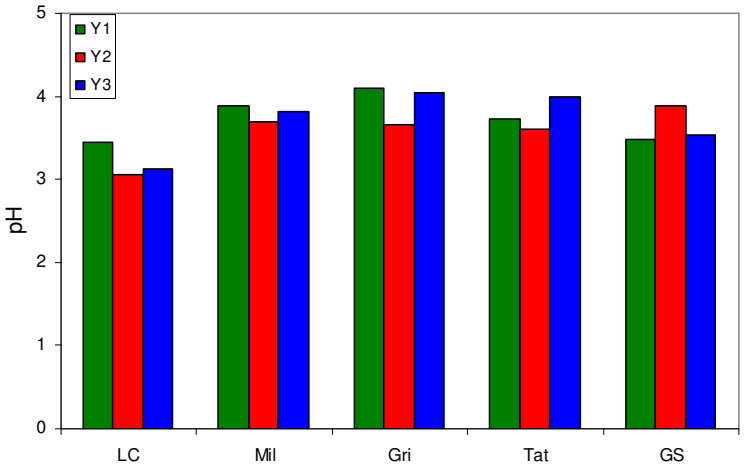


Fig. 46. Average juice pH at the five sites for Y1, Y2 and Y3. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

There was little variation in pH at LC compared to the other sites (Fig. 47). pH was consistently variable at Mil although the most variation occurred at Gri in Y2 where pH ranged from 3.1 to 4.2.

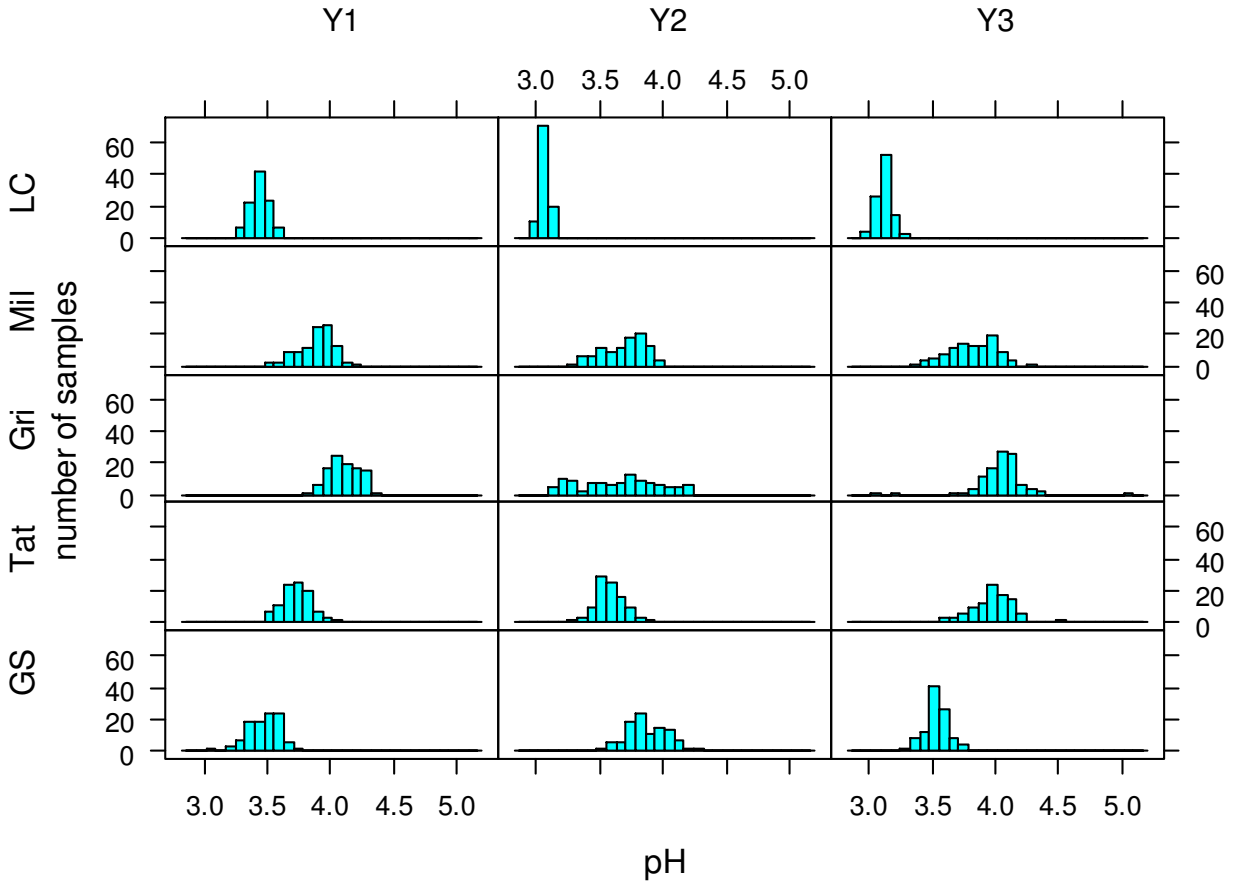


Fig. 47. Frequency distribution of juice pH at the five sites for Y1, Y2 and Y3. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Berry juice total titratable acidity

Berry juice TA at harvest varied significantly across sites and seasons ($P < 0.0001$) (Fig. 48). Furthermore, these variations showed highly significant sites x season interaction ($P < 0.0001$). Grapes from the LC site generally had higher TA, particularly in Y2 where TA = 9.3 g/l, and a correspondingly low pH (cf. graphs of TA and pH above) than the other sites. TA was consistently low at Gri.

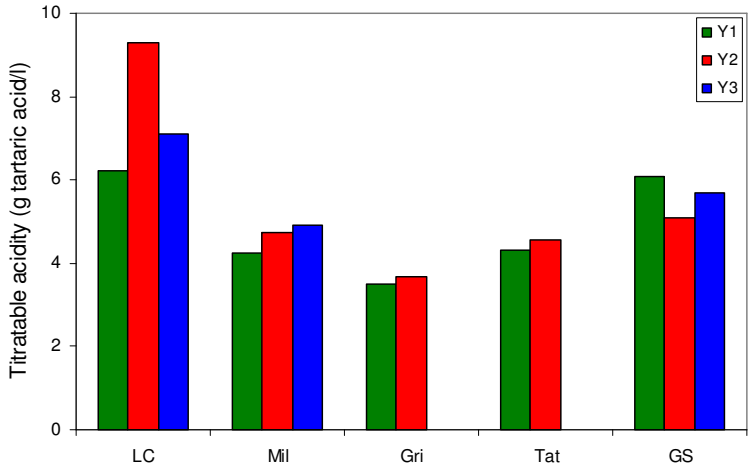


Fig. 48. Average juice total titratable acidity (g tartaric acid equivalents/l juice) at the five sites for Y1, Y2 and Y3. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

There was consistent variation in TA at Mil. For example, TA ranged from 3.4 to 8.5 g/l in Y2 at Mil. The least variation in TA occurred at Gri in Y1, Y2 and Y3, Tat in Y2 and GS in Y3 (Fig. 49).

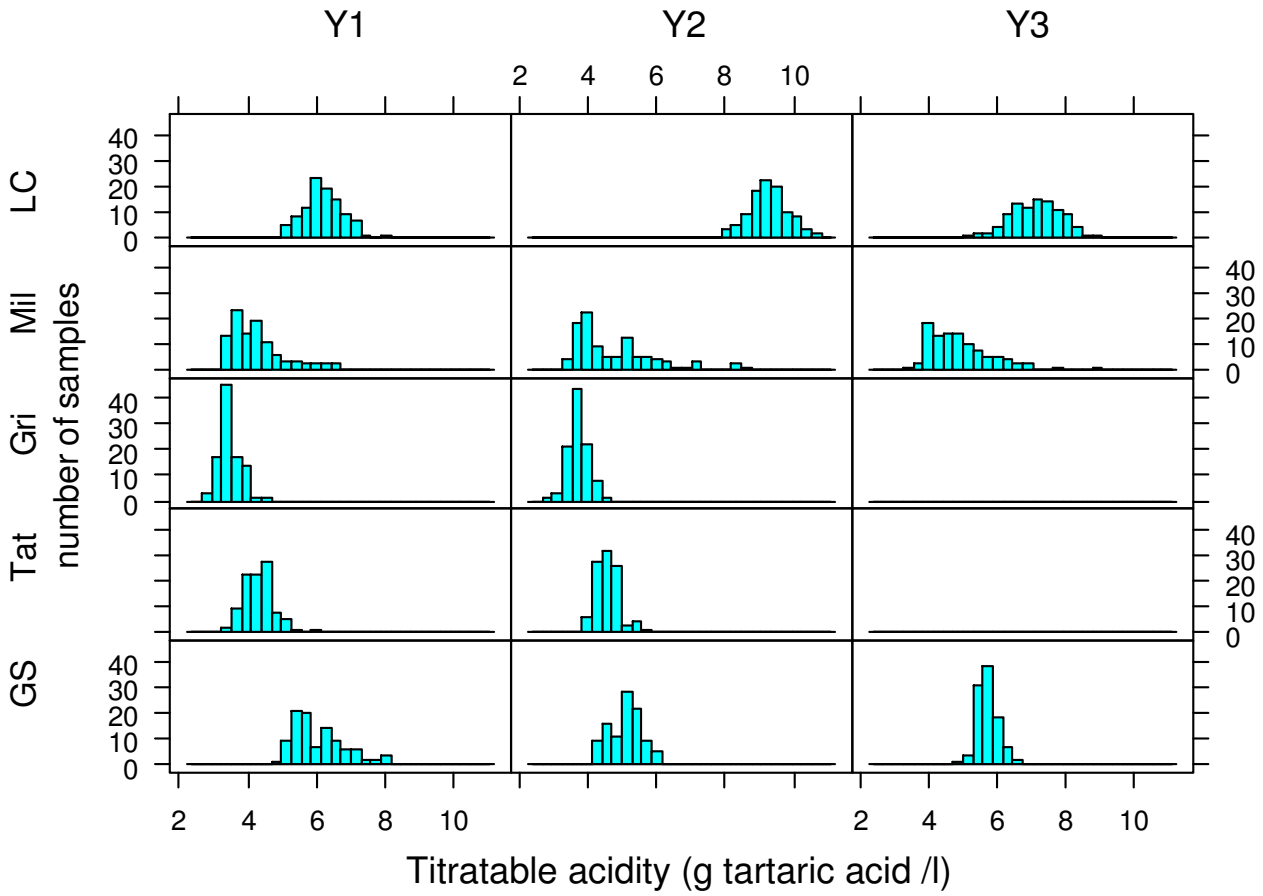


Fig. 49. Frequency distribution of juice total titratable acidity (g tartaric acid equivalents/l juice) at the five sites for Y1, Y2 and Y3. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Wine composition

The range in wine attributes produced varied between sites and years (Fig. 50). Wine composition can be assessed between sites for the two years that a complete set of wines were made for each site (i.e. Y2 and Y3). Grapes at LC and GS were harvested at significantly higher levels of sugar maturity ($P < 0.05$) than the other sites as suggested by different levels of alcohol in the wines. Whilst the aim was to pick the grapes at a specified sugar level, logistics, local weather conditions and within vineyard variability meant that this task could not be met.

The GS site had the highest level of all spectral properties ($P < 0.05$) except tannins. Tannins levels were highest at LC but not significantly different to GS ($P < 0.05$). In general, there were no differences in average spectral properties between LC, Tat and Gri. The Mil site, however, had the lowest level of all spectral properties ($P < 0.05$) except tannins. Tannins levels were lowest at Gri but not significantly different to Mil ($P < 0.05$). Despite Mil having the lowest values in spectral properties, this site and GS had the largest range.

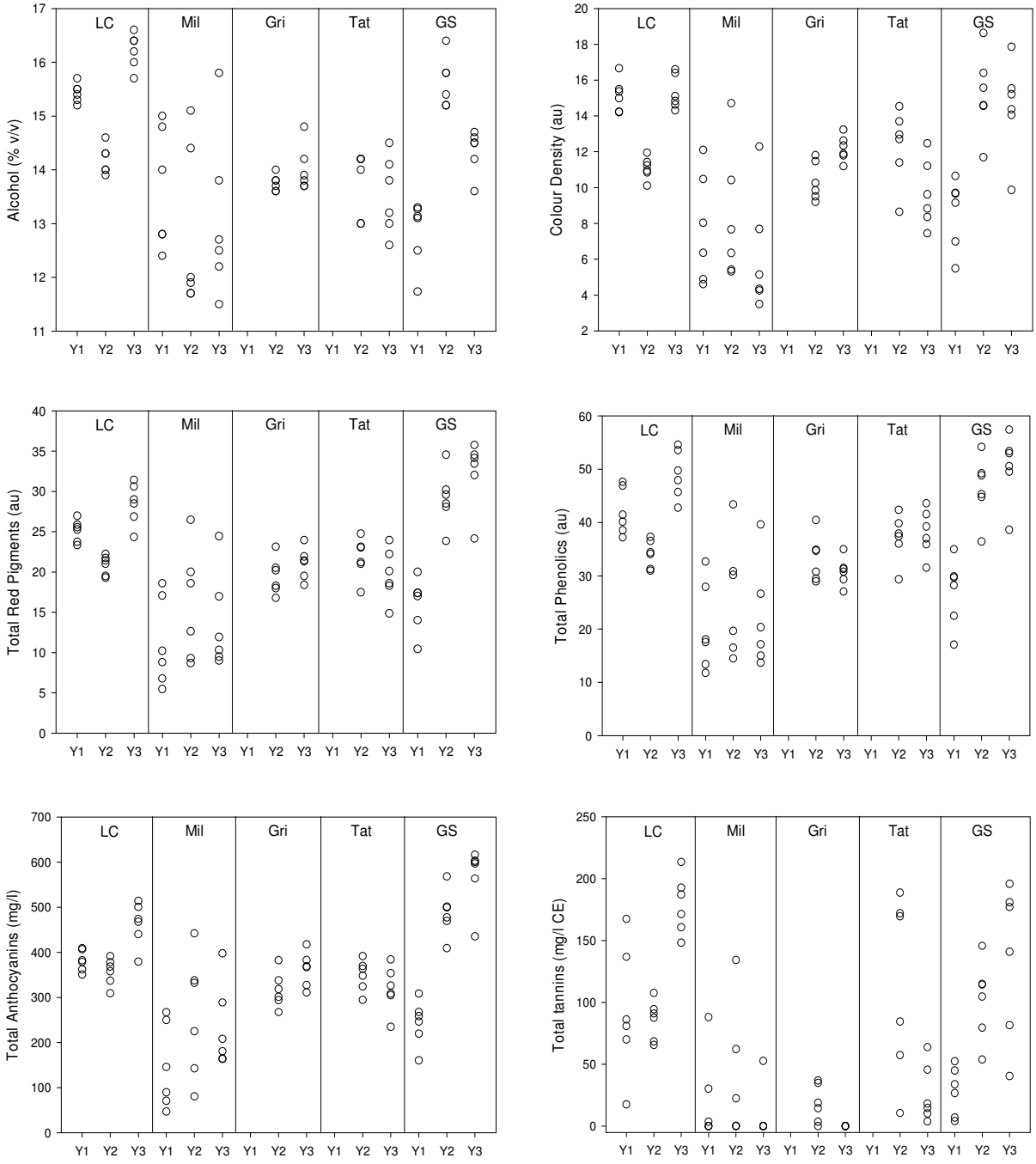


Fig. 50. Distribution of alcohol, colour density, total red pigments, total phenolics, total anthocyanins, total tannins of wines made from Langhorne Creek (LC), Griffith (Gri), Tatura (Tat), Mildura (Mil) and Great Southern (GS) for Y1, Y2 and Y3.

Variation in wine sensory attributes between sites and years is less obvious than the comparison of spectral properties (Fig. 51). Whilst the overall shape of the sensory plots are relatively consistent variation in body and drying are apparent and seem to match the differentiation described in the spectral properties. Spicy aroma and stalky flavour also seem to fluctuate between years and site, however, the variation is mixed. Like the spectral analysis, the Mil site shows the greatest range in sensory attributes compared to other sites.

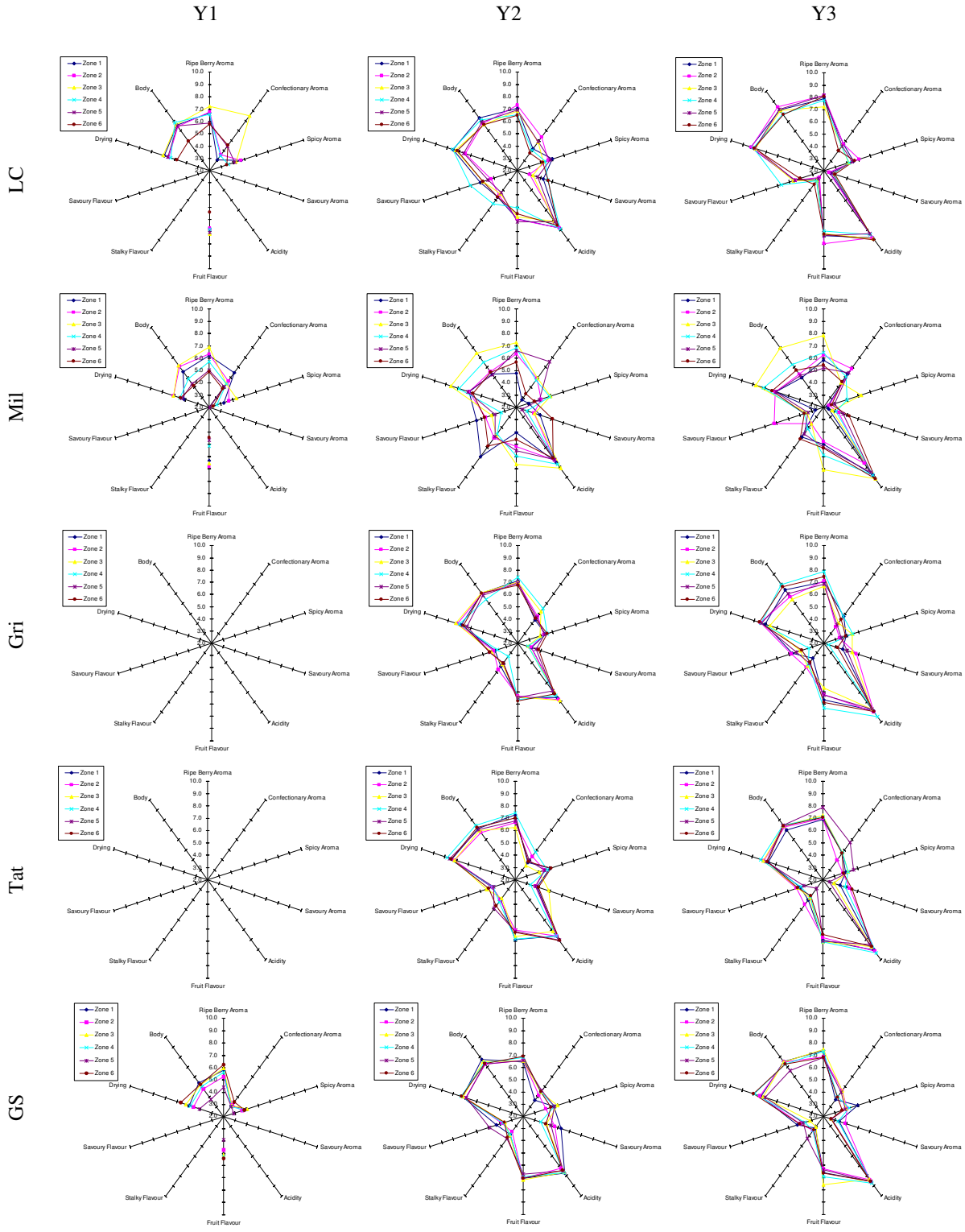


Fig. 51. Combined aroma and flavour sensory envelopes of the wines made from Langhorne Creek (LC), Griffith (Gri), Tatura (Tat), Mildura (Mil) and Great Southern (GS) for Y1, Y2 and Y3, NDVI was derived from aerial imagery date collected at veraison for each site. A neighbourhood statistical procedure was used to derive this figure without the removal of non-vine data points.

Relationships between vine parameters, management inputs, soil and climate

Soluble solids yield and water inputs

Figure 52 shows the relationship between soluble solids yield and water inputs (irrigation + rain) for the period from flowering to harvest for each site (and block within site) and year. Analysis of this data suggests a ceiling relationship for Shiraz; WUE_{SS} = 2.4 t/Ml.

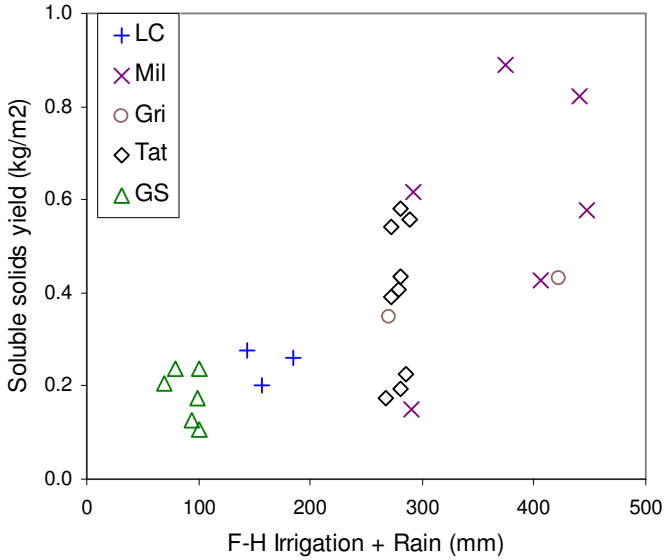


Fig. 52. Relationship between soluble solids yield and water inputs (irrigation and rain) from flowering to harvest for each site and year. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS). Sub-block data is shown for Mil, Tat and GS.

Vigour, soil properties and fruit composition

Principle component analysis of vine vigour, soil physical and chemical properties and fruit composition has shown that vigour, crop load and berry size is negatively associated with berry composition (secondary metabolites, Brix & pH) but these are positively associated with acidity. The effects of soil physical and chemical properties (when present) appeared to be expressed via their influences on vigour and crop load. Often the soil physical and chemical properties had contrasting influences on vigour and berry composition.

Factor analysis was employed to identify variables that co-vary with berry composition variables. The analysis identified complex patterns of associations: generally, across sites, measures of vine size (PCD, vigour, NDVI), yield and berry mass had negative impacts and/or associations with berry flavonoid composition (anthocyanin, tannin and IRP), soluble solids concentration and pH, whereas effects of these variables on TA and were positive (Fig. 53). The effects of soil variables on berry composition were effectively dependent on their effect on vine vigour, yield and berry mass. To the extent that a soil variable had a positive effect on vigour, yield and berry mass, its effect on berry composition, especially anthocyanin and soluble solids, was negative. For example, vines which were located in areas with high levels of rhizospheric pH, Cl- and EC had low vigour and yield, with small berry mass, and consequently high levels of berry flavonoids and soluble solids, and vice versa. Areas with relatively high sand, readily available water content and bulk density maintained high -vigour and -yielding vines with large berry mass and thus low levels of berry flavonoids and soluble solids concentration. However, where localised soil conditions were unfavourable (i.e., resulting in low vigour vines), it had a negative impact on berry composition. Thus, there appears to be a trade-off in that there is a point beyond which the positive effect of reduction in vigour on berry quality is offset by negative impacts.

The relationships between vigour, soil properties and fruit composition will be discussed in the paper 'Deconvoluting effects of pedospheric and phytomeric variables on berry composition' (Zerihun et al., draft).

