Department of Environment and Primary Industries

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Australian Grape and Wine Authority

Setting benchmarks and recommendations for management of soil health in Australian viticulture



FINAL REPORT to

AUSTRALIAN GRAPE AND WINE AUTHORITY

Project Number: **DPI 1101**

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Research Organisation: **Department of Environment and Primary Industries**

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Setting benchmarks and recommendations for management of soil health in Australian viticulture

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Abstract

This project has laid the groundwork for a soil quality monitoring service that can be used by grape growers to assess the health status of their soils to help them manage this resource. The most appropriate set of indicator tests (a minimum dataset, MDS) to characterise soil quality was identified and published as two companion review papers in the *Australian Journal of Grape and Wine Research*. The MDS was used as a standardized tool to build a database of regional soil datasets for Barossa Valley, McLaren Vale, Yarra Valley and Murray Darling hosted on the website: www.soilquality.org.au as part of a national cross-industry soil monitoring database. The MDS and the standardized sampling methods were adopted by Treasury Wine Estates, Peter Lehmann and the Mornington Peninsula Vignerons Association in 2014 which will expand the regional benchmarking databases into the future.

Executive Summary

This project has laid the groundwork for a soil quality monitoring service that can be used by grape growers to assess the health status of their soils to help them manage this resource. It is the first time the industry has standardized comparisons of soil quality for the midrow, undervine and an adjacent native site. This information is important for correct management within vineyards and can also be used by the industry as a whole to support industry stewardship.

In order to develop such a monitoring system, the project team identified the most appropriate set of indicator tests (a minimum dataset, MDS) which can be used to characterise soil quality, including tests of the physical, chemical and biological properties. The key focus of the first year was to review current indicator tests to identify those tests which provide a MDS that can predict required changes needed for vineyard management. The MDS was chosen on the basis of both scientific merit and practicality. The project team drew on available expertise and datasets within the viticultural research community and from soil scientists engaged in soil quality monitoring conducted outside the wine industry. Two companion review papers have been published in the *Australian Journal of Grape and Wine Research* providing the basis for the choice of the MDS.

The MDS was tested at several sites in project year 1, using standardized sampling methods developed by the team, to ensure that the indicators were able to discriminate between paired sites where different management practices, such as mulch application and undervine compost, had been applied. The MDS variables were affected by the treatments and therefore can be expected to measure improvement associated with management practices. This information formed the basis of a Project Review workshop held at the end of the first year to review the direction of the project and determine the activities and outcomes for the subsequent project years 2 and 3. Project years 2 and 3 included (i) assessments based on regional grower groups of the ease of utilisation of a standardized set of soil health indicators, (ii) benchmarking studies associated with these, and (iii) the provision of industry information packages and workshops.

In project years 2 and 3, the MDS was used as a standardized tool to build a database of regional soil datasets for Australian viticulture. These provide benchmark values against which grape growers can determine the quality of their soils compared with the averages for their region, aiding decisions on management practices for maintenance and enhancement of soil condition, vine productivity and fruit quality. The project benchmarked four regions: Barossa, McLaren Vale, Yarra Valley and Murray Darling, providing valuable data from significant grape growing regions in south eastern Australia and identifying potential constraints of relevance to industry thresholds. The website: www.soilquality.org.au is expanding to host this data and incorporate viticulture into a national cross-industry soil monitoring database.

During the regional benchmarking process, the MDS was examined for robustness by examining year to year variation and laboratory reproducibility of results. There was little year to year variation demonstrating that the MDS variables are stable over time when no practice change is applied. Reproducibility of results from commercial laboratories was identified as an area for improvement. Examples of using the MDS are presented from demonstration trials to identify and manage salinity in the Yarra Valley and, in collaboration with the Barossa Grounds project, to investigate the influence of soil properties on the quality of Barossa Shiraz.

The project was showcased at “Workshop 19: How to interpret soil health tests to assess vineyard performance” as part of the 15th Australian Wine Industry Technical Conference held in Sydney in July 2013. This Workshop reached full capacity of 50 participants from many Australian wine regions and included several from overseas. Outputs of the project are already being taken up and used by industry. Information on using the MDS to assess soil quality was included in Wines of Western Australia Fact Sheet 3 “Assessing soil quality and interpreting soil test results’ funded through GWRDC’s Regional Program. Additionally, in May 2014, the MDS and the standardized sampling methods were provided to Treasury Wine Estates technical viticulture team, who expressed interest in integrating these into their current soil health monitoring programs so that they can contribute to the regional benchmarking databases. Similar requests were received in June 2014 from the Mornington Peninsula Vignerons Association, Victoria, to help them benchmark their own region (analyses are currently being completed and the data prepared for delivery to the database), and from Peter Lehmann Wines, South Australia, so that they can continue to expand the Barossa database.