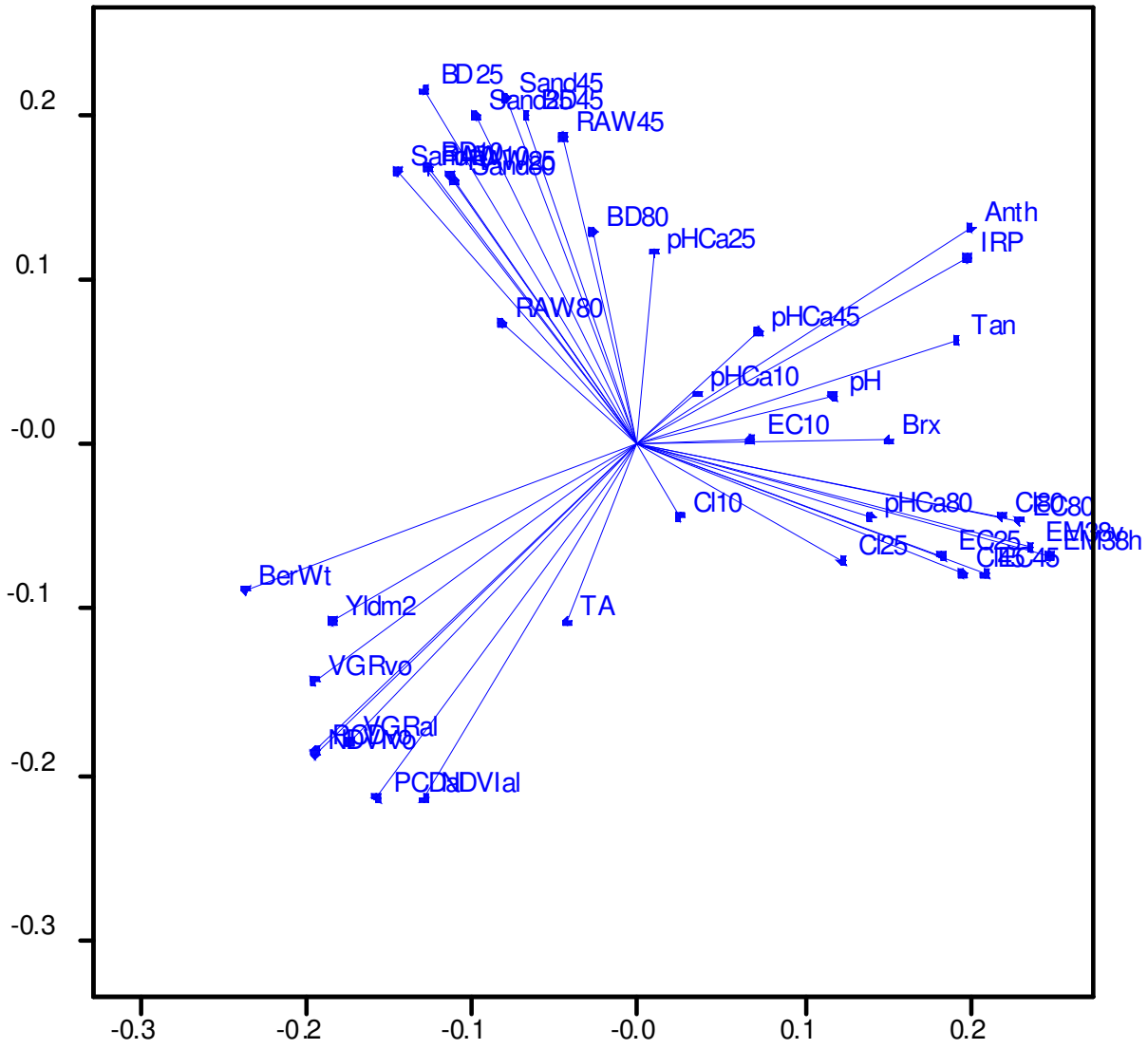


Fig. 53. Biplot showing the relationships between berry composition, soil physical and chemical properties, vine size (aerial imagery data of NDVI, PCD and vigour), yield and berry fresh weight for LC in Y1.

Vigour, soil properties and wine composition

The correlations between wine properties and associated soil (EM38 and GRS) and vine (normalised difference vegetation index, NDVI) data are presented in Tables 13 and 14. The immediate observation is that wine chemical and sensory properties are more significantly correlated with NDVI data than the soil EM38 and GRS data. All sites except Tatura have the same directional correlation ($P < 0.05$) with NDVI apart from wine hue. Since NDVI is a measure of vine size or vine vigour, the data suggests that higher vigour vines show a decrease in wine phenolic and anthocyanin compounds as well as a decreased in wine colour density. Further, higher vigour tends to reduce the spicy characteristic that Shiraz is known for (data not shown). This is important as it shows some consistency in the observed relationship despite regions of differing climates. In contrast, the correlation of wine properties with soil EM38 and GRS data is less pronounced and lacks directional consistency. There was a positive relationship between EM38 and

wine colour, phenolics and tannins at Griffith and Langhorne Creek. Example plots of correlations between NDVI and EM38/GPS with selected wine properties is shown in Figures 54 and 55.

Table 13. Pearson correlation coefficients between wine spectral properties and normalised difference vegetation index (NDVI) at Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Site	Year	Colour density	Wine hue	Total red pigments	Total phenolics	Total anthocyanins	Total tannins
LC	Y1	-0.90	0.73	-0.91	-0.92	-0.85	-0.76
	Y2	-0.53	0.74	-0.69	-0.83	-0.70	-0.32
	Y3	-0.97	0.30	-0.96	-0.96	-0.93	-0.63
Mil	Y1	-0.85	0.29	-0.75	-0.81	-0.64	-0.83
	Y2	-0.72	0.34	-0.87	-0.86	-0.85	-0.45
	Y3	-0.73	-0.83	-0.73	-0.72	-0.73	-0.54
Gri	Y1	NA	NA	NA	NA	NA	NA
	Y2	-0.68	0.34	-0.59	-0.53	-0.55	-0.78
	Y3	-0.59	0.34	-0.57	-0.61	-0.54	NA
Tat	Y1	NA	NA	NA	NA	NA	NA
	Y2	0.13	-0.19	0.47	0.33	0.66	-0.32
	Y3	0.16	-0.02	0.04	-0.04	0.00	0.40
GS	Y1	-0.66	-0.51	-0.67	-0.75	-0.64	-0.49
	Y2	-0.48	0.17	-0.55	-0.73	-0.56	-0.79
	Y3	-0.85	-0.72	-0.82	-0.83	-0.81	-0.59
Average		-0.57	0.21	-0.56	-0.59	-0.51	-0.47

NA – not available

Table 14. Pearson correlation coefficients between wine spectral properties and electromagnetic induction (LC. Mil, Gri, Tat) and gamma radiometric data (GS) for each site. Sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS).

Site	Year	Colour density	Wine hue	Total red pigments	Total phenolics	Total anthocyanins	Total tannins
LC	Y1	0.56	-0.50	0.32	0.55	0.18	0.55
	Y2	0.00	-0.46	0.23	0.48	0.29	-0.12
	Y3	0.48	0.16	0.55	0.71	0.50	0.66
Mil	Y1	0.08	-0.44	0.26	0.16	0.36	-0.19
	Y2	-0.46	0.32	-0.51	-0.50	-0.51	-0.33
	Y3	-0.62	-0.36	-0.66	-0.66	-0.69	-0.43
Gri	Y1	NA	NA	NA	NA	NA	NA
	Y2	0.67	-0.35	0.82	0.88	0.79	0.43
	Y3	0.74	-0.79	0.85	0.81	0.86	NA
Tat	Y1	NA	NA	NA	NA	NA	NA
	Y2	-0.26	0.07	-0.58	-0.45	-0.75	0.20
	Y3	-0.01	0.66	-0.09	-0.06	-0.18	-0.13
GS	Y1	0.16	0.29	0.13	0.15	0.10	0.20
	Y2	0.09	0.07	-0.01	0.06	-0.02	-0.12
	Y3	0.25	0.52	0.52	0.46	0.58	0.43
Average		0.12	-0.17	0.12	0.19	0.09	0.07

NA – not available

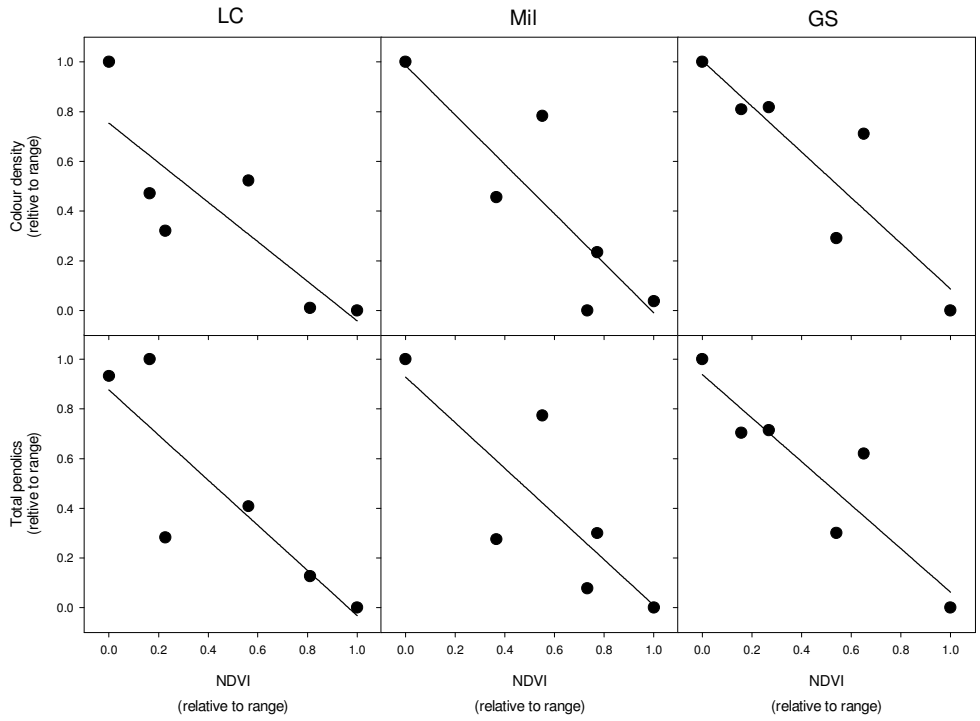


Fig. 54. Examples of scatter plots and regression lines between wine spectral properties (colour density and total phenolics) and normalised difference vegetation index (NDVI) for Langhorne Creek (LC), Mildura (Mil) and Great Southern (GS) sites. The 2006 vintage is used and all data has been scaled to a range between 0 and 1 to account for different measurements between sites.

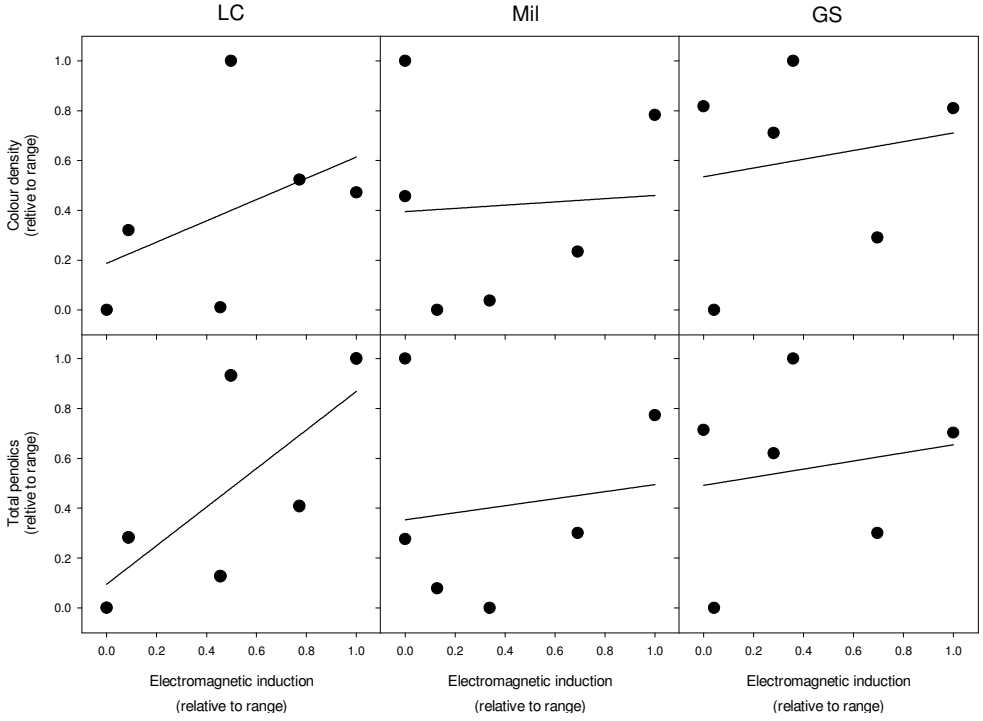


Fig. 55. Examples of scatter plots and regression lines between wine spectral properties (colour density and total phenolics) and eletromagnetic induction for Langhorne Creek (LC), Mildura (Mil) and Great Southern (GS) sites. The 2006 vintage is used and all data has been scaled to a range between 0 and 1 to account for different measurements between sites.

These results suggest that imagery data can be used more effectively than high density soil conductivity data (e.g. EM38) to differentiate wine quality although care needs to be taken at sites with narrow hedgerows (i.e. VSP). During the project awareness increased with respect to the potential wine produced within a block at the sites and some growers considered differential harvesting or management. Future research needs to investigate how much variation is necessary before differential harvesting produces different wine potential and can differential management overcome variation in vine performance.

The use of EM38 and GRS to estimate the variation in soil properties assumes that only one responsive soil property varies throughout the entire block. For instance the EM38 responds to changes in soil texture, moisture, salt and in some instances soil depth (Proffitt *et al*, 2006). All these properties can vary concurrently across a vineyard block confounding the correlation analysis. Using soil profile data collected from target vines showed that wine colour and total red pigments were negatively related to soil nitrogen and soil carbon and positively related to soil salinity (data not shown). This result, however, was only consistent across two of the five sites. Although the effect of soil carbon on wine properties is not consistent it potentially has significant implications for management practices that increase soil organic matter and for carbon sequestration in vineyard soils. The next step is to determine if this response is direct or indirect (through vine vigour).

The relationships between vigour, soil properties and wine composition will be discussed in the paper 'Vine size and soil conductivity impacts on wine spectral and sensory properties' (Lanyon et al., 2009).

Nutrient status and vine performance

Vine vigour and vegetative tissue nutrient concentrations

Significant linear relationships ($R^2 > 0.15$, $P < 0.05$) between vine vigour (measured as EAS) and vegetative tissue nutrient concentrations (blades at flowering and veraison, and petioles at flowering and veraison averaged for Y1, Y2 and Y3) were not common (76 significant relationships of a possible 390 at individual sites). Relationships were most common at Great Southern (23) and Griffith (18); and for N (14, positive) and Na (13, negative at LC).

Yield and vegetative tissue nutrient concentrations

Significant linear relationships ($R^2 > 0.15$, $P < 0.05$) between yield (and yield components) and vegetative tissue nutrient concentrations (blades at flowering and veraison, and petioles at flowering and veraison averaged for Y1, Y2 and Y3) were not common (215 significant relationships of a possible 1040 at individual sites). Relationships were most common at Great Southern (74) and Mildura (67). Significant positive relationships at individual sites were most common for N (30, predominantly with berry number per bunch, yield, and bunch number), S (29, predominantly with yield and berry number per bunch), P (23, predominantly with berry weight) and Mg (23, predominantly with berry number per bunch). Significant negative relationships at individual sites were most common for B (14, predominantly with yield and bunch number) and Na (11, predominantly with yield and berry weight). Plots of yield versus selected nutrients are presented in Figure 56.

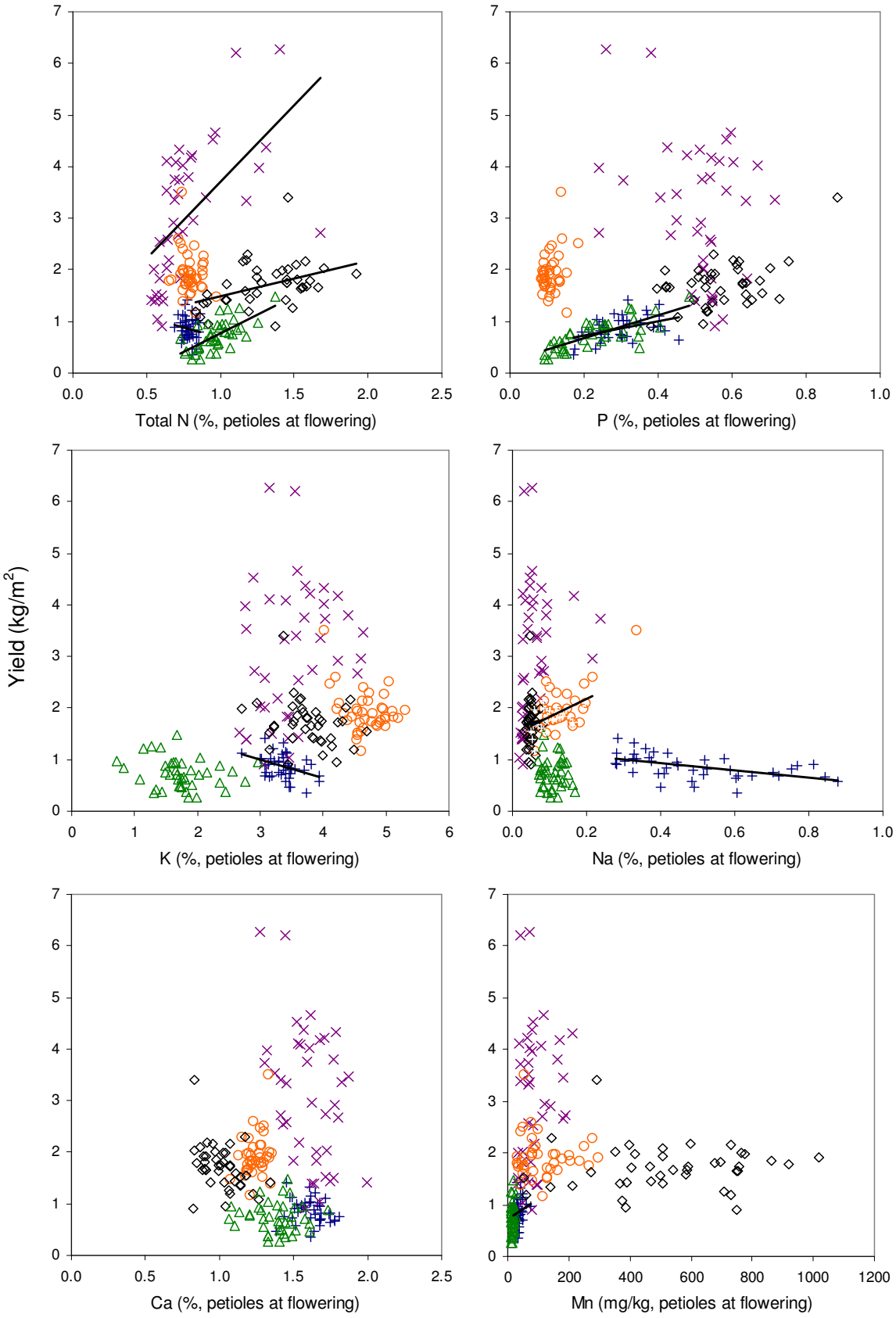


Fig. 56. Yield and nutrient concentrations in petioles at flowering (average of three seasons) at five sites. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS). Lines indicate significant linear relationships at individual sites.

Vine vigour, yield, fruit quality and nutrient concentrations

Significant relationships between concentrations of particular nutrients and other parameters occurred consistently at certain sites. For example, positive relationships occurred between EAS (R^2 = 30 – 46%), yield (R^2 = 48 – 53 %), bunch number (R^2 = 19 – 34 %), berry number/bunch (R^2 = 36 – 51 %) and berry weight (R^2 = 29 – 37 %) and P concentrations (in petioles and blades) at GS. Previous studies have linked limited P conditions with decreased yield, berry weight, berry numbers, bunch numbers and vigour (Haeseler et al. 1980; Skinner and Matthews, 1989; Grant and Matthews, 1996). While cause and effect cannot be determined in this study, it can be concluded that limiting conditions, with regard to vine vigour and yield, were closely associated with P uptake at GS. Vigour and yield parameters at GS were also closely associated with N, S and Mg concentrations. The same nutrients (N, P, Mg and S) tended to have positive relationships with EAS, yield and yield components at other sites and negative relationships with quality attributes.

Consistent trends occurred within sites and across all sites combined for certain parameters and nutrients. For example, all significant relationships between bunch number and berry number per bunch and N in petioles and blades were positive, and all significant relationships between quality attributes and Ca in berry homogenate were positive. However, significant relationships for all sites combined were often driven by differences between sites, rather than a common trend for vigour, yield or quality attributes to increase or decline with increasing nutrient concentrations within sites. For example, for all sites combined, EAS and yield tended to have negative relationships with S but at individual sites these relationships were positive. Similarly, relationships between yield and P concentrations in petioles at flowering appeared to be consistent at LC, Tat and GS but not at Gri and Mil (Fig. 56).

Multivariate analysis

Summaries of all subsets regression analyses between yield (response variate) and EAS at veraison and nutrient concentrations (explanatory variates) are presented in Table 15. Nutrient concentrations were grouped into petioles at flowering, petioles at veraison, blades at flowering or blades at veraison. Three, four and five-component models with highest adjusted r-squared values are shown.

Table 15. Model components, adjusted r-squared and Mallow's Cp values for three, four and five component models determined by all-subsets regression for yield response variate with petiole or blade nutrient concentrations and vine vigour explanatory variates.

Nutrient data	Model components	Adjusted R^2 (%)	Mallow's Cp
Petioles at flowering	EAS, Al, N	56.3	12.4
	EAS, Al, N, P	57.0	8.7
	EAS, Al, N, P, Mg	57.4	6.6
Petioles at veraison	EAS, N, B	58.6	22.6
	EAS, N, B, Mg	59.3	18.1
	EAS, N, B, Mg, Na	59.8	15.2
Blades at flowering	EAS, Ca, Mg	58.3	21.1
	EAS, Ca, Mg, Fe	59.9	10.3
	EAS, Ca, Mg, Fe, Zn	60.1	9.6
Blades at veraison	EAS, N, S	58.5	27.3
	EAS, N, P, Mg	60.5	13.0
	EAS, N, S, Mg, Al	61.5	5.8

EAS at veraison was included in all models with more than one component and, alone, had an adjusted r-squared value of 53.3 %. The 'best' models had five (petioles at flowering), seven (blades at veraison) or eight (petioles at veraison and blades at flowering) components, however, there was little improvement in adjusted r-squared values (< 1.4 %) or Mallow's Cp values compared to models with five components.

The strong influence of vine size on yield was indicated by the presence of EAS at veraison in all models with more than one component determined by all subsets regression. Nutrition influences vine size and so

increases in adjusted r-squared values with inclusion of nutrient concentrations as model components should be considered to indicate altered yield capacity as a result of nutrition status (or factors associated with nutrition status) independent of vine size, rather than the influence of nutrition on yield per se.

Summaries of all subsets regression analyses between quality attributes (anthocyanins, tannins or IRP as response variates) and berry homogenate nutrient concentrations, yield components and EAS at veraison (explanatory variates) are presented in Table 16. Three, four and five-component models with highest adjusted r-squared values are shown. Adjusted r-squared values for best models with three components were high (> 50%), and improvements in either adjusted r-squared or Mallow's Cp values were slight for models with more than five components. 'Best' models, as indicated by lowest Mallow's Cp values, had twelve (anthocyanin and IRP) or eight (tannins) components, however, these models offered very little improvement in adjusted r-squared values (less than 1 % average increase per additional component) or Mallow's Cp values compared with five component models.

Table 16. Model components, adjusted r-squared and Mallow's Cp values for two, three and four component models determined by all-subsets regression for fruit quality response variates (anthocyanin, iron-reactive phenolics, IRP, and tannin) with yield component, vine vigour and berry homogenate nutrition explanatory variates.

Attribute	Model components	Adjusted R^2 (%)	Mallow's Cp
Anthocyanin	S, Berry weight, EAS	71.8	184.1
	Mg, S, Berry weight, Bunch number	74.6	135.2
	K, Mg, S, Berry weight, Bunch number	75.9	111.7
IRP	Ca, Berry weight, S	64.7	69.7
	Ca, Berry weight, S, Bunch number	66.6	48.8
	Ca, Berry weight, S, Bunch number, Cu	68.1	33.5
Tannin	Ca, Mg, Bunch number	53.5	198.3
	Berry weight, Ca, Mn, Bunch number	60.5	119.5
	Berry weight, Ca, B, Bunch number, S	65.4	64.8

Berry weight alone had an adjusted r-squared value of 27.2 % (anthocyanin), 21.1 % (tannin) and 32.8 % (IRP). K, Mg, N and S alone accounted for a greater percentage of variance in anthocyanins than berry weight (38.7, 30.0, 29.5 and 27.6 % adjusted r-squared, respectively), while Ca and Na alone accounted for a greater percentage of variance in tannins than berry weight (36.5 and 21.6 % adjusted r-squared, respectively). EAS at veraison and bunch number alone accounted for 18.3 and 14.8 % of variance in anthocyanin, respectively. However, bunch number only accounted for approximately 3.1 and 5.8 % of variance in tannins and IRP, respectively.

All subsets regression indicated the strong influence of yield components, particularly berry weight, on quality outcomes. Berry weight was included in the three, four and five component models for anthocyanins and tannins, and four and five component models for IRP with highest adjusted r-squared values. S was also included in all selected models for anthocyanins and tannins and Ca was present in all selected models for tannins and IRP.