The key recommendation arising from this project is to ensure that momentum is maintained and the pilot soil monitoring program set up in this project is expanded for use by the whole industry. To date, four regions have been benchmarked and a fifth is underway (Mornington Peninsula). To be nationally relevant, the database should be expanded to include regional datasets of all geographical indications. The soil monitoring system is expected to be utilized by growers in partnership with consultants who can ensure that the standardized sampling methods and soil tests are followed and, equally important, provide interpretation on how to use the information for on-farm management decisions. Further analysis of the data obtained in this project with consultants and other industry experts will assist the industry to better define regional thresholds for soil quality and ensure the national industry can address significant soil quality constraints to grapevine production. To realize this outcome, engagement with and training of consultants is strongly recommended in the next stage to ensure continued uptake and expansion of the soil monitoring program developed by this project.

It is recommended that industry consider providing resources to:

1. Expand the use of the standardized sampling and protocols to more regions throughout the national industry, through regional workshops and investment
2. Continue to analyze and evaluate the information gained in this project, particularly to identify regional constraints and appropriate management actions, and
3. Ensure the data is fully developed as a module that growers can access and use on the soilquality.org website.

Acknowledgements

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The project was a collaboration with team members based in two states (Victoria and South Australia) and from three separate organisations (DEPI Vic, CSIRO, SARDI). Different members of the team took responsibility for different components of the work. The Workshops and validation trials were a team effort driven by DEPI Victoria (Edwards, Porter and assistants); the literature reviews were driven by Danni Oliver and David Riches with input from the team as reflected by the authorship; the McLaren Vale study was undertaken by CSIRO (Bramley, Oliver and assistants), the Barossa study by SARDI (Rawnsley and assistants) and the demonstration trials, Yarra Valley study and Murray Darling study by DEPI Victoria (Edwards, Porter and assistants).

The project team would like to acknowledge the many McLaren Vale, Barossa, Murray Darling and Yarra Valley growers who allowed us to sample soils from their vineyards and otherwise provided information about their operations. The assistance of the following people and organisations in the regional benchmarking component of the project is greatly appreciated:

- McLaren Vale - Irina Santiago-Brown (McLaren Vale Grape Wine and Tourism Association – MVGWTA) and Toby Bekkers who assisted in selecting sites for the first year of the study, and Belinda Bramley (MVGWTA) who facilitated liaison with growers
- Yarra Valley - the Yarra Valley WineGrowers Association, Mark Krstic (AWRI) and Lee Duffy (E.E. Muirs & Sons) who assisted in selecting sites and facilitating liaison with growers
- Murray Darling - Jenny Treeby (DEPI Victoria - Irymple) who selected sites and facilitated liaison with growers
- Barossa – the Barossa Grape and Wine Association for allowing us to collaborate with the Barossa Grounds project.

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- Professor Robert White (The University of Melbourne)
- Soil science colleagues at DEPI Victoria: Dr Pauline Mele, Mark Imhof, Dr Richard McEwan, Dr Lexie McClymont and Dr Ian Goodwin

- Dr Dean Lanyon (Arris Consulting) for advice on sampling and assessing physical soil properties
- Dr Michael McCarthy, SARDI
- Dr Mark Krstic, AWRI

We are also very grateful to:
- Treasury Wine Estates and Yalumba Wines for providing confidential company datasets of soil information for interrogation by the team
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Background

Strong interest from the wine industry for information on soil health at the 2009 Australian Society for Viticulture and Oenology Seminar and follow up workshops in five states conducted under the Water and Vine Innovators Network, along with Professor Robert White's 2010 review "The status of soil health in the viticulture and wine industry" which was commissioned by GWRDC, provided the impetus for the development of this cooperative project led by DEPI Victoria in conjunction with the CSIRO Sustainable Agriculture Flagship. This project was commissioned by GWRDC to address recommendation 1 of Professor White's review, which focuses on the development of a 'minimum dataset' of key soil properties which the Australian wine industry can use to benchmark and monitor soil health, and so gauge the impact of management practices on soil health and identify practices which aim to improve vineyard management.

Better management of soil health potentially offers growers the benefits of sustained yields, disease suppression, increased efficiency of water and nutrient use, and improved overall environmental management systems. With appropriate monitoring, it also offers a basis for demonstration of the use of sustainable practices. Globally, there is an increasing awareness of the fragility of the environment and natural resources and the decline in soil health due to agriculture and the need for more sustainable production practices. In 2006, the Australia State of the Environment Report proposed that loss of soil carbon and increases in soil salinity and acidity were the three major areas of concern to soil health in Australia.

In viticulture, the relationships between key soil quality factors, such as amount of soil carbon or nitrate nitrogen are seen as critical components for soil health, vine health and wine quality. However, there has been no coordinated effort to improve the knowledge of such soil health factors or establish relationships in major wine regions across Australia.

During a series of national workshops in five states held in 2009/2010 attended by over 450 industry representatives, improvement in knowledge on soil quality / soil health was identified by attendees as key priorities for research and development in order to gain the benefits to vine performance, vineyard sustainability and profit. There was a clear lack of knowledge on the relationship between management factors which improve the physical, chemical and biological status in soils, improve its functions (e.g. water holding capacity, disease suppression, nutrient recycling) and vine productivity and vine health. Attendees also saw the benefits of maintaining or developing 'clean and green' credentials to maintain environmental responsibility right through the value chain.

The project aimed to develop a list of the priority tests of soil physical, chemical and biological properties that can be used to benchmark the impact of management practices on soil health within key viticultural regions. This would be used to create a database of information from soil health indicator tests which can be used by industry to set thresholds for best practice for management of soil health within key regions. This would be supported by fact sheets for better use of indicator tests and management of soil health.

Project Aims and Performance targets:

Objectives

The key objectives of the project were;

1. To use a set of national (and international) experts to identify a minimum dataset of key indicator tests (physical, chemical and biological) for soil health (eg soil pH, organic carbon content, water infiltration, etc.) for effective monitoring of vineyard soil condition to help improve wine quality, vine health and longevity.
2. To benchmark different management systems with potential to improve soil health in key regions and to determine the relationship to yield, vine health, grape quality and grower profit. A database of this information was to be developed for future use after the project using a suitable model, such as that developed by Cornell University.
3. To produce fact sheets that detail links between indicators of soil health, grower management and vine performance.
4. Engage with key viticulturists in discussion groups and one-on-one meetings in major wine growing regions of Australia to prioritise the major constraints affecting soil health and determine the major outcomes required by the wine grape industry (representatives from Winemakers Federation of Australia and Entwine expected to attend). The discussion groups will identify existing data that can be used to further develop benchmark tests and to identify and report threshold values which suit particular regions. In years 2 and 3 key viticulturists will commit to improve management of soils on their vineyards.

Outputs and Activities

*Outputs and Activities are research outputs (**up to a maximum of 6 a year**) and the activities that will be undertaken to deliver the outputs. A target date is required for each output.*

Year 1	Output	Target Date dd/mm/yy	Activities
a	Selection of standardized indicator tests (minimum set)	31/10/11	Expert group to review, select and validate the performance of indicator tests used by viticulturists, GRDC, HAL, Cornell University and other research programs.
b	Better management of constraints	31/10/11	Expert group (or one to one meetings with key viticulturists) to identify the benefit to be gained by use of indicators to improve vineyard management and soil sustainability under their circumstances.
c	First round of benchmarking studies established and analysed (at least one paired site per 2 regions)	30/04/12	Soil samples and petiole tests from paired sites, taken at key times during the season (dormancy, anthesis) will be analysed by the standard set of tests on at least 1 key property within two regions to establish relationships.
d	Project Review workshop	30/04/12	A workshop will be held to review the outcomes of the first years research and demonstrations. The projects aims and outputs will be redirected if necessary in collaboration with GWRDC.

Outputs for Years 2 and 3 will only be confirmed after the project review workshop in April, 2012

As a result of the Project Review Workshop held in June 2012 (instead of April 2012), the project was modified to concentrate on developing regional databases using the minimum dataset and standardized methodology for future use after the completion of the project. Industry participants were strongly in favour of developing this resource and indicated that defining relationships between soil characteristics and vine performance, and developing fact sheets linking these to management practices, should not be included in this current project.