Sensitivity of yield to variation in canopy radiation interception, crop load and water stress

Relative contributions of yield components to soluble solids yield

Analysis of the data combined by year revealed that the variability in bunch number was the main determinant (Tat, Mil and Gri) or co-determinant along with the number of berries per bunch (GS) of variability in Y_{ss}, whereas at the LC site berry number per bunch had greater influence or contribution than each of the other yield components (Table 17). The influence of mass per berry varies from moderate to low depending on site. Compensatory adjustments between components were also evident whereby the influences of berry number per bunch and/or mass per berry are generally counterbalanced by the influence of soluble solids concentration. A further outstanding outcome of this analysis was that in low-

volume irrigated and low yielding areas, bunch numbers and berry numbers were equally influential whereas in highly irrigated and high yielding areas, bunch number alone contributed between 53 and 92 % of variability in total soluble solids yield.

Table 17. Covariances between yield of soluble solids (Y_{ss}) and yield components normalised to variance of Y_{ss} for each site. Note that for log-transformed data since the sum of the covariances between the yield components and Y_{ss} is equal to the variance of Y_{ss}, the data in the table are equivalent to percentage contribution of a component to variance in Y_{ss}. It is also noteworthy that, mathematically, the values given in this table are equal to coefficients of regressions of Y_{ss} on each yield component, thus can be calculated as such. Sample size = 300 per site.

Site	Yield Component			
	Bunch number per ha	Berry number per bunch	Fresh mass per berry	Soluble solids concentration
Langhorne Creek	21.8	45.9	28.2	4.1
Mildura	63.0	32.1	10.6	-5.6
Griffith	53.5	20.8	28.5	-2.8
Tatura	91.9	22.0	-6.7	-7.2
Great Southern	47.1	55.5	9.0	-11.6

For all sites, there was a strong linear relationship between log-log transformed Y_{ss} per ha and berry number per ha. However, the slopes of these relationships differed between sites (Fig. 57). The differences in slopes between sites were consistently attributed to berry fresh weight. At the cooler sites (LC, Tat and GS), the concentration of soluble solids declined as berry number per ha increased and this impacted, to a lesser degree than berry fresh weight, on the slope of the relationship between log-log transformed Y_{ss} per ha and berry number per ha.

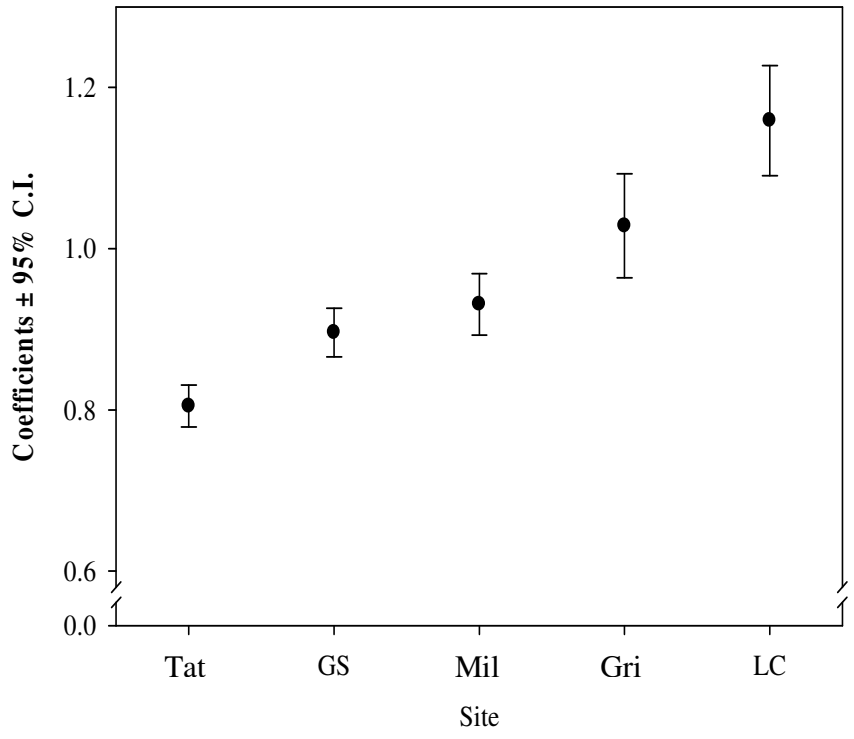


Fig. 57. The coefficients of regression of ln(Yss, kg per ha) on ln(berry number per ha) for each site. Note that coefficients, and hence sites, with non-overlapping 95 % C.I. are different from each other.

Source-sink limitations and radiation use efficiency

Analysis of the data in terms of source and sink limitations was undertaken using an allometric model. The results suggest Y_{ss} was source limited at Tat and GS, and sink limited at Gri and LC (Table 18).

Table 18. Parameter estimates for the reduced major axis (RMA) regression of total soluble solids yields per ha on berry number per ha for each site. 95% C.I. for the RMA regression slope are also given. If the intervals envelope unity (isometric scaling) then a sink-source balance (co-limitation) is implied, if the intervals fall below unity then source limitation is suggested whereas where intervals fall above unity, total soluble solids yield is sink limited.

Site	α	β	95% C.I. for β	n, r^2	suggested limitation
LC	-3.71	1.31	1.23 – 1.39	300, 0.79	sink
Mil	-0.48	0.99	0.95 – 1.03	300, 0.94	co-limitation
Gri	-1.91	1.18	1.10 – 1.25	298, 0.76	sink
Tat	0.81	0.81	0.81 – 0.87	300, 0.92	source
GS	-0.07	0.93	0.90 – 0.97	298, 0.92	source

Radiation use efficiency was determined based on Y_{ss} and PAR interception during the flowering to harvest period. The duration of this period was either similar between seasons (GR and LC) or was longer by 7-18 days in Y3 than in Y2 (GS, ML and CV) (Table 19). These differences in the duration of berry development and ripening phase partly affected the amount of radiation intercepted by the grapevine canopy, however, canopy radiation interception also differed even where the duration between seasons was the same. The major factor contributing to radiation interception differences between environments was canopy size ($r = 0.977$, $p < 0.0001$). Averaged over environments (sites and seasons), radiation use efficiencies varied by up to two-fold within a site between seasons and by more than three-fold across regions. Considerable differences in canopy biomass partitioning were also observed across and within sites. Across environments, variability in Y_{ss} was significantly associated with PAR interception ($r = 0.87$, $p < 0.001$), RUE ($r = 0.90$, $p = 0.0004$), within canopy carbon partitioning pattern ($r = 0.88$, $p = 0.0009$) but not with the amount of PAR incident during berry development and ripening phase ($r = 0.44$, $p = 0.22$).

Table 19. Regional and seasonal differences in the duration of berry development and maturity (i.e. flowering to harvest, F-H), average canopy size (effective area of shade, EAS), soluble solids yield (Y_{ss}), incident and intercepted PAR from F-H, radiation use efficiency from F-H (RUE) and canopy carbon partitioning (harvest ratio).

Site	Year	Duration of F-H (d)	Mean EAS	Y_{ss} (g/m^2)	Incident PAR (MJ/m^2)	Intercepted PAR (MJ/m^2)	RUE (g Y_{ss}/MJ)	Harvest ratio (Y_{ss}/pruning mass)
LC	Y2	100	0.24	172	1230	290	0.59	1.68
	Y3	103	0.30	255	1306	386	0.66	2.21
Mil	Y2	102	0.47	536	1310	614	0.84	3.04
	Y3	109	0.54	816	1468	793	1.02	4.67
Gri	Y2	110	0.35	350	1430	496	0.70	1.52
	Y3	111	0.28	570	1367	381	1.14	2.42
Tat	Y2	105	0.28	192	1461	415	0.46	1.99
	Y3	123	0.38	562	1607	604	0.93	3.61
GS	Y2	115	0.22	111	1353	300	0.36	0.32
	Y3	126	0.26	246	1385	354	0.68	0.48

Yield determinants are discussed in the paper 'Determinants of soluble solids yield in Shiraz vineyards in southern Australia' (Zerihun et al., 2009).

Relationships between vine water use, canopy light interception and water stress

Vine water use and canopy light interception

Sap flow (SF) responses corresponded with diurnal and seasonal patterns of environmental conditions (ET_o and radiation interception) and irrigation events (McClymont et al., 2007). A significant positive linear relationship between grapevine SF and $EAS.ET_o$ was found from field work conducted at the Tatura site over a number of seasons (Fig. 58, McClymont et al., 2009). Verification of the relationship using a weighing lysimeter at CSIRO Griffith is continuing.

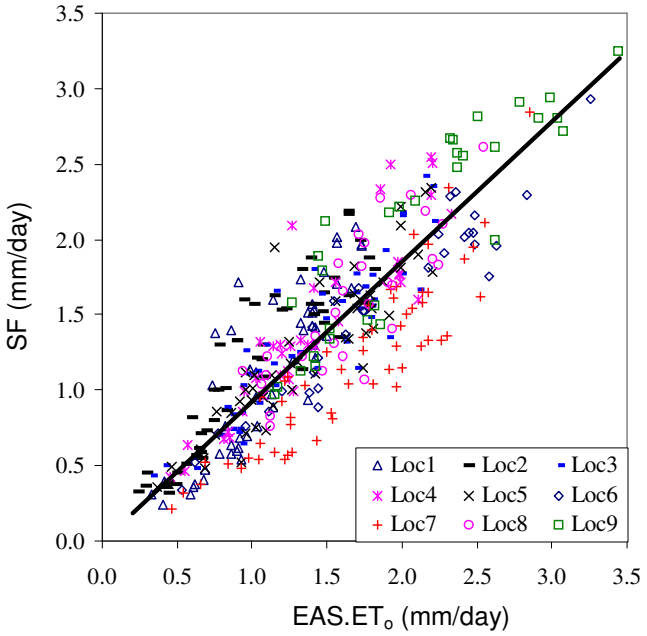


Fig. 58. Relationship between daily sap flow (SF) and daily $EAS.ET_o$ for well watered conditions at nine locations within the Tatura study site. ; R2=0.751, n=383, P<0.001.

Guidelines for measurement of EAS were developed for growers (Goodwin et al., 2009). This new information provides growers with a simple method for accurately predicting potential crop water use based on vine size (measured as EAS) and either historical or current weather data.

Vine water use and canopy temperature

Seasonal patterns of T_c-T_a reflected changes in vine transpiration rates due to water stress (McClymont et al., 2008). For example, decreases in sap flow, associated with soil water deficits when irrigation was withheld for an extended period, were coupled with increases in T_c-T_a. A negative linear relationship existed between relative grapevine transpiration (sap flow/ET_o) and canopy temperature (Fig. 59). Further work is required to establish threshold levels of T_c-T_a for irrigation purposes.

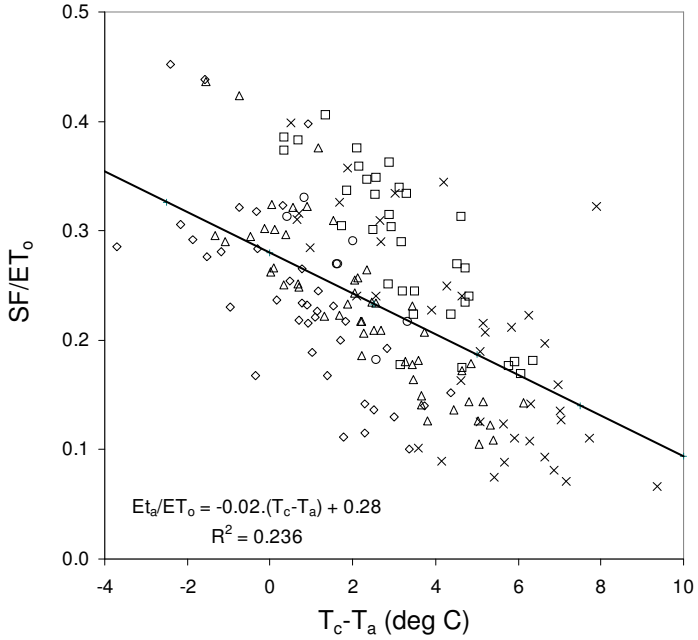


Fig. 59. Relationship between relative grapevine transpiration (sap flow/ ET_o) and average canopy temperature – air temperature (Tc-Ta) between 1200 and 1500 h at five locations within the Tatura site.

Relationships between nutrition and fruit composition

Vegetative tissue and soil nutrient concentrations

Significant positive linear relationships ($R^2 > 0.15$, $P < 0.05$) between like nutrient concentrations in vegetative tissues (blades at flowering and veraison, and petioles at flowering and veraison averaged for Y1, Y2 and Y3) and soil samples (averaged for samples taken at 0 – 10 cm and 15 – 25 cm depths) were determined by simple regression analysis. None of the nutrients had significant relationships at all sites. Given the interactions of soil pH, soil physical structure, soil moisture content and antagonism between soil nutrients with regard to plant nutrient uptake and the potential impacts of fertiliser inputs this was expected. In total, 42 (out of a possible 220) significant linear relationships occurred at individual sites and these were most common at Mil (18). Significant relationships (either for individual or combined sites) occurred most commonly for N and Mn. When sites were combined, relationships between vegetative tissue and soil nutrient concentrations for Na and K tended to be significant. Certain nutrients tended to have significant relationships between vegetative tissue and soil nutrient concentrations at specific sites, e.g. P relationships were consistently significant at LC, Mg at Tat and Na and Ca at Mil.

Plots of selected nutrients are presented in Figure 60. Grapevine nutrition status is most commonly assessed using petioles at flowering, consequently, petioles at flowering data are plotted. The general trend of increasing vegetative tissue Na with increasing soil exchangeable Na was not observed at Tat. Tatura had relatively high soil exchangeable Na compared to other sites but maintained amongst the lowest vegetative tissue Na concentrations. Mil recorded comparatively high vegetative tissue Na for a small number of locations with soil exchangeable Na concentrations similar to those at Tat. These locations were omitted from the analysis for Mil, as outliers, but significant relationships between vegetative tissue Na and exchangeable Na remained. It has previously been suggested that site.rootstock/scion interactions are important with regard to vine nutrient status (Whiting 1990). Apparent exclusion of Na at Tat may be related to the use of Schwarzmann rootstock at the site. It should be noted that, while most sites (Gri, GS and LC) were on own-roots, vines at Mil were also grafted to Schwarzmann and did not appear to exclude Na.

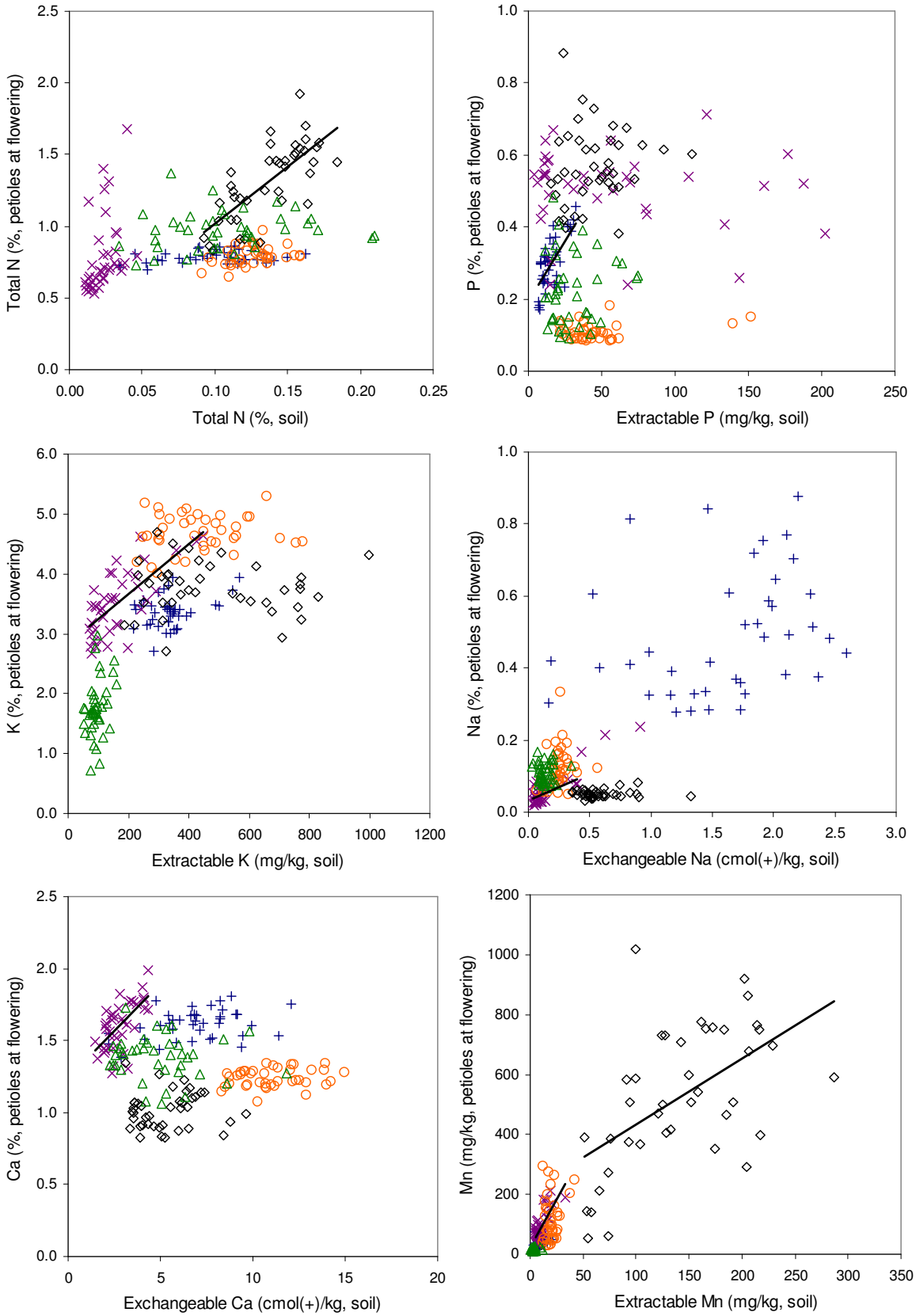


Fig. 60. Nutrient concentrations in petiole at flowering (average of three seasons) and soil samples (average of two depths) at five sites. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS). Lines indicate significant linear relationships ($P < 0.05$) at individual sites.

While soil tests prior to vineyard establishment can help to identify potential vine nutrition problems they cannot be relied on as sole indicators of vineyard nutrition status. Petiole K concentrations were generally greater than adequate (1.8 – 3 % in petioles at flowering according to Robinson et al. 1997) when soil extractable K was greater than 200 mg/kg (or when exchangeable K was greater than approximately 0.5 cmol(+)/kg, data not shown). However, petiole K concentrations greater than adequate occurred even at the lower soil K concentrations seen in this study (70 – 200 mg/kg extractable K at Mil). Furthermore, low petiole Ca at Tat was not associated with low exchangeable Ca in the soil (relative to other sites). This suggests that Ca deficiency in the vines was not due to an absolute deficiency of soil Ca. Soil chemistry and physical attributes at this site should be taken into consideration when planning Ca applications.

Berry homogenate, free-run juice and vegetative tissue nutrient concentrations

Significant positive linear relationships ($R^2 > 0.15$, $P < 0.05$) between berry homogenate or juice nutrient concentrations and vegetative tissue nutrient concentrations (blades at flowering and veraison, and petioles at flowering and veraison averaged for Y1, Y2 and Y3) were common. In total, 137 significant linear relationships (out of a possible 300) between berry or juice and vegetative tissue nutrients occurred at individual sites. Relationships tended to be strongest at veraison and were most common for petioles at veraison. Na, N, Mn, K and B were most likely to have significant relationships between berry and vegetative tissue nutrient concentrations at individual sites (14 – 18 of a possible 20). Significant relationships between berry and vegetative tissue Mg or S concentrations occurred at Tat and Mil, respectively. Plots of selected nutrients are presented in Figure 61.

The prevalence of significant relationships at different sites and the strength of these relationships should be considered when determining the type of tissue sample that is most appropriate for a particular purpose. For example, significant relationships between berry K and petiole K at veraison occurred at all sites and R^2 values tended to be higher than for other samples. Petioles at veraison would therefore be the best indicator of berry K.

Examination of the selected nutrients shown in Figure 61 reveals that while some trends appeared to be generally consistent across all sites (although not necessarily significant within sites) other trends were clearly affected by site differences. Berry Ca tended to increase with petiole Ca when considering data for LC, Mil, Gri, and Tat, but data points from GS clearly fell in a separate cluster. Likewise, while berry P at LC, Mil, Gri and Tat had a relatively low range and little trend in association with petiole P, berry P at GS clearly increased with increasing petiole P. By contrast berry K tended to increase with increasing petiole K when data for all sites was combined, but at individual sites the trend was usually not significant. If data for each site were considered in isolation the conclusions with regard to the relationships between berry K and vegetative tissue K would be contradictory. This highlights the value of multi-site trials, particularly for studies where environment or management practices may have a mitigating effect on variables being studied.

Berry secondary metabolites and vegetative tissue nutrient concentrations

Significant linear relationships ($R^2 > 0.15$, $P < 0.05$) between berry secondary metabolites (anthocyannins, iron-reactive phenolics (IRP) and tannins) and vegetative tissue nutrient concentrations (blades at flowering and veraison, and petioles at flowering and veraison averaged for Y1, Y2 and Y3) were determined by simple regression analysis. 184 of the 780 regressions were significant. Significant relationships at individual sites were most common for N (38), S (27), Mg (20) and Na (20); most relationships were negative.

Berry secondary metabolites and berry nutrient concentrations

There were 49 (out of 195) significant linear regressions ($R^2 > 0.15$, $P < 0.05$) between berry nutrient concentrations and anthocyannins, IRP or tannins. Significant relationships at individual sites were most common for Ca (9), N (8, predominantly with anthocyanins and tannins), and S (8, predominantly with anthocyanins); relationships with Ca were consistently positive, whereas relationships with N and S were both positive and negative. Significant relationships were most common at Langhorne Creek (19).

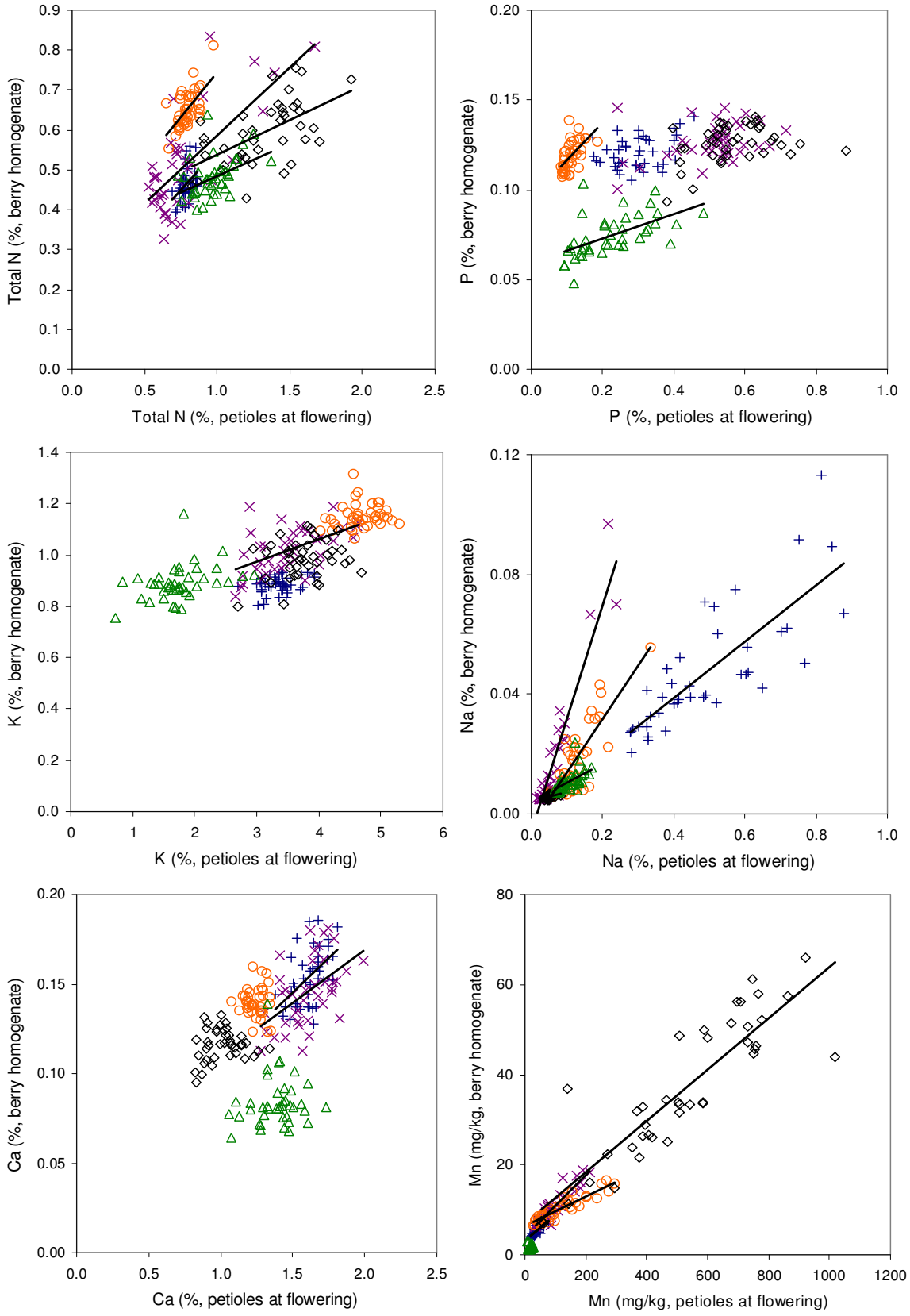


Fig. 61. Nutrient concentrations in petiole at flowering (average of three seasons) and berry homogenate nutrient concentrations at five sites. The five sites were Langhorne Creek (LC), Mildura (Mil), Griffith (Gri), Tatura (Tat) and Great Southern (GS). Lines indicate significant linear relationships ($P<0.05$) at individual sites.

Canopy temperature as a tool to assess grapevine water status

Airborne thermal imagery

Aerial thermal and optical images of the Waikerie site (Fig. 62) clearly showed the potential for this technology to identify water stress across a vineyard block. T_c ranged from 28.5℃ in the well-watered vines to 37.5℃ in the severe water deficit treatment. There was a significant negative linear relationship between leaf conductance and canopy temperature (Fig. 63). Such a relationship is expected to differ with changes in weather conditions, however, the principles of a CWSI could be applied to thermal images (results from ground-based CWSI analysis are presented in the next section).

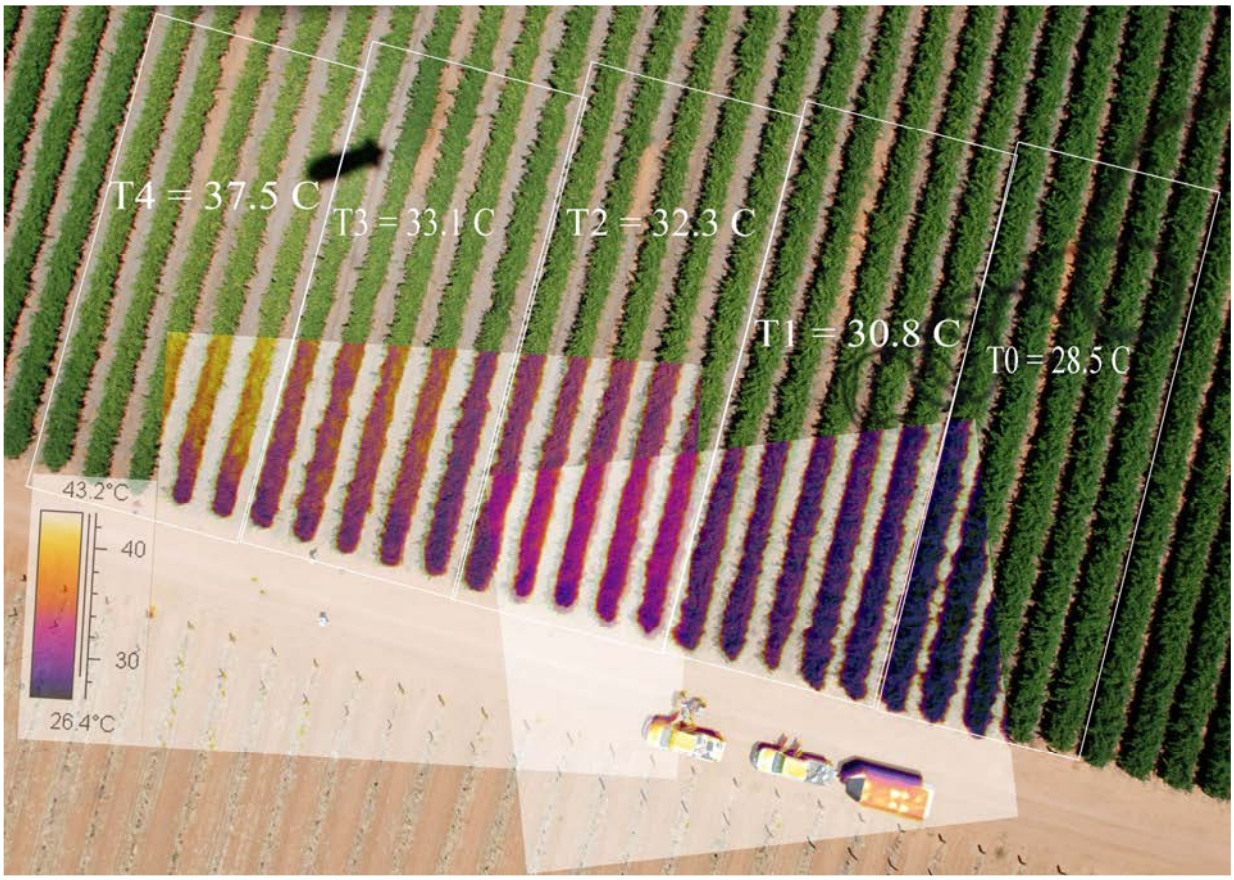


Fig. 62. Optical (green vegetation) and overlaid thermal images (coloured) taken on 9 January 2008 of Cabernet Sauvignon grapevines at Waikerie with different seasonal irrigation treatments; T0 = 6.7, T1 = 3.3, T2 = 2.3, T3 = 1.7, T4 = 0.6 ML/ha.

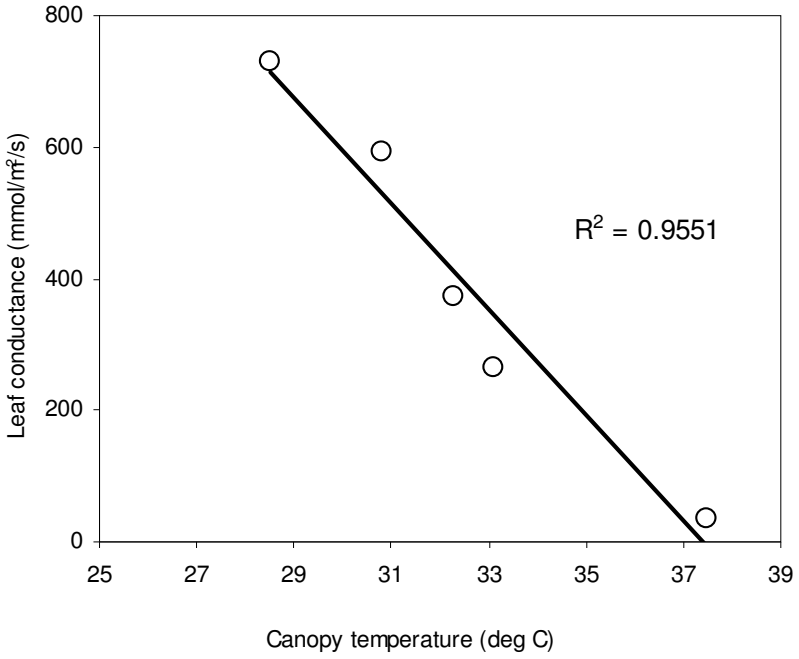


Fig. 63. Relationship between ground-based measures of leaf conductance and aerial measures of canopy temperature from data collected on 9 January 2008 at Waikerie.

Comparison of $CWSI_{Idso}$ with $CWSI_{Jones}$

The non-water stress baseline for well-watered Cabernet Sauvignon at Dookie is shown in Figure 64. The slope of this relationship was -0.7 °C kPa^{-1}. Published non-water stress baseline slopes for grape and other perennial crops range from -1.5 to -6.0 °C kPa^{-1} (Battilani 2000; Garcia et al. 2000).

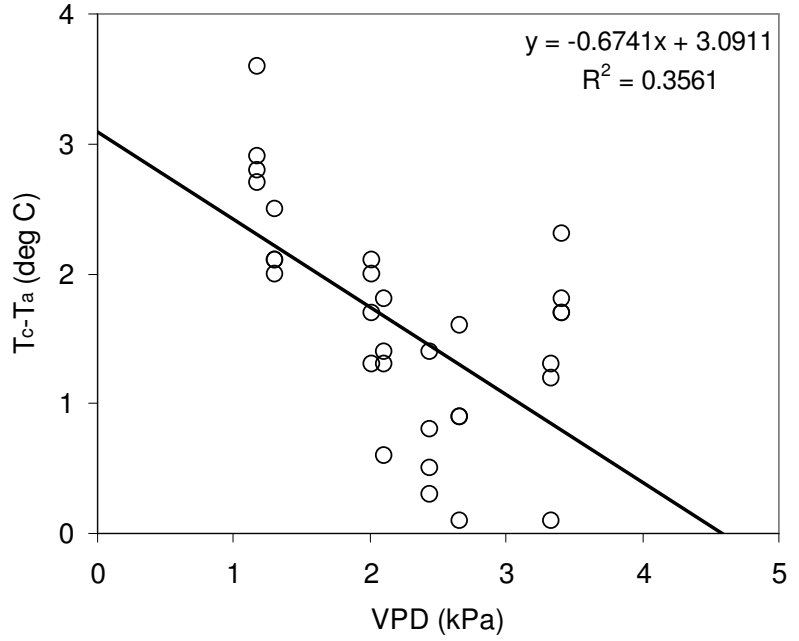


Fig. 64. Non-water stressed baseline relationship for Cabernet Sauvignon at Dookie. Canopy temperature (T_c) was determined from thermal images taken on 15 February 2007. Air temperature (T_a) and vapour pressure deficit (VPD) were measured in an on-site weather station.

The non-water stress baseline was used to calculate $CWSI_{Idso}$ and was compared with $CWSI_{Jones}$ for well-watered and deficit Cabernet Sauvignon vines at Dookie in 2007 (Fig. 65). Images were taken on 9 February, 3 days after irrigation of the Wet_{CS} treatment and 15 days after irrigation of the Dry_{CS} treatment. The corresponding stem water potential data in Figure 63 suggests vines were exhibiting moderate and high levels of stress after 3 and 15 days, respectively, without irrigation (Girona et al. 2005; Williams and Araujo 2002). The Jones method was able to detect a significant difference in water status in the Wet_{CS} compared with Dry_{CS} treatments. By contrast, the variation in the $CWSI_{Idso}$ values resulted in a non-significant difference.

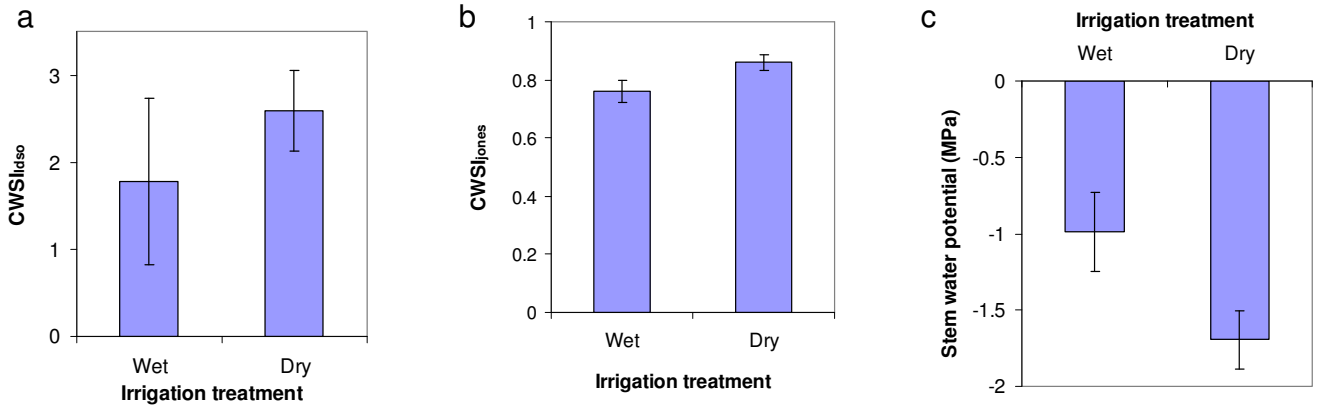


Fig. 65. Crop water stress of Cabernet Sauvignon vines at Dookie on the 9 February 2007 for Wet and Dry treatments (a) calculated from thermal images using Idso method ($CWSI_{Idso}$), (b) calculated from thermal images using Jones method ($CWSI_{Jones}$), and (c) measured by stem water potential. Irrigation had been withheld for 15 days in the Dry treatment.

The Idso method relies on the input of VPD and T_a. Therefore, any shaded parts of the canopy included in T_c will create large variation in the computed T_c-T_a. The manual method used here to identify sunlit leaves from the thermal image to represent T_c was likely to include some shaded leaves set deeper in the canopy. Further complications with the Idso method can arise if the non-water stress baseline does not represent a well-watered example of the crop on a clear sky day. The water status of the grapevines was confirmed as non-stressed from SWP. The most negative SWP of any of the 8 grapevines was > -1.0 MPa at a maximum daily VPD of 3.8 kPa, suggesting no stress (Williams and Araujo, 2002). However, weather conditions on the day used to establish the non-water stress baseline did have some cirrus cloud that may have impacted on the true relationship between T_c-T_a and VPD for the Cabernet Sauvignon grapevines under investigation. The low R^2 value suggests that the slope estimate was not robust and hence the non-stressed baseline should be used with caution.

Gardner et al. (1992) suggested reasons for generation of a $CWSI_{Idso}$ greater than 1 and hence the unreliability of $CWSI_{Idso}$. The points of Gardner et al. (1992) that are relevant here include:

- Some shaded leaves were include in estimation of canopy temperature (T_c)
- Air temperature (T_a) was taken from weather station 500 m away
- The relationship between T_c-T_a and VPD was in error due to variation in net radiation

Comparison of $CWSI_{Jones}$ and I_G with vine water status

$CWSI_{Jones}$ and I_G calculated from either northern or southern facing canopies identified differences in vine water status between Wet_{CS} and Dry_{CS} on all occasions except on a day of very high VPD (5.8 kPa). On this day, at time of measurement, the SWP of both treatments was low (< -1.5 MPa) suggesting the Wet_{CS} may have been under-irrigated.

There was a good relationship between the indices and SWP (Fig. 66). $CWSI_{Jones}$ increased and I_G decreased as SWP decreased.

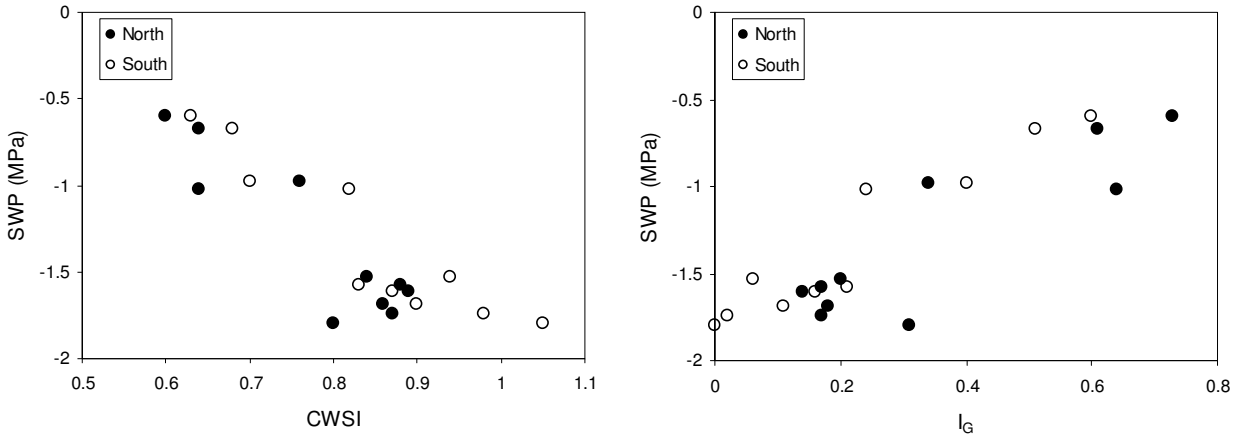


Fig. 66. Relationship between stem water potential (SWP) and crop water stress index using the method of Jones ($CWSI_{Jones}$ and I_G) for Cabernet Sauvignon vines at Dookie.

The standard deviation of the image area selected to represent canopy temperature was different (dry > wet) between treatments on one occasion (day 4 without irrigation). This difference was apparent for the northern facing canopies only. On day 15 without irrigation the standard deviation of the canopy temperature for southern facing canopies was different between treatments, but with wet > dry treatment. The poor reliability of using the variation in canopy temperature to detect onset of water stress may be due to inclusion of shaded leaves in the analysis. Leinonen et al. (2006) found that more precise identification of shaded and sunlit leaves improved repeatability and reliability of indices (CWSI or I_G) to represent vine water status.

Image analysis

The standard scientific protocol for image analysis was used in this project and found to have substantial limitations. The method uses a visual image to manually determine the location of the sunlit canopy. The operator then selects a region in the thermal image that represents sunlit canopy and employs software to calculate a mean sunlit temperature. This method is time consuming and there was great potential for variations in operator interpretation, which could lead to significant variation in results for each image. Discussions with Hamlyn Jones confirmed this as his biggest source of error.

During the project an alternative method of image analysis was developed in collaboration with the Melbourne Systems Laboratory, Department of Electrical & Electronic Engineering, The University of Melbourne. Images were registered through a range of viewing angles (that is the visible camera was at a different angle to the IR camera, a common situation with in field data collection). Structures within the images were identified. Data from the soil and sky were removed, and sunlit leaves, shade leaves and fruit were identified. Mean temperatures for these organs were determined. This automated registration method allow for a non-bias determination of temperature for a transpiring canopy (sunlit leaves).

Spatial variation in canopy temperature

Ground-based measures of canopy temperature for the Mil site in mid-January showed substantial variation across the vineyard. T_c-T_a ranged from -8.5 to 4°C (Fig. 67). There was a distinct strip through the block where vines were much cooler and this appeared to correspond to vigorous vines with high EAS and NDVI. Analysis of vine water requirement and the irrigation inputs suggests these vines should, in theory, be water stress. Vines were obviously accessing soil water derived from another source than irrigation. Sub surface water may have flowed from surrounding blocks of citrus or avocado. Alternatively, irrigation may have drained below the root-zone in the higher areas in this block. Irrespective of the source of water, the measurement of canopy temperature provided data that could be used to improve irrigation efficiency.

There a several management options for this block. Firstly, by applying less water more frequently the smaller vines on light soil are less likely to become water stressed. Sub-daily irrigation may be required to increase lateral wetting. Secondly, the vineyard could be divided into three sub-block so that irrigation can be applied to match the water status. For example, irrigation should be withheld from the sub-block where the vines have low T_c-T_a values.

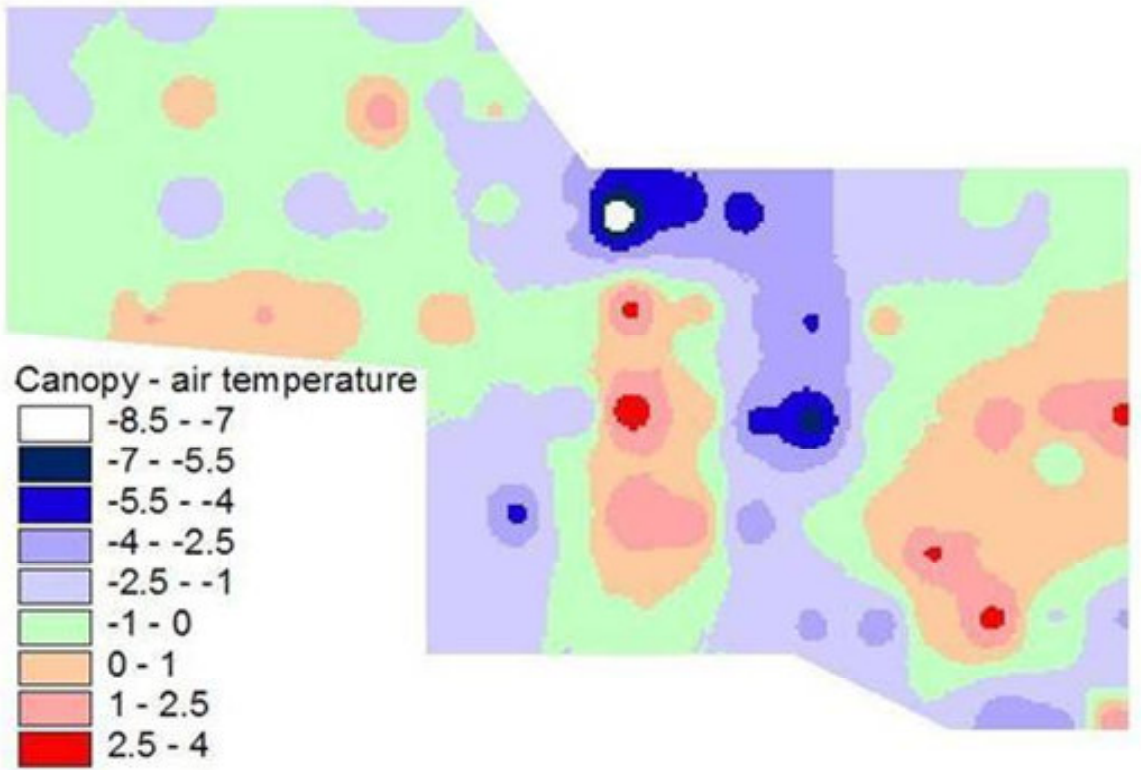


Fig. 67. Spatial variation in canopy – air temperature at Mil site in Y3 (7 Jan 2008). Measurements were taken in the mid-afternoon from directly above the canopy using IR sensors mounted on an ATV.

Outcome/Conclusion

This project set out to explore relationships between vine performance, soil properties, climate and management inputs using data collected from commercial vineyards. Natural variation in the vineyard sites provided a broad range in data that was used to test specific hypotheses and to push the boundaries of current viticulture knowledge. Such an approach was new and aimed to identify research direction for future project. The project was not designed to investigate cause and effect. The viticulture industry must be acknowledged for funding this type of project, which in the short term may not provide immediately practical benefits but does provide an opportunity for major breakthroughs in our understanding of the factors that influence yield and fruit composition.

The project met > 90 % of the planned outputs and performance targets. Outputs partially achieved were associated with the measurement of temporal variation in fruit temperature and the PhD study on monitoring vine water stress. A technique to measure fruit temperature was researched, developed and implemented based on previous studies using thermocouples embedded in berries. Thermal images of instrumented bunches were also taken to determine the feasibility of using a thermal camera to assess spatial variation in fruit temperature. Data was collected for one season and then discontinued because the GWRDC project "Managing grapevines in variable climates: the impact of temperature" commenced detailed experiments on the effects of transient periods of heat stress on fruit composition. Outputs in the PhD study were modified based on the student's review of the literature and the development of the thesis. Thermal imaging of vines and corresponding measures of leaf conductance and water potential became the focus of the PhD, replacing the collection of trunk, cordon and cane shrinkage data. The PhD student has successfully undertaken a confirmation, completed most of the field data collection and has formulated the structure and content of the thesis. Chapter contents have been determined and the writing of these chapters has commenced. Some of the methodology developed by the student has been used and published (Jones et al., 2009; Yang et al., 2009).

Specific practical implications and benefits to the wine industry are given below for yield, fruit and wine composition, nutrition, water use and canopy temperature.

Yield

At each site there was large spatial and temporal variation in yield and yield components. Such variation provided a useful data set for this project to examine the determinants of yield. The variation also highlighted the current status of winegrape growing where year-to-year, paddock-to-paddock and vine-to-vine variation severely limits consistent production.

Analysis of the yield data showed that bunch number was the main component of yield, followed by berry number per bunch and berry fresh weight. Wine grape production relies not only on fresh weight yield but also the production of sugars. With the concentration of berry soluble solids incorporated into the analysis of yield determinants, vines at some sites were shown to be predominantly source limited (Tat and GS) whereas at other sites, vines were predominantly sink limited (Gri and LC). At Mil there was a mixture. At the hotter sites (Mil and Gri) the concentration of soluble solids remained relatively constant irrespective of crop load whereas the concentration of soluble solids declined with crop load at Tat, GS and LC.

The comparison of elevation and high-density soil information with the variation in yield suggests, at least for data derived from EM38 and gamma spectrometers, they should not be used as a surrogate for possible vine yield variation and any vineyard design related to yield.

Berry and wine composition:

The large multi-year dataset collected from across the major Shiraz growing regions in Australia conclusively confirmed the negative association between berry flavonoids and vine vegetative vigour, crop load and berry size. The influence of soil factors on berry composition was largely mediated via their effects on vigour – pedospheric factors that had mild negative influence on vigour appeared to increase berry flavonoids levels. When a soil factor had a strong positive or negative effect on vigour and yield, the consequential effect on berry composition was largely negative.

There was a consistent negative relationship between aerial spectral data of vine size (i.e. NDVI, PCD and vigour) and wine colour, phenolics and tannins at each site apart from Tatura. The narrow hedgerow training system (i.e. VSP) at Tatura probably limited the use of aerial imaging to assess vine size. The relationships between EM38 and wine colour, phenolics and tannins was positive at LC where salinity is high and at Gri, however, other sites were inconsistent and in some cases negative. Aerial spectral data is thus the preferred method to differentiate wine quality.

Nutrition:

Efforts to analyse and interpret nutrition data collated by this project have so far focussed on descriptive reporting of grapevine nutrition status and temporal and spatial patterns of individual nutrients. The analysis will provide industry with increased information regarding Shiraz nutrition and identify nutrients that show practical promise with regard to zonal nutrition management in terms of spatial autocorrelation and temporal stability across a number of sites.

Current standards regarding grapevine nutrition status focus on concentrations of nutrients in vegetative plant tissues, commonly petioles at flowering. The relationships between nutrient concentrations of vegetative tissues and berry homogenate or juice should be integrated into the process of evaluating grapevine nutrient status, particularly with regard to those nutrients considered to have an important impact on wine quality (e.g. N and K). The relationships established in this study form a valuable basis for this integration.

Continuing multivariate analysis of nutrient data will indicate the degree to which nutritional status impacts on grape yield and fruit quality, relative to other parameters, such as irrigation inputs and environmental conditions. Such analysis is vital to determining the value of future efforts to manipulate yield and quality via nutrition management and in identifying factors that may limit the effectiveness of such approaches.

Water use:

This component of the project successfully determined the relationship between vine water use, canopy light interception and water stress. The results were used to provide information on accurate and site-specific prediction of potential crop water use throughout the growing season. Such information will improve water use efficiency by allowing growers to closely match irrigation supply with plant demand. The method is simple, requires no new on-farm technologies and can be implemented by growers immediately. The method for grower assessment of EAS will potentially highlight variability of certain blocks and encourage differential irrigation management leading to further increases in water use efficiency. Improvement of water use efficiency will improve economic returns by reducing unnecessary vine stress and subsequent yield losses and maximising production per unit of water used. Environmental benefits are also possible through the reduction of water losses by drainage or evaporation.

Canopy temperature:

There is some potential for using stationary ground-based canopy temperature measurements to aid irrigation scheduling, however, this approach requires further development. A number of difficulties associated with temporal measurement of canopy temperature were recognised during the project. These problems were systematically addressed, primarily through the adjustment of equipment set-up configurations and data processing. There are further difficulties in determining a CWSI from canopy temperature measurements. Recent published data suggest that this can be calculated from net radiation and wind speed. Future work needs to collaborate with other researchers who are developing these techniques.

Spatial variation in canopy temperature using sensors mounted on an ATV highlighted the need to consider the variation in vine water status across vineyard blocks. Data showed that vineyards can have areas where vines are non-stressed despite inadequate irrigation supply. Vice-versa areas with lack of water were easily identified.

Thermal images of vineyards blocks have the potential to identify spatial range in vine water status and simplify ground-based measures. On-ground thermal imagery of grapevine canopies clearly identified that this technology can discriminate between grapevines supplied with different levels of irrigation. The

limitation to using this approach to identify water stress is mainly associated with image analysis. It is anticipated that a rapid image registration and object identification procedure will be completed by the end of 2009.

Recommendations

Resource use efficiency

Spatial data collected during this project highlighted that future research needs to focus on improving water and nutrient use efficiency in vineyards by matching irrigation and fertiliser to vine requirement. To date, improvements in on-farm water use efficiency have been largely provided by modification of irrigation systems (conversion to drip irrigation) and industry bench-marking exercises. Enabling growers to closely match irrigation supply with grapevine demand is the most immediately applicable method for future improvements in water use efficiency. The relationship between grapevine sap flow and EAS.ETo, determined by this project, is a fundamental component of this method. Research regarding the actual benefits of matching irrigation supply with grapevine demand at scales from block to vine is recommended. Such research will drive the improvements in technology to implement smaller irrigation management units.

Nutrient status within each site was highly variable but showed relative temporal stability and spatial structure. Like irrigation, there is scope to impose spatial management through fertigation of smaller blocks or individual rows or ultimately to individual vines. Research is needed to examine the environmental and production benefits of applying nutrients at sub-block or row-based scales to overcome deficiencies or excessive nutrient levels. Comparisons need to be made with variable rate broadcast applications similar to that used in the grains industry.

Wine composition and soil nutrition

While conclusions regarding nutrient impacts on fruit quality cannot be made based on the results on this project alone, they can be used to highlight nutrients of interest for inclusion in controlled experiments. Correlation analysis of the data showed that wine colour and total red pigments were negatively related to soil nitrogen and soil carbon and positively related to soil salinity at some sites, however, this may have been an indirect effect through vine vegetative growth. Future research needs to determine if this response is direct or indirect (through vine vigour), particularly with respect to soil carbon.

Multivariate analysis of the data indicated that berry secondary metabolites were related to berry Ca. Specific studies of Ca impacts on the growth of inner mesocarp and exocarp and the resultant secondary metabolites are needed as well as investigating the potential direct impact of Ca on biosynthesis of secondary metabolites.

Water use

The relationship between EAS and grape vine water use needs to be tested in terms of irrigation supply. Some studies have shown substantial irrigation losses from understorey evapotranspiration in drip irrigated vineyards. Other studies have shown that understorey management may directly influence vine water use. Simulation studies and field validation are needed to understand the non-vine contributions to irrigation requirements and develop appropriate practical methods to estimate irrigation.

Recent advances in calculating crop evapotranspiration from satellite data could be used to test the relationships between EAS (and NDVI), vineyard water use and irrigation supply. Already a project is developing regional crop coefficients from satellite data and this could be expanded to incorporate irrigation supply, ground based measures of EAS and vine performance indicators.

Differential harvesting for targeted wine composition

Whilst this project has shown that aerial imagery data is consistently related to variation in wine composition, the degree of compositional difference can not be predicted. Hence, companion indicators that can inform the potential range in wine composition within a site need to be developed and matched to aerial imagery data. This allows for a better decision to be made as to the financial implication of differential harvesting.

Setting crop load in a changing climate

The data collected during this project has provided a start on defining the effects of crop load (i.e. berry number per vine), climate, water deficits and vine size on fruit composition, berry size and total yield. The data has been appraised in terms of radiation use efficiency, harvest index and source/sink limitations. More detailed studies of harvest index and radiation use efficiency, particularly the effects of cool climates, are needed so that crop load (through pruning management) can be objectively set to meet yield and quality specifications.

Appendix 1: Communication

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Field Days

Stand at the Wine Grapes Marketing Board Riverina Field Days showcasing research – 8000 visitors

'Water into Wine' Field Day at GWRDC experimental site in Yenda showcasing latest finding on drip systems and effects on wines. Included field walk and wine tasting.

Country News article 15 September 2008. http://www.countrynews.com.au/

Local Media\Radio

'Turning water into wine never tasted so good' - Area News 'Focus on Farming' 31/3/2008

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Appendix 5: Technical Protocols

Soil and Water Initiative

Managing Soil and Water to Target Quality and Reduce Environmental Impact

Materials and Methods
Protocols

September 2009
GWRDC Project DPI 04/04

Acknowledgements

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1. General information

1.1 Occupational health and safety

Appropriate OH&S requirements for each vineyard must be followed. For example, at all Foster Wine Estate vineyards, arms and legs must be covered at all times, safety glasses worn within the vineyard, and robust footwear (i.e. no thongs or sport shoes) and safety vests must be worn at all times.

1.2 Phylloxera

The Tatura vineyard falls within a phylloxera infestation zone (PIZ). The Department of Primary Industries, Tatura, is also within a PIZ. Appropriate precautions must be taken when visiting these sites or when dealing with vine material or equipment from these sites.

For more information on phylloxera, see:

- http://www.phylloxera.com.au
- http://www.phylloxera.com.au/regulation/pdfs/diagnostic.pdf
- http://www.dpi.vic.gov.au/dpi/nrenfa.nsf/LinkView/DB5976FB29F05BBCCA256EFB000952C12233704E4F5B7E8CCA256F0F0013E489#Phylloxera
- http://www.dpi.vic.gov.au/dpi/nrenfa.nsf/LinkView/47E3E43D0A5A36AACA256CF50081B2C60CC67C895DBAF56ECA256EF50015A549
- http://www.gwrdc.com.au/downloads/National%20protocol%20overviewJUNE.pdf

1.3 Contacts

First Name	Family Name	Email address	Office Phone	Mobile Phone
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Julie	Kirby			
David	Smith	David.J.Smith@csiro.au	02 6960 1580	0429439226
Des	Whitfield	Des.whitfield@dpi.vic.gov.au	03 5833 5252	
Ayalsew	Zerihun	a.zerihun@curtin.edu.au	08 9780 5826	

1.4 Sharepoint

The Sharepoint address is: https://partnerportal.csiro.au/gwrdc.

Sharepoint files should never be the only location data is stored. Hard-copies and/or electronic files of all data collected should be kept by the personnel responsible for collecting the data.

Templates are provided for the data that is to be added to Sharepoint, however, these may need to be modified for individual sites. The personnel uploading the data to Sharepoint are responsible for checking the information prior to uploading it.

The procedure for uploading files is outlined in 'Editing Protocols within Sharepoint site' under Documents – Shared Documents (Barnes). Alternatively, if your computer does not allow this method, keep a copy of the files on your hard-drive, make additions or changes to these files and save. Delete the corresponding file from Sharepoint then upload the new version.

1.6 Field-task timeline

Regular tasks:

Management records (discuss with vineyard manager at the start of each season and update regularly).

Emitter rates (once per season).

Each site visit - Manual read of flow meters
- Visual estimate of phenological stage of block (modified E-L system)

Once per month - Measure EC of irrigation water and test well.
- Record test well depth.

Regular downloads - GBugs (at least every 20 days) and manual read 150 cm gypsum block.

- Sap flow loggers (Tatura, Griffith and Great Southern at least once per fortnight).
- Bunch temperature loggers (Tatura and Mildura, once per week).
- Flow meters (once per fortnight – will store up to 167 days).
- Weather stations (Tatura, Griffith and Mildura to compile and send data to Damian each week; Langhorne Creek and Great Southern to be collected by Damian each week).

Budburst: (early-September, early-October) Percentage budburst assessment.

Budburst + 3-4 weeks: Tag shoots for later phenology assessments; Radiation interception and canopy temperature measurements.

Flowering: (November) Flowering assessments; Petiole and blade sampling; Radiation interception measurements (pre- and post- wire-lifting where necessary); Canopy temperature measurements.

Veraison: (December-February) Veraison assessment; Petiole and blade sampling; Radiation interception and canopy temperature (including airborne thermal images) measurements.

Harvest: (February-April) Yield and components (bunch number and berry weight); free-run juice for total soluble solids, pH, titratable acidity, nitrogen and chloride measurements, and berry sampling for anthocyanin, phenolic, tannin and nutrient

measurements; fruit for winemaking; Radiation interception and canopy temperature measurements.

Harvest + 4 weeks: Radiation interception measurements.

Leaf-fall: (May) Leaf-fall assessment.

Dormancy: Pruning, cordon length, and trunk circumference measurements and bud counts. Collect one-year-old wood samples.

2. Gypsum block installation

2.1 Equipment description

The measurement of soil matric potential will be undertaken using gypsum blocks installed at 5 depths in the soil profile. Four of the gypsum blocks at depths ranging from 10-80 cm will be measured continuously with a GBug that will be downloaded every 20 days using a MEA Retriever. A fifth gypsum block will be installed at 150 cm depth and measured manually every 20 days with a GBReader. Watermark sensors are available to use if, after time, the shallow gypsum blocks are deemed insensitive to frequent irrigation events.

2.2 Location within experimental area

Four locations will be identified within the vineyard using either a vegetation-based data or a combination of vegetation-based data and soil based data.

2.3 Depth of installation

The gypsum blocks will be installed at five depths within the soil profile to correspond with the soil physical and chemical sampling protocol. These depths are:

- 10 cm,
- 25 cm,
- 45 cm,
- 80 cm, and
- 150 cm.

2.4 Location along the vine row

Gypsum blocks will be installed adjacent to the target vine. Each gypsum block will be installed using a separate insertion hole. The insertion hole for the gypsum block at 10 cm depth should be located approximately 10 cm from the dripper outlet. Gypsum blocks at 25, 45 and 80 cm depth should be located approximately 20 cm from a dripper outlet. Gypsum blocks at 150cm depth can be located further from the dripper outlet (20-40 cm) to avoid disrupting the gypsum block when the shallower blocks are installed. The insertion hole can be offset from the vine row. Note that in some instances the dripper outlet does not correspond to where the

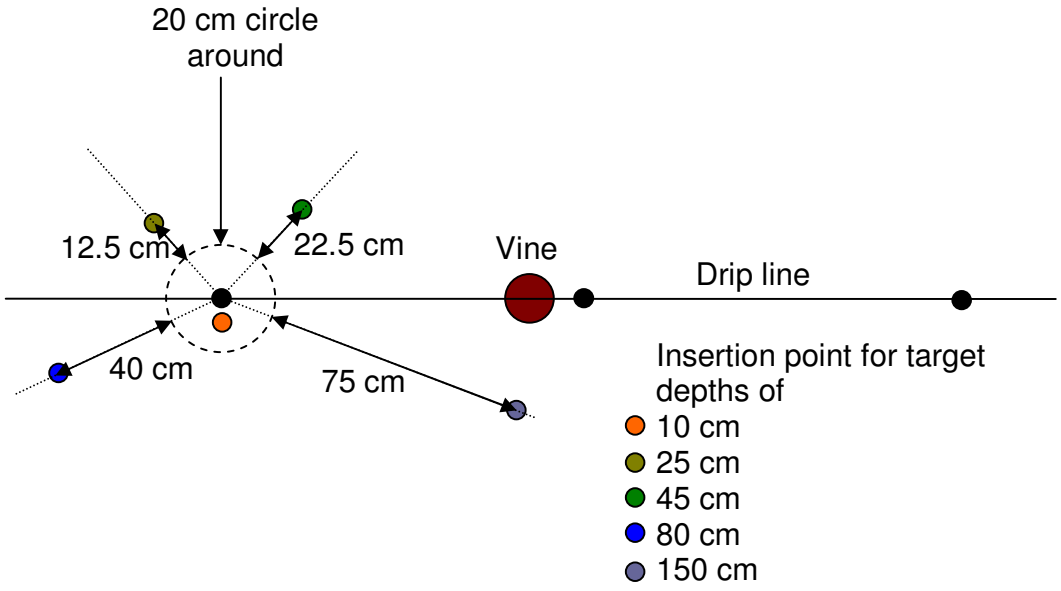
‘drip’ actually occurs due to the water travelling along the PVC tubing. Location should be based on where the drip actually occurs.

2.5 Materials for installation

- 20 litre Bucket
- Approximately five litres of distilled water
- 20 kg of sand:bentonite mix at a ratio of 4:1
- 50 mm diameter auger with extensions to auger to 150 cm
- a broom handle at least 150 cm long
- 20 mm diameter electrical conduit at least 150 cm long with depth marks
- Tape measure (if required)
- Pliers (for connecting cables to the GBug)
- 60 degree guide (cardboard triangle or similar)
- garbage bags or tarp

2.6 Method of installation

To avoid interference with the vine canopy and to further prevent preferential flow, the gypsum blocks at 25, 45, 80 and 150 cm depth will be installed at a 60 degree angle to the horizontal. Hence, the holes used to insert the gypsum blocks at 25, 45, 80 and 150 cm will need to be 29, 52, 92 and 173 cm deep. A cardboard triangle, or similar guide, should be used to aid augering at 60 degree to the horizontal. The diagram below may help with locating the point of insertion to achieve the desired location of the gypsum block. Try to maintain the insertion point within the vine row width to avoid wheel traffic. Note that the gypsum block at 10 cm depth can be inserted vertically.



Mark out four entry points (insertion points) for the auger around a single dripper near the target vine (see diagram above). Gypsum blocks should be unwrapped and soaked in a clean bucket of water for about 15 minutes, this will ensure good contact with the soil when installed.

Auger a hole to 2.5 cm short of the intended depth (eg the 150 cm vertical target depth the hole should be augered to 170.5 cm deep at a 60 degree angle to the horizontal). Keep the augered soil for later backfilling the hole. Insert the electrical conduit down the hole and firmly push the conduit a further 5 cm into the soil and remove. This should leave a small hole in which to insert the gypsum block. Thread the cable of the gypsum block up the electrical conduit and hold the gypsum block tight against the end of the conduit. Lower the gypsum block and conduit into the hole to the bottom of the augered hole and then gently push the gypsum block into the 5 cm hole at the bottom of the augered hole. Remove the conduit and pour ½ a cup of water down the hole to ensure good contact with the surrounding soil. Pour three hand fulls of soil into the hole (from that layer) and gently compact the soil with the blunt end of the broom handle. Continue to backfill the hole with soil, gently compacting as the hole is filled. For the last 15 cm, backfill with a mixture of 1 part bentonite to 4 parts sand (mixed dry in a bucket prior to backfilling) leaving

approximately 2.5 cm of the hole to be filled with surface soil. For the 10cm depth installation only backfill with the soil removed. Label the cable with the depth and date of installation.

In gravel or hard clay soils it may not be possible to take a plug of soil to insert the gypsum block. Alternatively, auger the hole to the appropriate depth, place the gypsum block in the bottom of the hole and then pack fine soil around the block followed by a ½ cup of water. Backfill the hole as above.

2.7 Connection to logger

Connect the 10, 25, 45 and 80 cm deep gypsum block leads to the GBug as instructed in GBug installation manual. If possible, hang the GBug on the irrigation wire and tie the loose gypsum block lead to the same wire.

2.8 Retrieval of data

The GBug data logger is programmed to log every 20 minutes and will have enough memory for 20 days of data. Hence, to maintain continuity of the data the GBug should be downloaded (following the procedure outlined in the GBug manual) at least every 20 days. At the same time, measure the gypsum block at 150 cm depth using a hand held meter. Record the date and time of measurement. Transfer the manually recorded data to a spreadsheet.

2.9 Transfer of data

The data from the GBug and the manual measurements must be uploaded to Sharepoint on the following day after measurement.

2.10 Things to consider

Be aware that in some instances the drippers may block or that the aperture may be restricted by fine deposits or sediments causing the dripper to spray rather than drip. Look for evidence on the soil beneath the dripper that wetting has occurred (e.g. crusting of the soil surface, darkened area).

2.11 Sharepoint files

Data downloaded from GBugs is added to the 'GBUG data – site' file and manual readings are added to the 'Gypsum block manual readings – site' file under '5 Sites Data' on Sharepoint. Each site should adjust the 'GBUG graphs GS' file created by Mary Barnes to suit their sites and upload this to Sharepoint, raw data can then be examined graphically.

2.12 References

http://www.dpi.vic.gov.au/notes/

3. Leaf petiole and blade sampling

3.1 Sampling procedure

When: At flowering (50 % cap fall) and again at veraison (50 % berry colour change)

Where from on vine: Opposite the basal bunch, and evenly distributed throughout the vine. Samples must be taken from shoots arising from the top and bottom cordons where applicable, left and right of the vine trunk and on each side of the vine - working in pairs with a person on each side of the vine makes this much easier.

How many petioles/blades per vine: 20 are needed at flowering. 20 at veraison (or all remaining petioles/blades). If the number of petioles/blades collected is too low to provide an adequate sample for analysis, take the next petioles/blades along from the basal bunches.

Where from in vineyard: Sample 40 target vines. The 40 target vines are a subset of the 100 target vines as determined by the biometrics group in Adelaide. In 2005/06 season the 100 target vines were sampled at flowering (apart from Great Southern and Griffith where 149 and 40 target vines were sampled, respectively).

How to collect the sample: Gloves must be worn to prevent contamination with sunburn cream/hand lotions and salt (perspiration). Rubber surgical gloves are best, but are uncomfortable after a while. Cotton gloves are a reasonable compromise, but discard when they get dirty. Wearing a long-sleeved shirt is also advisable to protect skin from agri-chemicals on the vines. Place intact petiole and blades from each target vine in a labelled paper bag. Immediately place sample in a portable insulated container with a freezer pack placed in the bottom. Wrap freezer packs in tea towels so the samples are not sitting directly on them. Transfer samples to an esky when the container is full. Alternatively place samples directly in esky if using a vehicle to collect samples.

3.2 Washing and drying samples

Preferably wash samples on day of collection. Alternatively, petioles/blades may be left in a cool room (4° C) overnight.

Wash petioles in a series of three basins. Wear clean plastic gloves during the washing process.

Step 1: Wash each intact petiole and blade in a 15 litre plastic tub filled with a mixture of distilled water, two drops of non-phosphate detergent and two drops of 1N HCl. Using a small paint brush (3-4 cm head size) lightly scrub each surface of the blade.

Step 2: Transfer the scrubbed petiole and blade to the second basin, containing distilled water only (no detergent or HCl). After scrubbing all the samples from the target vine, collectively rinse the samples in the distilled water by dunking petioles and blades.

Step 3: Repeat rinsing in third basin (distilled water only) and then place samples on paper towel to remove excess water.

Step 4: Change the water in the first basin after every six target vines, change the water in the second and third basins after twelve target vines. (Note: Water changes may have to become more frequent if there is potential contamination from sample-to-sample).

Step 5: Separate petiole from blade (manually twisting or snapping). Place the petiole and blade in separate paper bags (new – do not use previous field bags) that are labelled. Fold lip of paper bag to avoid loss of sample and/or contamination.

Step 6: Dry in an oven at 60 deg C for at least 48 h.

Step 7: Post drying, store samples in a dry dust free environment prior to grinding

3.3 Grinding

Dried leaf petiole and blade samples must be ground prior to shipment to Adelaide Laboratories. Leaves need to be cut up into pieces prior to grinding. Grind samples to a particle size < 2 mm in a commercial mill (e.g. http://www.retsch.de/english/db/overview.php?AKZ=B01) or a coffee grinder.

The grinder must be cleaned between samples by wiping down accessible surfaces and blowing air through the internal parts of the grinder.

Place ground sample in a plastic vial. Label vial with SAWI, site (e.g. Griffith), date of sampling, phenological stage (flowering or veraison), type of sample (blade or petiole) and target vine number

3.4 Sample delivery to Adelaide for analysis

The phylloxera prevention protocol must be followed prior to dispatch from each site (see http://www.phylloxera.com.au/regulation/pdfs/diagnostic.pdf). Samples will need to be brought in to SA under permit from PIRSA. Samples from Tatura, WA, Mildura and MIA will need to obtain a Plant Health Certificate indicating both the treatment process and the origin of the samples. Samples from Tatura will need to be issued with a permit for movement out of the PIZ by the Manager, Plant Standards, DPI. Samples must be placed in a double zip locked bags and labelled with the origin and nature of the sample and contact details. Send (including the Plant Health Certificate) via overnight courier to Gill Cozens, C/- CSIRO Analytical Services, Adelaide Laboratories, Waite Road, Urrbrae, SA 5064. Once sent, email Dean Lanyon (dean.lanyon@csiro.au) that the samples have been sent with a list of the labelled samples.

3.5 Sharepoint file

Nutrient concentration data are added to the 'Blade and petiole nutrition - site' file under '5 Sites Data' on Sharepoint.

3.6 References

Robinson, J.B. (1992) Grapevine nutrition. In: *Viticulture Volume 2 Practices*, (Eds. B.G.Coombe and P.R.Dry), Winetitles, Adelaide, 178-208.

4. Phenology assessments

The phenological stages of budburst, flowering, veraison and leaf-fall are assessed once during each stage. The primary aim is to determine the spatial variation in phenological development across the site.

4.1 Sampling procedure

When: As close as possible to budburst, flowering and veraison. Ideally assess flowering and veraison when leaf petiole and blade samples are taken for nutrient analysis. Leaf-fall should be assessed prior to vines losing the majority of their leaves. Vineyard managers will be able to provide an estimate of the dates based on observations in previous years. Observations made when visiting the sites will also help determine an assessment date.

Where from on vine: Evaluation of budburst involves classifying each bud on the target vines as burst or unburst and then calculating the percentage of buds burst on each target vine for the day on which observations were made. Evaluation of flowering and veraison involves assessing clusters (inflorescences at flowering and bunches at veraison) on randomly selected shoots on the target vines. Tag six representative fruitful shoots, evenly spaced along the cordons, on each target vine early in the season (approximately three weeks after budburst). Evaluation of leaf-fall involves a visual assessment of the entire vine.

Where from in vineyard: Assess all 100 target vines.

4.2 Budburst

All primary buds on each target vine are classified as burst or unburst. Buds are considered to have burst when they reach stage 04 of the modified E-L system, in accordance with Coombe (1995). Avoid counting buds that are not clearly defined particularly on wood older than 1 year.

4.3 Flowering

Clusters on the six tagged shoots of each target vine are visually assessed. Each cluster is ranked on a scale of 0-5 depending on the degree of cap-fall (Fig. 1), as per Martin and Dunn (1999), the scores are:

- 0 = no cap-fall,
- 1 = 1 cap-fall to 10% cap-fall,
- 2 = 10-50% cap-fall,
- 3 = 50-90% cap-fall,
- 4 = 90% cap-fall to 1 cap remaining, and
- 5 = 100% cap-fall.

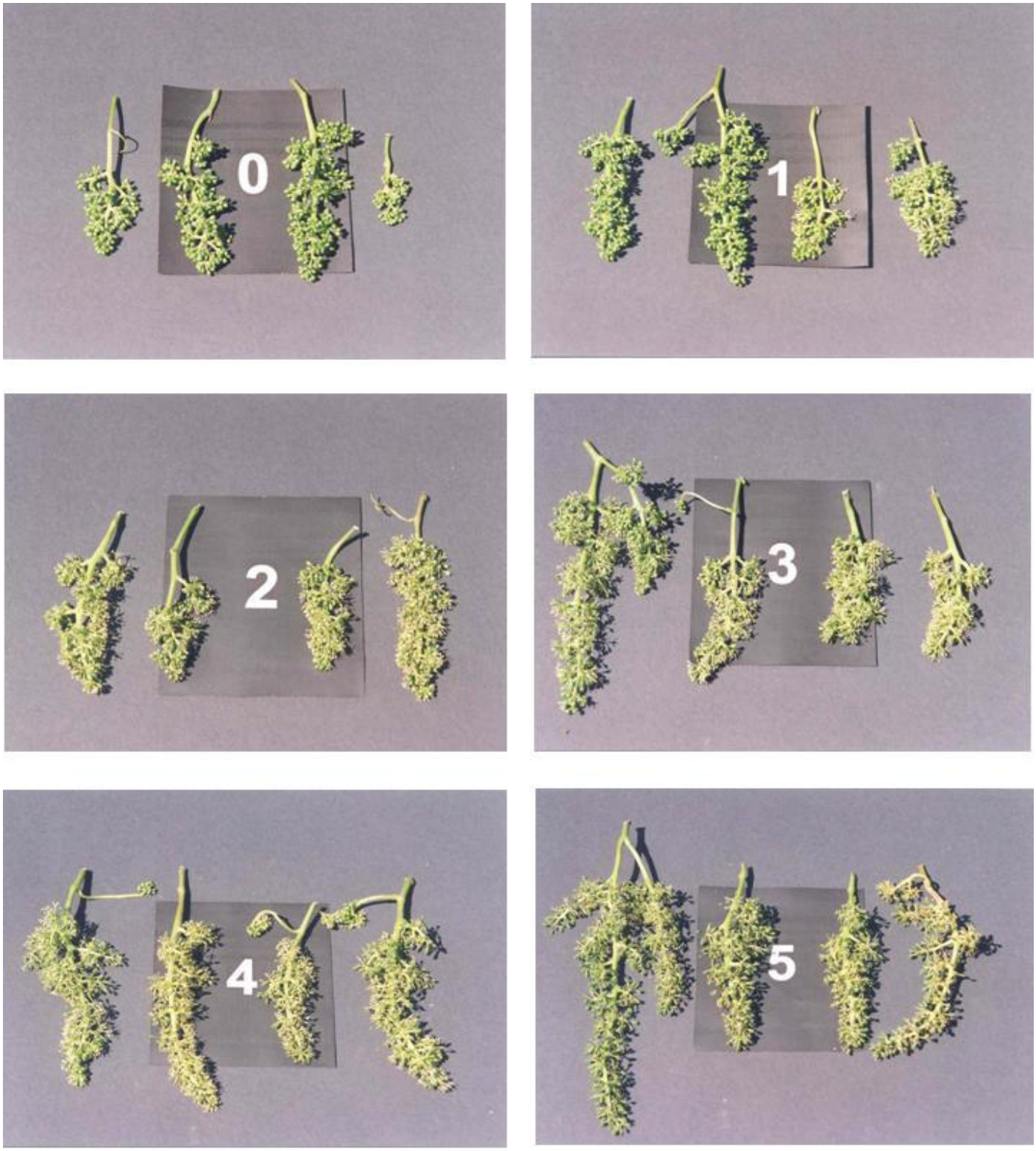


Figure 4.1 Scorecard for assessment of flowering. **0** = no cap-fall, **1** = 1 cap-fall to 10% cap-fall, **2** = 10-50% cap-fall, **3** = 50-90% cap-fall, **4** = 90% cap-fall to 1 cap not fallen, **5** = 100% cap-fall (Martin and Dunn, 2000).

4.4 Veraison

Clusters on the six tagged shoots of each target vine are visually assessed. Each cluster is ranked on a scale of 0-5 depending on the percent colour (Fig. 2, Martin and Dunn 1999). The scores are:

- 0 = no berries coloured,
- 1 = 1 berry coloured to 10% coloured,
- 2 = 10-50% coloured,
- 3 = 50-90% berries coloured,
- 4 = 90% berries coloured to 1 berry not coloured, and
- 5 = 100% berries coloured.

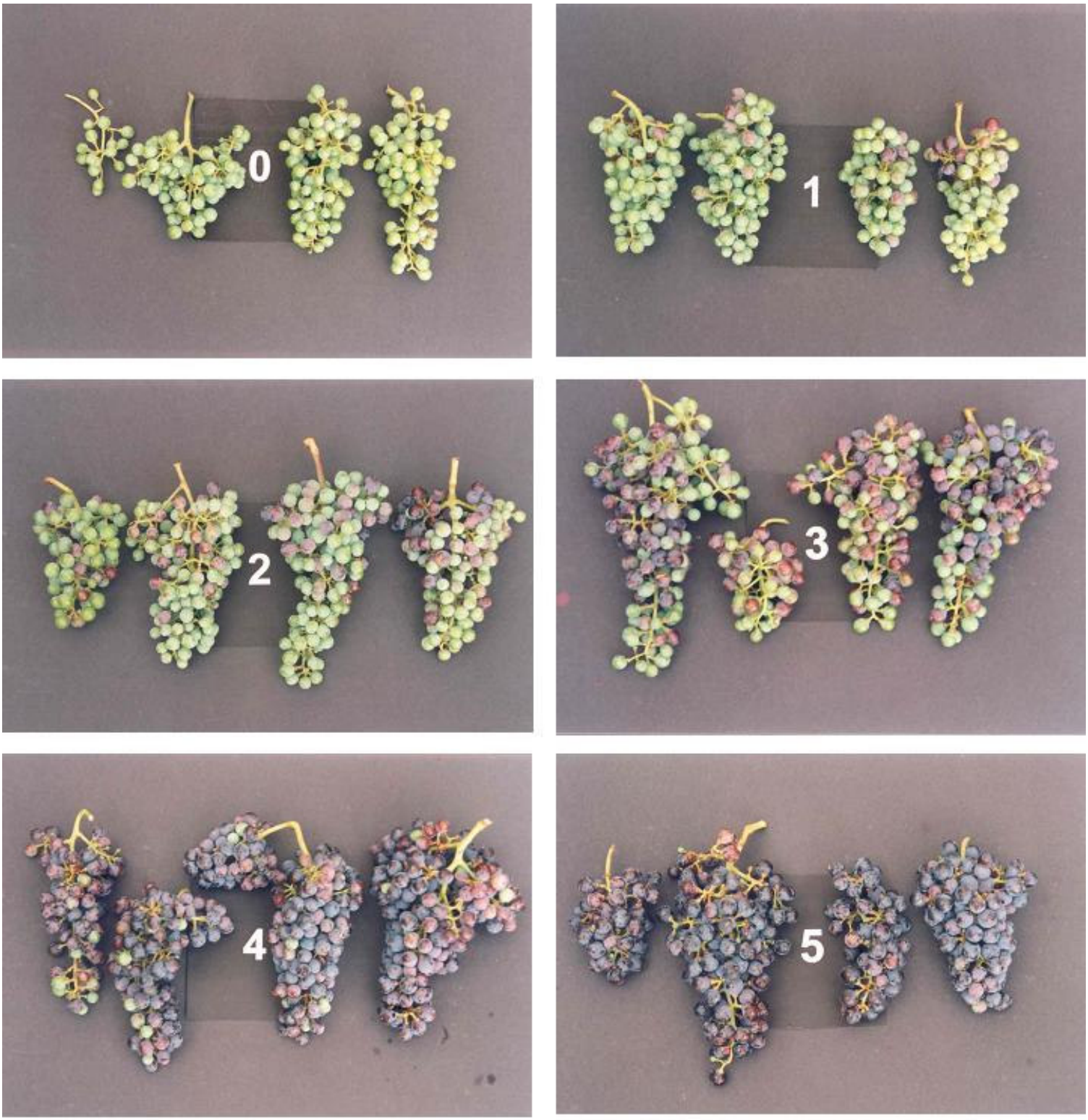


Figure 4.2 Scorecard for assessment of colour change. **0** = no berries coloured, **1** = 1 berry coloured to 10% coloured, **2** = 10-50% coloured, **3** = 50-90% berries coloured, **4** = 90% berries coloured to 1 berry not coloured, **5** = 100% berries coloured (Martin and Dunn, 2000).

4.5 Leaf-fall

Vines are assessed visually. Practice scoring a small number of vines with different degrees of leaf-fall prior to beginning assessment of the 100 target vines, this will help ensure consistent scoring for a given level of leaf-fall. Each vine is ranked on a scale of 0-5 depending on the percent leaf-fall (Fig. 3). The scores are:

- 0 = no leaves fallen,
- 1 = 1 leaf fallen to 10% fallen,
- 2 = 10-50% fallen,
- 3 = 50-90% fallen,
- 4 = 90% leaves fallen to 1 leaf not fallen,
- 5 = 100% fallen.

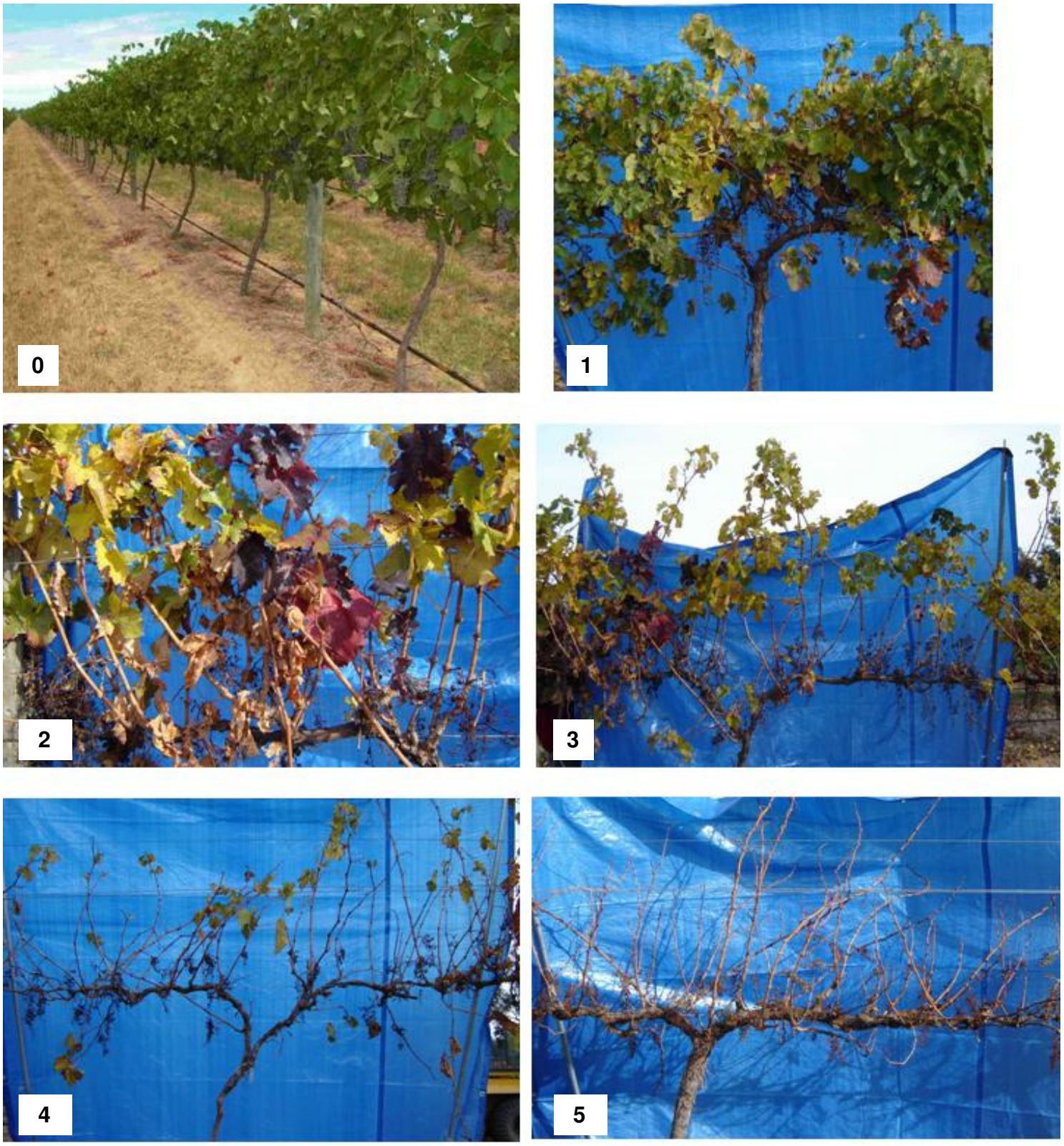


Figure 4.3 Phenology scores at leaf-fall. **0** = zero leaves fallen. **1** = 1 leaf fallen to 10% fallen. **2** = 10% to 50% fallen. **3** = 50% to 90% fallen. **4** = 90% fallen to 1 leaf remaining. **5** = 100% fallen.

4.6 Things to consider

A general assessment of the phenological stage (modified E-L system, Coombe 1995) of the entire block should be recorded every time the block is visited. This information is added to the 'Management records – site' file on Sharepoint.

4.7 Sharepoint files

Budburst, flowering, veraison and leaf-fall scores are added to the 'Phenology - site' file under '5 Sites Data' on Sharepoint.

4.8 References

Coombe, B.G. (1988) Grape phenology. In: *Viticulture Volume 1 Resources in Australia*, (Eds. B.G.Coombe and P.R.Dry), Australian Industrial Publishers Pty Ltd, Adelaide, 139-153.

Coombe, B.G. (1995) Adoption of a system for identifying grapevine growth stages. Australian Journal of Grape and Wine Research, **1**, 100-110.

Martin, S.R. and Dunn, G.M. (1999) Effect of pruning time and hydrogen cyanamide on the budburst and phenology of *Vitis vinifera* L. var. Cabernet Sauvignon in central Victoria. Australian Journal of Grape and Wine Research, **6**, 31-39.

5. Harvesting of target vines and bunch sampling

5.1 Sampling procedure

When to harvest:

Harvesting of the target vines should occur as close as possible to the actual harvest date. However, to allow time to process the grape samples after the harvest for berry weight and basic juice characteristics, harvesting should occur early in the week (either Monday or Tuesday). Harvest can occur up to a week prior to the machine harvest date.

Where to harvest:

Each of the 100 target vines are harvested. In the hot climate locations (Mildura and Griffith) a 50 cm section of the target vine is harvested. The 50 cm section is located to one side of the vine centred at the mid-point of the cordon (ie not straddling the trunk). In the warm climate areas (Tatura, Langhorne Creek and Great Southern) the entire target vine is harvested. This means that fruit from a neighbouring vine is excluded from the harvest even if the vine cordons over-lap. In some instances it may help to tag the end of the cordons with flagging tape prior to the harvest day. This will speed up harvest and help reduce the occurrence of inadvertently sampling the neighbouring vine.

5.2 How and what to harvest

Equipment required:

- Three 50 cm lengths of coloured dowel (Mildura and Griffith only)
- Up to 50 buckets or crates that hold at least 15 kg of grapes (usually 15 litres)
- 100 tags – one for each of the target vines, clearly labelled with the following numbering system: Langhorne Creek 401-500; Mildura 501-600; Griffith 601-700; Tatura 701-800; Great Southern 801-900)
- 100 spare tags
- snips (enough for all staff if they do not have their own)
- Field balance (20-30 kg capacity), accurate to 0.01 kg
- Notebook for recording data

- Up to 250 plastic shopping bags for sub-sampling
- Large tubs for transporting grape samples (could use crates if enough on hand)
- Portable cooler room (Optional)
- Access to quad-bike/gator with trailer (better than trying to carry everything by hand)

At each target vine, using a pair of snips that have been sterilised prior to harvest, remove and count all bunches within the 50 cm zone (Mildura and Griffith) or from the entire vine (Tatura, Great Southern and Langhorne Creek) and place into a bucket or crate. With respect to the 50 cm zone, a bunch is deemed 'in' the 50 cm zone if the point where the bunch stalk attaches to the shoot falls within the 50 cm zone. Care should be taken to keep bunches intact where possible (sometimes this is impossible and bunches must be cut in half to be removed). Removing and counting bunches is usually done in pairs with one person either side of the vine. The bucket is then left under the vine for collection since the bucket is usually too heavy to carry to the end of the row.

A 'bunch' includes all current season fruit forming a cluster or bunch. This includes bunches that have not ripened, bunches that are desiccated for any reason, and cluster of fruit with only a couple of berries.

5.3 What to measure during the harvest (vine yield and bunch number)

As the bunches are removed they are counted. The target vine identification number and the total number of bunches removed from the vine must be written on a tag at completion and placed in the bucket of grapes under the vine ready for collection. If two buckets are required then two tags, with target vine identification number and total bunch number, should be used – one for each bucket.

The bucket of grapes is collected and transported to a 'weighing and sub-sampling station'. Here the total weight of grapes is recorded (note: either weigh the buckets individually after the removal of the grapes or weigh a set of 10 buckets and take the average weight as representative of all buckets).

The total bunch number for the vine is also recorded using the numbers written on the tag accompanying the harvested grapes. Note that it may be advisable to ask people to write the number of bunches on the tag for each person harvesting and counting fruit for that target vine – this removes the problem of incorrect addition of the numbers whilst in the field.

5.4 Bunch sampling

After weighing, a representative sample (30 bunches) of the harvested bunches are removed and placed into separate plastic bags with a tag that has the target vine identification number on it. The bag should be placed into a cool room (~4° C) as soon as possible to avoid spoilage of the fruit.

The phylloxera prevention protocol must be followed prior to transporting the bunch samples to DPI Tatura (see http://www.phylloxera.com.au/regulation/pdfs/diagnostic.pdf). Samples will need to be issued with a permit for movement out of the PIZ from Plant Standards, DPI.

5.5 How many people are required?

As an initial suggestion, three pairs should be picking (i.e. six people), one person to drop off the buckets under each target vine and fetch full buckets, and a further person to weigh and sub-sample. Hence, a total of eight people to harvest 100 vines in one day.

5.6 Sharepoint file

Harvest data is added to the 'TargetVine Harvest Data and Pruning siteYR' file under '5 Sites Data' on Sharepoint.

6. Processing bunch samples – berry weight and berry sampling for analysis

Using the procedure outlined below, two samples of berries are taken from the bunch sub-sample taken during harvest (see 'Harvesting of target vines and bunch sampling'). One sample of 150 berries is weighed to determine berry weight and is then frozen and kept for analysis of tannin, anthocyanin and phenolic content. The remaining sample is kept in cool-storage and used, as soon as possible, for measurement of total soluble solids (TSS), titrable acidity (TA) and pH.

6.1 Sampling procedure

When to process samples:

All bunch samples (30 bunches per target vine) should be processed as soon as possible, ideally within two days of harvesting. The samples should remain in a cool room (~4°C – do not freeze the samples) until they are to be processed.

Equipment required:

- Access to a cool room (~4°C)
- Open bench area
- A bowl to pick berries into
- Plastic dinner plates to count berries from
- 100 medium zip-lock bags (Dean Lanyon to provide)
- 100 tags with target vine identification numbers, year of harvest, Shiraz, SAWI (use the following numbering system: Langhorne Creek 401-500; Mildura 501-600; Griffith 601-700; Tatura 701-800; Great Southern 801-900)
- Approximately twelve 125 mL vials to count berries into
- Approximately four 250 mL vials for weighing
- A further 100 x 250 mL vials for further berry analysis (TSS, pH and TA)
- 100 sticky labels with the target vine number (if required)
- Laboratory balance (0.01 g accuracy)

6.2 Removing berries from the bunch

Care needs to be taken when removing berries from the bunch. It is difficult to remove berries from the bunch without splitting the berry or leaving behind the seeds and/or flesh. It is important that the berry is removed intact. Any berry that is not intact should be discarded.

ALL berries in the bunch should be considered when sampling berries from the bunch. Hence, sampling can include green berries and shrivelled berries.

Step 1: A sample of berries is removed from all the 30 bunches. From each bunch approximately ¼ of the berries are removed and placed into a bowl. The position in the bunch from which the berries are removed is alternated between the top half and the bottom half of the bunch removing all berries from the right portion of the top or bottom half. This is to ensure that a selection of berries is obtained from the top to the bottom, the inner and outer, and the sun exposed and shaded portion of the bunches. Approximately 500 berries are removed using this process.

6.3 Counting berries, weighing and storing

Step 1: Mix the berries by hand using your fingers.

Step 2: Randomly take a handful of berries and place onto a plastic plate. Randomly count 50 berries into a 125 mL vial. Repeat this process a further two times into separate vials (it is easier to count to 50 three times than to 150 once – especially if you loose count). One method to use during counting is to split the plate into thirds. Count 50 berries from each third. If you run out of berries on your plate randomly remove another handful of berries from the bowl.

Step 3: Tare the balance with a 250 mL vial in place. Tip the 150 berries into the 250 mL vial and record the weight and the vine number.

Step 4: Once weighed, tip the 150 berries into a zip-lock bag and distribute in a single layer. Place associated tag in the bag and label the outside of the bag with a permanent marker. Layer the bags in a polystyrene box. With the polystyrene box

open, place into a freezer (preferably -30° C). Once all the berry samples have been frozen, seal the polystyrene box ready for transport to Mildura (Julie Kirby, DPI Irymple) for further analysis. Please ensure that appropriate health certificates are obtained prior to transport.

Step 5: At this point, after 150 berries have been counted, the remaining berries can be placed into a 250 ml vial, labelled with the vine identification number, and returned to a cool-room or fridge. These are used for TSS, pH and TA analysis (see 'Processing berry samples – TSS, pH and TA) – excess berries are discarded along with the rest of the bunch sub-sample.

6.4 Sample delivery to Mildura for analysis

The phylloxera prevention protocol must be followed prior to dispatch from each site (see http://www.phylloxera.com.au/regulation/pdfs/diagnostic.pdf). Samples from Tatura will need to be issued with a permit for movement out of the PIZ from Plant Standards, DPI. Samples must be placed in a double zip locked bags and labelled with the origin and nature of the sample and contact details.

6.5 Sharepoint file

Berry weight data is added to the 'TargetVine Harvest Data and Pruning siteYR' file under '5 Sites Data' on Sharepoint.

7. Processing berry samples – juice TSS, pH, TA, nitrogen and chloride

7.1 Sampling procedure

When to process berry samples:

All 100 berry samples should be processed as soon as possible, ideally within 2 days of harvesting. The samples should remain in a cool room or fridge (~4° C – do not freeze the samples) until they are to be processed.

Please note all grapevine material (e.g. grape samples from Griffith for analysis of TSS, pH and TA) entering DPI Tatura must be recorded in a laboratory log book.

Equipment required:

- centrifuge
- digital refractometer
- auto-titrator
- plastic potato mashers (one per person), ice-cream containers and sieve and bowl (one set per person); OR, alternatively, a grape press and bowl
- centrifuge tubes
- tissues
- 100 small vials for juice N samples (30 mL screw-top vials can be purchased from Crown Scientific, customer code P30).
- 100 mL beakers

7.2 Juice extraction

Step 1: Tip all berries from a sample into an ice-cream container and gently crush with the potato masher, taking care not to crack seeds. Pour the juice off through the sieve. Transfer portions of the grapes to the sieve and crush evenly, then discard the pulp. The juice collected in the bowl can then be returned to the original sample container (labelled with the target vine identification number).

OR: Place the berries in the clean dry press and extract the juice into a clean bowl. Agitate the pressed grapes and press again to remove any remaining juice. Pour the extracted juice into a labelled container and set aside.

Step 2: Pipette 10 mL of juice into each of two centrifuge tubes, labelled with the vine identification number.

Step 3: Wash and dry all utensils before repeating steps one and two.

Step 4: When enough samples have been prepared, centrifuge the samples for 5-10 min to clarify the juice. The speed will depend on the type of centrifuge, and laboratory supervisors should be able to provide an indication of an appropriate speed (for example, 3000 rpm at Tatura and 3500 rpm at Adelaide).

Step 5: The remaining juice sample (not centrifuged) is to be frozen in vials (labelled with SAWI, the vine identification number, date and site) for later nitrogen and chloride analysis by CSIRO Analytical Services, Adelaide Laboratories. The minimum sample size is 5 mL, however, larger samples are recommended. The phylloxera prevention protocol must be followed prior to transporting the juice samples to Adelaide (see below). Adelaide Laboratories use the following method: After thawing, the juice samples are centrifuged. Total N is determined by high temperature catalytic combustion and chemiluminescence detection (FormacsTN, Skalar Analytical Ltd., Breda, Netherlands). Total chloride is determined by an automated colorimetric method (APHA, 2005 – method 4500-Cl- E) using an automated segmented.flow analyser (Alpkem Flow Solution 3, OI Analytical, Texas, USA).

7.3 Total soluble solids

Step 1: Wash the eye of the refractometer with distilled water. Cover the eye with a drop of distilled water and take a measurement. If a zero reading is not given, wash the eye again and repeat (repeat again if necessary). If a zero reading is still not given, re-calibrate the refractometer. Dry the eye with a tissue.

Step 2: Cover the eye of the refractometer with a drop of juice. Take a measurement and record the TSS (° Brix).

Step 3: Wipe the eye clean with a tissue and repeat step 2 for each sample. At regular intervals, repeat step 1.

7.4 pH, and titratable acidity

Step 1: Calibrate the titrator. Laboratories at each site should have guidelines for the calibration of titrators (including settings and programs for auto-titration), and preparation of solutions (these may differ between sites).

Step 2: Decant the juice from the centrifuge tubes into small vials, labelled with the vine identification number.

Step 3: Pipette 10 mL of juice into a 100 mL beaker containing 30 mL of distilled water. Rinse the electrode with distilled water and blot dry with a tissue, to remove any buffer or storage solution. Immerse electrode (juice should cover junction and bulb, the electrode should not touch the beaker) in sample and take pH measurement.

Step 4: Add magnetic stirrer. Start auto-titration. Record reading. Rinse electrode and magnetic stirrer with distilled water and blot dry with a tissue. Repeat steps 3 and 4 for the remaining samples. Return electrode to the storage solution between sample batches.

7.3 Things to consider

Dilutions for titratable acidity measurements may vary at different sites, ensure that your autotitrator is programmed with the correction calculations for the dilution you use.

7.4 Sample delivery to Adelaide for analysis

The phylloxera prevention protocol must be followed prior to dispatch from each site (see http://www.phylloxera.com.au/regulation/pdfs/diagnostic.pdf). Samples will need to be brought in to SA under permit from PIRSA. Samples from Tatura, WA, Mildura and MIA will also need to obtain a Plant Health Certificate indicating both the treatment process and the origin of the samples. Samples from Tatura will need to be issued with a permit for movement out of the PIZ from Plant Standards, DPI. Samples must be placed in a double zip locked bags and labelled with the origin and nature of the sample and contact details. Send (including the Plant Health Certificate) via overnight courier to Gill Cozens, C/- CSIRO Analytical Services, Adelaide Laboratories, Waite Road, Urrbrae, SA 5064. Once sent, email Dean Lanyon (dean.lanyon@csiro.au) that the samples have been sent with a list of the labelled samples.

7.5 Sharepoint file

TSS, pH and TA data is added to the 'TargetVine Harvest Data and Pruning siteYR' file under '5 Sites Data' on Sharepoint.

7.6 References

Iland, P., Ewart, A. and Sitters, J. (1993) Techniques for chemical analysis and stability tests of grape juice and wine. Patrick Iland Wine Promotions Pty Ltd, Cambelltown, SA.

Iland, P., Bruer, N., Edwards, G., Weeks S. and Wilkes, E. (2004) Chemical analysis of grapes and wine: techniques and concepts. Patrick Iland Wine Promotions Pty Ltd ISBN 0-9581605-1-1

CRCV (Rob Bramley)

8. Processing berry samples – whole berry anthocyanins, phenolics, tannins, nitrogen, carbon and nutrients

Frozen berry samples (see 6.3) are transported to DPI Mildura from each site, using dry ice or refrigeration to ensure samples remain frozen. Whole berry samples are stored in a -80°C freezer. Samples are ground and three weighed sub-samples are taken for analysis of phenolics, anthocyanins and tannins. The remaining homogenate is stored (-20°C freezer) and later transported to Adelaide for analysis of total berry N and C by LECO and P, K, Ca, Mg, Na, S, Al, B, Cu, Fe, Mn, and Zn by ICP.

8.1 Grinding whole berries

Note: See dry ice and decanting Liquid Nitrogen work instructions. Safety glasses, cryogenic gloves and laboratory coat must be used at all times when handling Liquid Nitrogen and dry ice. Dry ice and liquid nitrogen will only be used in a well-ventilated environment.
Ear protection must be worn at all times when the grinder is operating.

Equipment required:

- PPE (lab coat, appropriate footwear, ear and eye protection, latex and cryogenic gloves)
- Liquid Nitrogen dewars (check adequate amounts)
- Dry ice in two eskies
- Pre-labelled falcon tubes
- Pre-labelled 120 ml containers
- Grindomix grinder (inc gravity lid)
- Tube racks
- Liquid nitrogen bath x 2
- Liquid nitrogen decanting container
- Ladle
- Spatula x 2
- Sieve

- Stainless steel basin
- Stainless steel dessert spoon
- Funnel (must fit into top of flacon tube)
- Sink filled with warm water
- Dish washing brush and cloths
- Trolley (for dry ice eskies)
- Long handled tongs

Step 1: Setting up Grinder

1. Position two dry ice tubs on trolley next to work station
2. Place an insulated bath to the left hand side of work station and fill with 10cm depth dry ice.
3. Place pre-labelled 120 ml containers in dry ice to chill.
4. Position a liquid nitrogen safe bath on a stable work bench Fill with liquid nitrogen to depth of rack, then use tongs to place two tube racks in liquid nitrogen filled bath.
5. Chill pre-labelled Falcon™ tubes by placing in racks, then place funnel and spatula in tub of liquid nitrogen. Have ladle and tongs in place.
6. Plug in grinder unit and switch Power ON.

Step 2: Operating Grinder

1. Remove berry samples from –80° C freezer and transfer to dry ice esky.
2. Pre-set grinder to 25 seconds at 10,000 rpm (max). These can be knocked out of place, so check settings before every grind.
3. Assemble grinding beaker and blade into grinding position
4. Remove berry sample from bags and gently tap with ladle (if required) to separate berries.
5. Place frozen berries in stainless steel basin and ladle in liquid nitrogen to completely immerse the berries.
6. Once liquid nitrogen has evaporated, pour whole berries into sieve and shake to separate.
7. Transfer whole berries into grinding beaker and spread evenly
8. Insert gravity lid and lock down grinder cover

9. Press grinder start button
10. Wait until grinder unit stops and lid releases.
11. Remove gravity lid and place in water filled sink. Place blade in water filled container next to sink.
12. Gently lift the beaker off grinder (may require leverage with spatula)
13. Spoon powdered berry sample into chilled funnel on top of pre-labelled 15 ml falcon tube held in racks in liquid nitrogen bath, use a spatula to tamp down.
14. Screw on cap and store tube in rack immersed in liquid nitrogen.
15. Use remaining ground homogenate to fill pre-labelled 120 ml container, then screw on lid and store in second ice esky.
16. Discard any excess sample.
17. Place grinding beaker in sink for washing. Once washed, dry thoroughly.
18. Repeat step 3-17 as required.
19. Transfer ground sample in falcon tubes to labelled storage container in –80° C freezer and 120ml samples from dry ice to labelled container in -20° C freezer.

Step 3: After Operation of Grinder

1. After grinding last sample, wash all removable components.
2. Switch Power OFF and unplug grinder.
3. Leave grinder to warm up for approximately 1 hour
4. Remove grinder head to sink to be washed.
5. Wipe down grinder unit inside and out.
6. Wipe down all surrounding benches and under grinder unit.

8.2 Weighing out ground samples for anthocyanins, phenolics and tannins

Note: See decanting Liquid Nitrogen work instruction. Appropriate footwear, safety glasses, latex and cryogenic gloves and laboratory coat must be used at all times when handling Liquid Nitrogen

Equipment:

- Liquid Nitrogen dewars (check adequate volume available)
- Record sheet and pens
- Three pre-labelled 2.0 ml screw top tubes per target vine sample

- Pre-labelled freezer storage boxes
- Stainless steel spatulas (minimum 2)
- Tissues and ethanol to clean any spills
- Red storage rack
- Shallow polystyrene liquid nitrogen bath
- Deep liquid nitrogen bath
- Falcon tube storage racks
- Eppendorf tube storage rack

Setting up weigh station:

1. Fill deep liquid nitrogen bath, then use tongs to gently immerse falcon tube storage racks.
2. Load racks with falcon tubes of frozen berry homogenate samples to be weighed.
3. Using tongs, place a red eppendorf tube storage rack in the shallow polystyrene bath filled with liquid nitrogen.
4. Place end of steel spatulas in liquid nitrogen to chill.

Weighing procedure:

1. Press the RE-ZERO button to prevent possible error before placing material on the weighing pan each time.
2. Place pre-labelled 2ml tube on the weighing pan and press the RE-ZERO button to cancel net weight of the container.
3. Using a chilled steel spatula, scoop frozen berry homogenate powder from a falcon tube to the pre-labelled 2 ml tube.
4. Make sure that all glass doors are closed on balance so that there is no air movement when weighing.
5. Wait for the stabilisation indicator to be displayed and read the value.
6. Once weight is between 0.1650 and 0.1750 g, remove the material and container from the pan.
7. Cap the tube and place in red eppendorf tube rack in shallow liquid nitrogen bath.

8. Once you have completed weighing, place all 2 ml tubes in freezer boxes and store at -80° C.
9. Return homogenate falcon tubes to -80° C freezer.

8.3 Sample analysis for anthocyanins, phenolics, and tannins

Equipment:

- Microcentrifuge
- Eppendorf Multipette (positive displacement pippete)
- Pipette boy or manual equivalent
- Glass 10 ml pipettes
- Vortex mixer
- Aspirator
- 1 ml pipette
- 200 µl pipette
- White tube racks (for sonicator use)
- Blue tube racks
- Reduced volume cuvettes (Crown Scientific used)
- 10 ml tubes

8.3.1 Combitips for the positive displacement pipette

Protein = 10 ml

Washing Buffer = 10 ml

Ferric Chloride Reagent = 2.5 ml

HCl = 10 ml

50% Ethanol = 10 ml

Resuspension Buffer = 10 ml and 2.5 ml

8.3.2 Solution recipes

50% Ethanol

To a 1 L Schott Bottle add 500 ml of 96% Ethanol. Make up to 1.0 L with distilled water.

Washing Buffer

Dissolve 9.86 g sodium chloride (NaCl) into 500 ml distilled water, add 12 ml glacial acetic acid and adjust pH to 4.9 with sodium hydroxide (NaOH) and make volume up to 1.0 L with distilled water.

Can be stored at room temperature.

Resuspension Buffer

Dissolve 50 g SDS in 800 ml of distilled water in a beaker, then add 50 ml of triethanolamine. Gently stir (using magnetic stirrer) the solution in order to dissolve SDS and monitor the pH. When the pH stabilizes, adjust pH to 9.4 with HCl. Transfer the solution to a 1 L Schott Bottle. Rinse the beaker with approximately 200 ml of distilled water and use this to make volume up to 1.0 L.

Can be stored at room temperature.

Ferric Chloride Reagent

Dissolve 2.7 g ferric chloride ($FeCl_3$) in 800 ml distilled water, add 800 µl of concentrated HCl (12.1 N; 33-37% HCl) and make volume up to 1.0 L with distilled water.

Can be stored at room temperature.

Protein Solution

Dissolve 50 mg of BSA in 50 ml Washing Buffer. Makes sufficient quantity for approximately 50 assays. Final concentration = 1.0 mg/ml. Make up fresh as required. Discard unused solution.

Preparing protein solution for storage at -80° C or –20° C

Dissolve 10 g of BSA granules into 250 ml of water to reach maximum soluble concentration of 40 mg/ml. Aliquot 1 ml of concentrated (40 mg/ml) BSA solution into screw cap vials.

Store at –80° C (or –20° C).

Preparing stored protein for use.

Add 1 ml of concentrated BSA (40 mg/ml) to 39 ml of Washing Buffer and mix well (Final concentration 1 mg/ml = sufficient quantity for 40 assays).

8.3.3 Measurement of anthocyanins, phenolics and tannins

Step 1: Preparing the Grape Extract samples

Remove weighed samples from -80° C freezer and place on a bed of dry ice.
Remove one replicate of 32 different samples and place in storage rack. Remove lids, placing in mirror image for re-capping.
To 0.17 g of weighed out homogenate sample add 1.7 ml 50% Ethanol (using multipette). Replace cap and secure (repeat for all samples).
Vortex samples and then sonicate for 20 minutes.
Re-vortex samples
Centrifuge tubes for 10 minutes at 13,200 rpm.

Step 2: Anthocyanin measurement

1. Into a reduced volume cuvette, reverse pipette:
   1 ml 1M HCl (using multipette)
   100 µl grape extract (using 200 µl pipette)

NOTE: immerse the pipette tip in HCl when transferring grape extract.

2. Mix sample (using vortex) and allow to stand for 3 hours.
3. Zero Spectrophotometer with 1M HCl at 520 nm.
4. Read samples at 520 nm

Step 3: Tannin Measurement

1. Into a 1.7ml flip-top microcentrifuge tube pipette the following:
   500 µl grape extract (using 1 ml pipette)
   1 ml Protein Solution (using multipette)

   Incubate for 15 minutes at room temperature with occasional inversion.

2. Centrifuge at maximum speed for 5 minutes to form a pellet.
3. Aspirate remaining supernatant from pellet.
4. Add 500 µl Washing Buffer (using multipette), close the lid and gently invert the tube.
5. Centrifuge microfuge tube for 5 minutes at maximum speed for 5 minutes.
6. Aspirate supernatant.
7. Add 1ml of Resuspension Buffer to pellet (using multipette).

8. Incubate for 20 minutes **WITHOUT** mixing.
9. Vortex sample to resuspend pellet.
10. Transfer 875 µL resuspended pellet solution to a cuvette and let incubate for 10 minutes.
11. Zero Spectrophotometer with 875µl Resuspension Buffer at 510 nm.
12. Read samples at 510 nm = **BACKGROUND TANNIN.**
13. Add 125 µl Ferric Chloride solution to samples. Mix and incubate for 10 minutes.
14. Zero Spectrophotometer with 875 µl Resuspension Buffer + 125 µl of Ferric Chloride solution at 510 nm.
15. Read absorbance of the final samples at 510 nm = **FINAL TANNIN.**

Step 4: Total phenolics measurement

1. Into a reduced volume cuvette, reverse pipette:

   800 µl Resuspension buffer (using multipette)

   75 µl of grape extract (using a 200 µl pipette)

NOTE: immerse the pipette tip in buffer solution when transferring grape extract.

Vortex sample and allow to incubate for 10 minutes.

2. Zero spectrophotometer with 875 µl Resuspension Buffer at 510 nm.
3. Read samples at 510 nm **= Total Phenolics Background.**
4. Add 125 µl of Ferric Chloride Solution to the samples (using multipette). Mix and allow to incubate for 10 minutes.
5. Zero Spectrophotometer with 875 µl resuspension buffer + 125 µl Ferric Chloride Solution at 510 nm.
6. Read samples at 510 nm **= Total Phenolics Final.**

Enter values into Total Phenolics worksheet.

REAGENT LIST

Reagent Name	Supplier	Catalogue No.
SDS (sodium dodecyl sulphate) 100 g	Sigma	L-5750
Triethanolamine 500 mL	Sigma	T-1377
Ferric chloride hexahydrate ($FeCl_3$) 100 g	Sigma	F-2877
Albumin from Bovine Serum (BSA) 10 g	Sigma	A3803
Sodium hydroxide Solution (NaOH) 5.0 M, 150 mL	Sigma	S8263
Hydrochloric acid (37% HCl) 2.5L	Sigma	435570
Glacial acetic acid 500 mL	Sigma	A6283
Sodium chloride (NaCl) 500 g	Sigma	S9888
Maleic Acid	Sigma	M153

8.4 LECO and ICP Analysis

Unweighed sample is retained and kept in storage freezer (-80° C) until transported to CSIRO Analytical Services, Adelaide Laboratories for analysis of total berry N and C by LECO and P, K, Ca, Mg, Na, S, Al, B, Cu, Fe, Mn, and Zn by ICP. Total N (%) and C (%) is determined by high temperature combustion in an atmosphere of oxygen (CNS2000, LECO Corporation, St Joseph, Michigan, USA). Total N was measured as N_2 by thermal conductivity detection and total C was measured as CO_2 by a non-dispersive infrared detector. Whole berry P (%), K (%), Ca (%), Mg (%), Na (%), S (%), Al (mg/kg), B (mg/kg), Cu (mg/kg), Fe (mg/kg), Mn (mg/kg), and Zn (mg/kg) is determined by inductively coupled plasma optical emission spectroscopy (SPECTRO ARCOS, SPECTRO Analytical Instruments, Kleve, Germany) following tube block sample digestion with nitric acid at 140°C for eight hours.

8.5 Transport of frozen berry homogenate (powder) to Adelaide for analysis

The phylloxera prevention protocol must be followed prior to dispatch from Mildura to Adelaide (see http://www.phylloxera.com.au/regulation/pdfs/diagnostic.pdf). Samples will need to be brought in to SA under permit from PIRSA. Samples will also need to obtain a Plant Health Certificate indicating both the treatment process and the origin of the samples. Samples must be placed in a double zip locked bags and labelled with the origin and nature of the sample and contact details. Send (including the Plant Health Certificate) via overnight courier to Gill Cozens, C/- CSIRO Analytical

Services, Adelaide Laboratories, Waite Road, Urrbrae, SA 5064. Once sent, email Dean Lanyon (dean.lanyon@csiro.au) that the samples have been sent with a list of the labelled samples.

8.6 References

Anthocyanin method:

Iland, P., Bruer, N., Edwards, G., Weeks S. and Wilkes, E. (2004) Chemical analysis of grapes and wine: techniques and concepts. Patrick Iland Wine Promotions P/L, Campbelltown, South Australia.

Note: Modified by using a 50% ethanol solution for the initial extraction (not acidulated 50% ethanol). M. Mazza, pers.comm (2007).

Tannin Method:

Harbertson, J.F., Kennedy, J.A., Adams, D.O. (2002) Tannins in Skins and Seeds of Cabernet Sauvignon, Syrah and Pinot Noir Berries During Ripening. Am. J Enol. Vitic. 53:1. 54-59.

Note: Modified by using a 50% ethanol solution for the initial extraction (not acidulated 50% ethanol). M. Mazza, pers.comm (2007).

LECO Method:

AOAC International (1995) In: Official Methods of Analysis of AOAC International 16th edition. P. Cunniff (Ed). AOAC International, Arlington, VA.

Matejovic I. (1996) The application of Dumas method for determination of Carbon, Nitrogen and Sulphur in plant samples. Rostlinna Vyroba 42:313-316.

ICP Method:

Zarcinas, B.A. and Cartwright, B. (1983) Analysis of soil plant material by inductively coupled plasma – optical emission spectrometry. CSIRO Aust. Div. Soils Tech. Paper No. 5, pp 1-36.

Zarcinas, B.A., Cartwright, B. and Spouncer, L.R. (1983) Nitric acid digestion and multi-element analysis of plant material by inductively coupled plasma spectrometry. Commun. Soil Sci. Plant Anal. 18(1):131-146.

9. Winter pruning weight, shoot number, cordon length, trunk circumference and bud number

9.1 Sampling procedure

When: Prior to and as close as practical to the actual pruning time for the site.

Where in the vineyard: All 100 target vines.

How to prune: Vines are pruned according to the directions of the vineyard managers. Where possible, vineyard employees or vineyard-trained contractors should be used to perform the pruning. Alternatively, individual project person is trained by vineyard manager and undertakes all pruning.

Machine pruned vineyards are hedged by hand to the approximate dimensions of the machine. Wood removed later when the vines are cleaned-up is assumed to be negligible.

Pruning must correspond to the same distance over which yield was determined by hand harvesting. For example, if vine bunches were picked, counted and weighed from 50 cm to the side of the vine trunk, then vines are pruned over the same distance.

Equipment:

- Field scales
- Tarp (to collect material on while pruning)
- Three containers – one large tub (100 L) and two smaller buckets (method 2)
- Secateurs, cleaned with disinfectant
- Notebook
- Flexible tape measure
- Spray paint
- Gloves
- Paper bags (for cane sampling, see Section 10)

9.2 Pruning procedure

Step 1: Prior to pruning, measure and record the cordon length – this is the previous season cordon length. Cordon length is measured from the midpoint of the vine trunk to the end of the cordon. Measure all cordons.

Step 2**:** There are two methods to measure pruning weights. Method 1 measures collectively all one-year-old shoots whereas Method 2 separates the pruning material into three groups. Method 1 is used in machine-pruned vineyards. Practicalities and time available will determine the choice of method in hand-pruned vineyards.

Method 1 - Total weight and number of shoots

Additional Equipment:

- 100 tags (with vine number)
- 200 cable ties
- marking pen

Count all shoots greater than 10 cm and record the number on the vine tag. Prune these shoots, bundle together and secure with a couple of cable ties and place next to the vine for collection. After collection, each bundle is weighed and the weight, number of cable ties used and number of shoots recorded.

Method 2 - Weight and number of shoots greater than and less than 5 nodes, and the weight of older wood

The vine pruning material greater than 10 cm in length is divided into three groups (shoots shorter than 10 cm are discarded):

1. shoots greater than 5 nodes (include the bud closest to the spur or cordon),
2. shoots less than or equal to 5 nodes , and
3. wood greater than one-year in age, i.e. spurs and cordons if these are shortened during pruning.

Shoots less than or equal to 5 nodes are removed from the vine, counted, placed in the appropriate bucket and weighed. Remaining shoots on the vine greater than 5 nodes are counted. The tarp is then laid on the ground next to the vine to collect the

pruning material. The vine is pruned making sure that all material is placed on the tarp. One-year-old shoots are removed from older wood, placed in the tub and weighed. The older wood is placed in the second bucket and weighed.
Record the weight of the tub and buckets at the outset and subtract their weights when processing the data – this eliminates the need to tare containers at each weighing. If the small buckets differ in weight, label them so that the same bucket is used at each vine to hold small shoots and the other to hold old wood.

Step 3: If the cordon length has been adjusted during pruning (either shortened or new wood laid down to fill a gap), measure the total length of the new cordon. Record this as the next seasons cordon length.

Step 4: Final bud number is counted and recorded. All viable buds on one-year-old wood (spurs and canes) should be counted, including obvious basal buds on spur-pruned vines.

Step 5: Measure the trunk circumference with the flexible tape. The measurement is taken approximately 30 cm above ground level (Myburgh 1996) between two nodes and above the graft union. Prior to making the measurement, remove loose bark by rubbing the trunk (wearing gloves). Mark the point of measurement with spray paint. The same point is measured each year.

Step 6: Collect cane samples (see Section 10). **This may need to be done prior to pruning, depending on the pruning method.**

9.3 Sharepoint file

All data collected is added to the 'TargetVine Harvest Data and Pruning siteYR' file under '5 Sites Data' on Sharepoint.

9.4 References

Myburgh, P. (1996) Response of *Vitis vinifera* L. cv. Barlinka/Ramsey to soil water depletion levels with particular reference to trunk growth parameters. South African Journal of Enology and Viticulture **17**, 3-14.

10. Cane sampling

10.1 Sampling procedure

When: During dormancy (while pruning).

Where from on vine: Evenly distributed throughout the vine (samples are taken from shoots arising from the top and bottom cordons where applicable, left and right of the vine trunk and on each side of the vine). The third node (counting the basal node as zero, node 1 is at least 1 cm from the base of the cane) and the internode arising from this node is collected (Figure 10.1).



Figure 10.1 a) Collect the third node and the arising internode (between dashed lines) for analysis of C and N reserves. b) Basal buds are counted as zero.

How many samples per vine: Collect eight samples from each vine (samples are to be taken from upper/lower cordons, left/right of the trunk and both sides of the canopy).

Where from in vineyard: Sample 40 target vines. The 40 target vines are the same vines selected for petiole and blade samples at flowering and veraison.

How to collect the sample: Select samples from well-developed, representative canes. Remove cane sections with secateurs and place samples from each target vine in a labelled paper bag, fold-over the top of the bag to prevent loss of material. While in the field, store samples in an esky that has been kept in a cool room the previous night.

10.2 Drying and grinding samples

Step 1: Dry in an oven at 70° C for at least 48 h. Post drying, store samples in a dry, dust-free environment prior to grinding.

Step 2: Cut samples into small pieces prior to grinding. The grinder must be cleaned between samples by wiping down accessible surfaces and blowing air through the internal parts of the grinder. Grind samples to pass mesh size of 0.12 mm. Place ground sample in a plastic vial. Label vial with SAWI, site (e.g. Griffith), date of sampling, type of sample (one-year old wood) and target vine number.

10.3 Sample delivery for analysis

Information regarding analysis location to come.

10.4 Sharepoint file

Data are added to the 'C and N reserves - site' file under '5 Sites Data' on Sharepoint.

10.5 References

pers. comm. Mike Treeby (2006)

11. Canopy radiation interception

11.1 Sampling procedure

When: To capture canopy development throughout the season, radiation interception is measured on a number of occasions:

- three to four weeks after budburst,
- flowering, if wires are lifted, measurements should be made both pre- and post-lifting,
- veraison,
- prior to harvest,
- three to four weeks after harvest.

Where in the vineyard: The 40 target vines selected for petiole and blade measurements.

Shade cast by individual vines is measured. Start and finish points for swipes will be influenced by canopy size and row orientation. Observation of the shade cast by the ceptometer, vine trunk or other markers will help determine the location of individual vine shadows. Overlap of vines, and hence shadows, will occur at some sites. Provided neighbouring vines do not differ greatly in size, this should not be a problem.

How: To assess effective area of shade (EAS), measures of fractional photosynthetically active radiation (PAR, μmol/m^2/s) interception (*f*) are taken at three times on a clear sky day (between 0830 and 0930 h, 1200 and 1300 h and 1530 and 1630 h, times not adjusted for daylight savings) using a handheld ceptometer (Decagon Devices Inc., model SF-80, Cambridge, UK). If all measurements cannot be made within these times, measurements can be completed on the following days.

11.2 Field measurements

Step 1: An initial measure of the incident flux of PAR above the canopy (PAR_A) is made (approximately 1.5 m above ground level in an open region within the vineyard), by holding down the measure ('A') button for a couple of seconds and then pressing the average ('B') button. This measurement is repeated at each vine.

Step 2: The transmitted flux of PAR (PAR_T) is measured at the base of the canopy over the planting square. The ceptometer is held horizontally and perpendicular to the row orientation. The ceptometer is 80 cm long and repeated 'swipes' are taken to measure the entire shaded area. By walking in straight lines up and down the inter-row and observing the shadow cast by the ceptometer to determine where to move at the start of each 'swipe' the user ensures that overlapping measurements are not taken and the entire shaded area is measured. Only the shaded area needs to be measured. Measurements are made by holding down the measure ('A') button and then pressing the average ('B') button to record a single value for each swipe. The user should move at a steady pace to avoid skewing results.

Step 3: Record the average PAR value for each swipe.

11.3 Calculations

f is calculated as:

$$f = 1 - \frac{PAR_T}{PAR_A}$$

If only the shaded area is measured, rather than the entire planting square, then:

$$f = \frac{80}{Row\ spacing\ \ (cm)} \times \left[\left(1 - \frac{PAR_{Ti}}{PAR_A} \right) + \left(1 - \frac{PAR_{Ti+1}}{PAR_A} \right) + \left(1 - \frac{PAR_{Ti+2}}{PAR_A} \right) ..... \right]$$

Repeat PAR measurements at three other locations in the orchard (i.e. a total of 4 regions).

EAS is calculated to be the mean of *f* at the three measurement times (f_{AM}, f_{MID} and f_{PM}). ECC is equivalent to f_{MID}.

Data recording template

e.g.

Plot	PAR_A (Sky)	Time	AM PAR_{Ti} (Vine)	AM PAR_{Ti+1}	AM PAR_{Ti+2}
1	803	8:32	426	603	710
2	839		433	450	605
3	872		482	540	683
4	939	8:42	498	300	594

Where row spacing = 300 cm.

$$f_{AM}\ (plot\ 1) = \frac{80}{300} \times \left[\left(1 - \frac{426}{803}\right) + \left(1 - \frac{603}{803}\right) + \left(1 - \frac{710}{803}\right) \right] = 0.22$$

11.4 Things to consider

Measurements are made on clear sky days.

11.5 Sharepoint file

Data is added to the 'Radiation interception - siteYR' file under '5 Sites Data' on Sharepoint.

11.6 References

Goodwin, I. (2004) Peach tree water use. Thesis. Doctor of Philosophy, The University of Melbourne, Australia.

Goodwin, I., McClymont, L. and O'Connell, M. (2009). Determining effective area of shade in orchards and vineyards to estimate crop water requirement. Agricultural Notes #AG1383, DPI.

http://www.dpi.vic.gov.au/DPI/nreninf.nsf/LinkView/FFB44D93F7BB6C37CA256C4A0083CDB7

12. Weather station

12.1 Siting

Ideally, weather stations should be situated on a well-watered, mown sward, at least 30 m from any paved area, a reasonable distance (ten times the height of obstructions) from the nearest structure (trees or buildings) and must not be shaded by any surrounding object.

In practice, these conditions are not often met for vineyard weather stations. Instead, suggested guidelines for the best location for an automatic weather station are for an area such as a headland or patch of unplanted land adjacent to the crop that is clear of nearby structures and away from roadways and dams.

Tatura: The weather station is located approximately 500 m east of the project block, in a bare, open area. It is approximately 10 m from the nearest row and 15 m from the farm road.

Great Southern: The weather station is located approximately 20 m west of the project block, in a bare, open area. It is approximately 20 m from the nearest row and 7 m from an access track.

Langhorne Creek: The weather station is located approximately 7 m south of the project block between two adjacent blocks, in a bare, open area. It is adjacent two headland tracks. The open area, approximately 15 m wide, is located within a hedge row of young Cyprus pine 2 m tall.

Mildura: Meteorological data is obtained from the Bureau of Meteorology Carwarp station number 76005 and the Lower Murray Water Group weather station at Nangiloc.

Griffith: The CSIRO weather station is located approximately 12.3 km SW of the project block, on a grassed area of approximately 10 x 10 m. It is surrounded

predominately by pasture 300 m to the west, citrus 100 m to the south and natural grasses 100 m to the east and north. The grassed area on the weather station is well watered to a height of approximately 10 cm.

12.2 Sensors

Table 12.1 Description of automatic weather stations at each site.

Site	Tatura	Great Southern	Langhorne Creek	Griffith
Rainfall	TB3A; Hydrlogical Services PL, Warwick Farm, Australia (logged with TinyTag TGPR-1201; Gemini Data Loggers (UK) Ltd, West Sussex, UK)	TB3A; Hydrlogical Services PL, Warwick Farm, Australia	TB3A; Hydrlogical Services PL, Warwick Farm, Australia	CS701; Campbell Scientific, Inc., North Logan, Utah, USA (on site) RIM7499020; Mcvan Instruments Pty Ltd, Mulgrave, Australia (at CSIRO)
Air temperature	HP102A; Rotronic Instrument Corporation, Huntington, USA	HMP 45A-T; Vaisala, Vantaa, Finland	HMP 45A-T; Vaisala, Vantaa, Finland	Copper Constantan Thermocouple, Type T; D&N Engineering Supplies, Lambton, Australia
Wet bulb temperature	NA	NA	NA	Copper Constantan Thermocouple, Type T; D&N Engineering Supplies, Lambton, Australia
Relative humidity	HP102A; Rotronic Instrument Corporation, Huntington, USA	HMP 45A-T; Vaisala, Vantaa, Finland	HMP 45A-T; Vaisala, Vantaa, Finland	RH is calculated from air temperature and wet bulb temperature. HMP 45AC Vaisala, Vantaa, Finland (backup)
Wind speed	AND-02; Monitor Sensors, Caboolture, Australia			014; Met One Instruments, Inc., Grants Pass, Oregon, USA
Solar radiation Logger	SK01D; Carter-Scott Design, Brunswick, Australia 6004B STARLOG; Unidata, O'Connor, Australia	SK01D; Carter-Scott Design, Brunswick, Australia 6004C-21 STARLOG; Unidata, O'Connor, Australia	SK01D; Carter-Scott Design, Brunswick, Australia 6004C-21 STARLOG; Unidata, O'Connor, Australia	EP08; Carter-Scott Design, Melbourne, Australia CR10X logger; Campbell Scientific, Inc., North Logan, Utah, USA
Frequency of measurement	5 sec	5 sec	5 sec	30 sec
Frequency of logging	15 min	15 min	15 min	1 h

12.3 Maintenance

The most important instrument to maintain is the wet bulb temperature sensor for the measurement of humidity (only at Griffith site). This sensor requires a

continuous supply of distilled water which is slowly evaporated off a muslin cloth wrapped around a temperature sensor. The water supply is via a wick which sits in a small plastic bottle. The water supply should be topped up weekly. The muslin cloth and the wick should also be replaced every month or sooner if they become dirty. The bottle of water will need to be cleaned every six months to prevent the build up of algae or sooner if algae is observed.

The wind speed sensor should be oiled every six months. The wind cups and arms can be lifted off the axle and central body of the sensor. A couple of drops of light machine oil are placed on the axle so that it runs down into the internal bearing.

The rain gauge and solar radiation sensor will need to be regularly cleaned. Debris can accumulate in the funnel filter of the tipping bucket rain gauge. Every six months remove the top of the rain gauge clean the filter. Dust and other contaminants can accumulate on the surface of the solar radiation sensor. The solar radiation sensor should be cleaned at least every 2 weeks by wiping the surface with a damp cloth.

12.4 Data collection and quality assurance

Weather station data should be downloaded once a week. Simple calibration checks are critical for accurate data collection from the automatic weather stations. This is best achieved when the data is downloaded.

Initially compare daily maximum and minimum temperature (up to 9 am the following day) and vapour pressure at 9 am with data from the nearest BOM weather station. Obvious differences will be apparent. Immediate checks on temperature can be done by comparing with a standard thermometer. Further checks on the temperature sensor can be made by inserting the sensor in an ice bath. Values should be approximately 0 deg C. Where humidity is calculated from dry bulb temperature and wet bulb temperature, a simple check can be made by removing the muslin from around the wet bulb temperature sensor, (effectively turning it into a dry bulb temperature sensor), and then comparing it to a standard thermometer. Also, the muslin removed should feel quite damp. If not, then the wick may not be transporting water to the muslin and should be replaced with a thicker wick.

Temperature and RH sensors will need to be serviced by the manufacturer if these simple checks show that the sensor is not accurate.

The following estimate of solar radiation can be used for routine checking of data. On a fine, crystal clear summer's day in Victoria, total shortwave solar radiation for the whole day will be approximately 33 MJ/m^2/day. At midday an instantaneous measure of shortwave solar radiation will be about 1000 W/m^2. Hourly or more frequent measurements of solar radiation on clear sky days can be checked by comparison with calculated potential solar radiation. Solar radiation sensors do tend to drift in their calibration and adjustments based on the relationship between measured and potential solar radiation can be applied to the raw data.

Wind can be estimated from the table below.

Descriptive term	Criteria	Wind velocity (km/h)	Wind run (km/day)
Light air	Direction of wind shown by smoke drift, but not by wind vanes.	5	120
Light breeze	Wind felt on face, leaves rustle, ordinary vane moved by wind.	10	240
Gentle breeze	Leaves and small twigs in constant motion, wind extends light flag.	15	360
Moderate breeze	Raises dust and loose paper, small branches are moved.	30	720
Strong breeze	Large branches in motion, umbrella used with difficulty.	50	1,200
Strong gale	Slight structural damage occurs (roof tiles removed).	80	1,920

12.5 Sharepoint

Daily weather data for each site is added to the files "Weather SiteYY.xls" under '5 Sites Data' on Sharepoint.

12.6 References

http://www.longpaddock.qld.gov.au/silo/

http://www.bom.gov.au/inside/services_policy/pub_ag/aws/aws.shtml

http://www.bom.gov.au/inside/oeb/networks/20131.pdf

13. Dripper uniformity

13.1 Sampling procedure

When: At least once. Sites with high variability in dripper flow rates are to be assessed each season.

Where in the vineyard: All drippers within the planting square of the 100 target vines.

How: A volume of water is collected at each dripper over a set time. The hourly flow rate is then calculated.

Equipment:

- approximately 300 vials with lids
- permanent marker pen
- stopwatch (one per person)
- notepad (one per person)
- tape-measure (one per person)
- weighing balance (0.01 g)

Step 1: Prior to going out in the field, label the vials with the vine identification number and a dripper identification (e.g. 701a, 701b, 701c,…). The number of vials needed for each target vine can be calculated based on the number of drippers per vine (i.e. vine and dripper spacing). Spare vials should be carried in case extra drippers have been added to sections of the drip line or in case of holes in the drip line.

Step 2: At each target vine, the flow rate of each dripper within the theoretical planting square is measured. For example, if the vine spacing is 2 m, the flow rates of all drippers 1 m either side of the vine are measured. In practice, vine spacing will vary. Hold the appropriately labelled vial under a dripper and collect water for a set time (e.g. 20 sec, based on the expected flow rate and the size of the vial). If the

flow rate is high, collect water for a shorter period and note the time taken to collect the sample.

If water is spraying from a point, rather than dripping, manipulate the drip line so that a sample can be collected. If water from a dripper is running along the drip line and falling at several points, collect a sample at each point in the vial allocated for that dripper. Alternatively, 'stop' the flow using a pig-tail or piece of blu-tack to force the water to drip at one point.

Make a note if:

- a dripper is blocked, absent or spraying,
- holes are present, or
- the vine spacing differs from the theoretical spacing.

Irrigation should be running for at least 10 minutes prior to beginning measurements, to allow pressure to build in the lines. Some residual flow will occur after pumps shut down – be aware of the time at which irrigation is to be turned-off and do not collect samples after this time. Ideally, all samples within an irrigation block should be collected during the one irrigation event, to ensure pressure is as uniform as possible.

Step 3: In the laboratory, weigh the samples. Allow the vials and lids to air dry and weigh. Calculate the flow rate for each dripper and the total flow rate for each target vine.

13.2 Sharepoint

Data is added to the 'Dripper uniformity - site' file under '5 sites Data' on Sharepoint.

Note: Tatura used the 'planting square' method (measured drippers within 90 cm either side of the vine. Great Southern, Griffith and Langhorne Creek measured the three drippers closest to the target vine. Mildura generally measured one dripper per vine.

14. Canopy temperature

Canopy temperature is an indicator of plant water status. Canopy temperature and air temperature (over grass and/or within the vineyard block) will be measured to investigate possible methodologies and equipment for future research. Canopy temperature will be measured across sites (Tatura, Mildura and Griffith) on single days (spatially) and at specific locations (Tatura and Great Southern target vines with sap flow sensors) throughout the seasons (temporally).

14.1 Procedure for spatial canopy temperature measurements

Equipment:

Sensors –

- two or four infrared temperature (IRT) sensors (3600 ZLC, FoV 15°; Everest Interscience, Tucson, Arizona, USA)
- two temperature/humidity sensors (HMP45A, Vaisala Oyj, Helsinki, Finland), one for within-block air temperature/humidity and one for over-grass air temperature/humidity
- GPS (AgGPS, Trimble Navigation Limited, Sunnyvale, California, USA) set-up to monitor latitude and longitude (or eastings and northings)

Computer –

- two USB-serial cables (Dontronics.com N14327)
- one USB hub, four port (Targus) plus cable
- program: V-Term x2 windows, one window is set-up to collect GPS data with time and date stamp, the other is set-up to collect IRT temperature and air temperature and humidity with time and date stamp; starting the log file creates named files that are stored on Desktop when windows are closed.
- DataTaker 800 (Biolab (Aust) Pty Ltd, Scoresby, Victoria, Australia) – program written into V-term start-up

Note: The Targus hub and Dontronics USB-serial cables have lights that indicate transmission of information and/or connection – this helps trouble-shooting – other brands with lights would also be suitable.

Frame –

1. Mildura

- two aluminium pipes approximately 4 m in length
- one pipe approximately 1.4 m (to brace long arms)
- one pipe approximately 3 m (cross-arm to bear sensors)
- PVC pipe frame for IRT sensors (single length with T-sections, 40 mm diameter)

OR

2. Tatura

- two long PVC pipes (40 mm)
- PVC cross-arm (40 mm)
- PVC pipe frame (40 mm) for IRT sensors (single length or U-shape depending on canopy)

OR

3.Tatura

- one short (~1 m) PVC pipe (40mm)

Miscellaneous –

- Toro, Gator or similar (frame design 3 can be used with a 4-wheel motorbike)
- U-bolts and T-pieces (EL-Gate)
- large (160 mm diameter) PVC pipe section (to shield within-block temperature/humidity sensor)
- temperature and humidity screen and tripod (for over-grass temperature sensor)
- duct tape, rope, wrenches, zip-ties etc
- PVC elbows and T-sections
- batteries (12V)
- second DataTaker (any version),

<u>How to wire sensors to the DT800:</u>

IRT sensor – green wire to channel; brown or orange wire to reference channel and looped to negative power, red to positive power (use 5V sw if using DT600 or DT500).

Temperature/humidity sensor – brown to channel, yellow to channel, purple to battery negative terminal, red to battery positive terminal.

How to set-up the frame and position the sensors:

See Figures 14.1 and 14.2 for frame designs 1 and 2, respectively. Frame 1 (Mildura) was easily assembled by one person. Frame 2 (Tatura) was assembled by two people. A tray-back vehicle is needed to provide height for attaching cross-arms and IRT sensors. A third design was used at Tatura in 2007/2008, a single piece of PVC pipe including T-sections was attached vertically to the front of a gator or four-wheel motorbike and IRT sensors were positioned in the Ts to view the western side of the canopy. Positioning of the IRT sensors will depend on canopy structure. The canopy at Mildura was generally wide and dense, consequently, sensors were positioned to view the canopy from above. The canopy at Tatura was narrow and sparse. Concerns that a nadir view would result in soil temperature being measured meant that sensors at this site were positioned to measure the temperature of the western (sunlit) face of the canopy, although nadir views were trialled in the 2005/2006 and 2006/2007 seasons.

The GPS head was connected to the back of the vehicle cabin.

The logger (DT800) and batteries were placed in plastic crates on the back of the vehicle. The laptop was positioned on the passengers' seat.

The within-block temperature and humidity sensor was hung within a section of 160 mm diameter PVC pipe and connected to the frame cross-arm or brace. The over-grass canopy temperature and humidity sensor, tripod and screen were set-up on the lawn by the lake at Deakin Estate or on the lawn beside the shed at the Tatura site.



Figure 14.1 Infrared temperature sensor frame at the Mildura site.



Figure 14.2 Infrared temperature sensor frame at the Tatura site.

How to initiate data acquisition using laptop to record AgGPS and DT800 data:

This process was designed by Des Whitfield.

1. Prepare AgGPS and DT800 for use up to the stage where they are ready to transmit data
2. Run 'Commports' with no RS232 attached
3. Attach AgGPS RS232, note new entry in Commports
4. Run AgGPSxx.exe, setting properties to 9600 baud, 8,1, n
5. Set AgGPS data logging ON - note log filename in window title.
6. Run 'Commports' without DT800 RS232 attached
7. Attach DT800 RS232, note new entry in Commports
8. Run DT800xx.exe, setting properties to 56000 baud, 8,1, n
9. Set DT800 data logging ON - note log filename in window title.
10. Use 'phone' button to send 'RESET', 'u/n/m' and channel acquisition sequence to DT800
11. At end of run, shut down in the order, AgGPS & DT800 > close log files > close AgGPS.exe & DT800.exe

Recommended that operator does not undertake 10 by hand: the channel sequence in the DT800 must be preserved to maintain a constant relationship between data and transducer.

Data collection:

Measurements were made at key phenological stages (flowering, veraison, and pre-harvest) at Tatura and Mildura. Environmental conditions (cloud) and clashes with other field-work meant that some data-sets was missing or incomplete. Data was collected at Mildura on three days at veraison in the 2007/2008 season, during a period of high temperatures and high irrigation. This data-set may be of particular interest.

Continuous monitoring of canopy temperature of single vines at the Tatura site in 05/06 indicated that relative canopy temperature (canopy temperature – air temperature) was generally stable throughout the afternoon (1200-1700 h AEST). It was therefore decided to take spatial measurements during the afternoons within a

two hour period. Measurements were usually made from 1300-1500 h (AEST), earlier start times (1200-1230 h) were used when cloud development was expected.

Two methods of data collection were trialled.
1. Measurements were made continuously along rows containing target vines. The vehicle was driven at a steady rate. Canopy temperature, air temperature and humidity measurements were logged at a rate of 10 Hz. Geographical coordinates were logged at a rate of 1 Hz.

2. Measurements were made over the target vines only. The driver stopped prior to each target vine, the DT800 logger program was turned on (command: G), the driver proceeded at a steady rate and then stopped at the end of the target vine and halted the logger program (command: H). The time and target vine number were recorded. Geographical coordinates were not required.

Data processing:
Relative canopy temperature (canopy temperature – air temperature) was determined. Data was matched to either geographical coordinates (averaging the temperature and humidity measurements taken each second) or target vine locations (average of measurements for each target vine).

14.2 Procedure for temporal canopy temperature measurements

Equipment required:

- IRT sensors (RAYMID10LTCB8, Raytek Corporation, Santa Cruz, California, USA)
- loggers (DT100, DT100F, DT500, DT600; Biolab (Aust) Pty Ltd, Scoresby, Victoria, Australia)
- plastic crates to house loggers and batteries
- PVC pipe, elbows, T-sections, and end caps with holes drilled for IRT sensors (40 mm diameter)
- star-pickets, duct tape, etc
- IRT shields (ice-cream containers covered in builders foil and a hole cut in the back, insulation foam to pack end-caps)

- IRT box shields (sections of 160 mm diameter PVC pipe, builders foil and insulation foam)

How to wire sensors to loggers:

Wires from 'OUT' and 'GND' within the sensor box were wired to analog input channels (*,+ or -, and R, respectively, for DT500 and DT600) and wires from '12..24V' and 'GND' were wired to positive and negative battery terminals.

How to set-up the frame and position the sensors:

Two sensor positions were trialled (Figure 14.3). Sensors were either positioned 10-20 cm above the canopy and were moved upwards as the canopy developed (Figure 14.3A); or were positioned in the neighbouring row facing the western side of the canopy (at a distance of approximately 2.7 m, Figure 14.3B).



Figure 14.3 Sensor positions for continuous measurement of canopy temperature.

Data collection:

Loggers were programmed to record average temperature every 15 min from readings taken at 10 s intervals.

Data processing:

Relative canopy temperature (canopy temperature – air temperature) was determined using air temperature data from the on-farm weather station. Diurnal data collected between 1200-1500 h was used for analysis of relationships with sap flow.

Things to consider: Canopy temperature is an indicator of plant water status. The time since the last irrigation or rainfall event therefore influences canopy temperature. Spatial differences may be less apparent either when soil water content is very low (all vines stressed) or during or just after irrigation (all vines 'well watered').

Canopy temperature varies throughout the day. Continuous monitoring of canopy temperature of single vines at the Tatura site in 05/06 indicated that relative canopy temperature increased and then decreased during the mornings and was generally stable throughout the afternoon (1200-1700 h AEST). However, it was also recognised that the Raytek IRTs were sensitive to temperature differences between the sensor head and the sensor box (Everest sensors contained all electronics within the head), and this resulted in unreliable temperature measurements when the sun heated the temperature head but the box remained shaded and vice versa. Hence, considerable effort was made to insulate both the temperature head and box. The temperature difference problem was of greatest concern when sensors were used to monitor diurnal temperature fluctuations. Spatial temperature measurements (Griffith) were not subject to this problem. Diurnal data collected between 1200-1500 h also appeared to avoid this problem.