Year 2	Output	Target Date dd/mm/yy	Activities
b	Second round of benchmarking studies established	30/09/12	Data from first years studies utilised to determine parameters for second round of benchmarking and a number (up to 3) of properties per region benchmarked (paired sites)
c	First round of dedicated field trials established	31/10/12	At least 2 demonstration trials (in selected regions) will be established to validate the use of indicators chosen in the first year. These sites will focus on a key management option to improve vine performance for a major soil health factor (ie constraint). It is anticipated that specific organic treatments, nutrient applications or irrigation treatments will be applied across a select number of sites. A minimum dataset will be used to determine impacts on factors, such as soil carbon, soil compaction, water infiltration and disease suppression.
d	Databasing and economic modelling	31/04/13	A means of public access to the project database and action thresholds will be explored and if necessary developed. Some tailoring per region anticipated. A simple input/output economic model will be developed to identify cost/benefit of changed practice within the vineyard.
e	Articles for National newsletter published (The Australian Grape and Wine Grower, etc.)	30/04/13	Articles prepared
f	Participatory workshops held (up to 3 in total)	31/05/13	Workshops held within selected regions and possible workshops held outside of trial districts (eg Margaret River, WA). WA industry has expressed an interest to be consulted with outcomes from the project

Year 3	Output	Target Date dd/mm/yy	Activities
a	Second round of field benchmarking studies analysed and reported	30/09/13	Excel database analysed using principal component analyses and other relevant analyses and data tabulated and reported in format suitable for publication
b	Third round of benchmarking studies set up	30/09/13	Data from second years studies utilised to determine parameters for second round of benchmarking and another set of 5 properties per region benchmarked (paired sites)
c	Continuation of long term field trials in selected regions	30/09/13	Repeat treatments applied to demonstration sites and soil and vine sampling conducted as required
d	Further database development	31/11/13	Excel database threshold information is established and potential incorporation of information is established possibly on the National soil quality website
e	Roadshows linked with other ASVO or GWRDC workshops	30/04/14	At least 3 roadshow workshops are conducted to present the information from the project identifying benefits to industry
f	Refereed articles published and final report submitted	30/06/14	Articles drafted and submitted to refereed journals

Chapter 1: Setting up a soil monitoring system for Australian viticulture – identifying a minimum dataset of indicator tests for soil quality

1.1 Introduction

Soil monitoring systems have been developed around the world for use by agricultural industries such as grains, dairy and vegetable production to provide growers with a resource to assess the impact of their management practices on soil. The quality or 'health' of a soil is generally measured in terms of the soil's physical, chemical and biological properties. Some of these properties, such as soil texture or clay type, are inherent and cannot be changed. Others, such as soil pH or soil organic content, are dynamic and respond to changes in management practice. Soil quality and its direction of change with time are the primary indicators of sustainable soil management. Effective monitoring of soil quality requires that indicator tests are sufficiently simple and robust for routine measurement, and can provide meaningful insights into the state of a soil and any deterioration in soil functions over time. In addition, factors, such as the availability of a test, its cost effectiveness, simplicity and relevance to the viticulture industry, need to be considered.

1.2 Aim

To determine the requirements for a soil monitoring system tailored to the Australian viticulture industry, to identify a set of soil measures that could be considered a minimum dataset (MDS) of key indicator tests for monitoring changes in soil quality in the vineyard, and to develop standardized soil sampling methodology for this purpose. These are to form the basis for establishing regional datasets for soil benchmarking purposes.

1.3 Method:

The project used knowledge from industry, researchers and consultants, existing datasets and an extensive literature review to present to a targeted audience of soil experts and key industry personnel at a two day Workshop held in Melbourne on 14-15 December 2011 (Table 1.1).

Examples of soil monitoring systems both in Australia and overseas were examined and consulted e.g. the Cornell Soil Health Assessment System, Soilquality.org.au, SINDI online (Landcare Research NZ). Key industry members were canvassed and interviewed regarding how they would use such a system. Access to confidential existing company datasets was provided by Treasury Wine Estates and Yalumba. Outputs from relevant previous GWRDC projects such as SAR 03/04 Implications of Strategic Irrigation Management Practices for Vine Root Health, DPI 04/04 Managing Soil and Water to Target Quality and Reduce Environmental Impact, SAR 04/02 Soil Management for Yield and Quality, and others were sourced and examined, as were in-house reports such as the CSIRO Land and Water Technical Report No. 34/04: 'The Effect of Soil Properties on Vine Performance' and the Fosters Foot Print Initiative (2006) (commercial in confidence). The project team reviewed numerous methods of measuring soil physical, chemical and biological properties through extensive literature searches combined with the information obtained from the sources mentioned above.

The workshop was facilitated to encourage debate to select the MDS for benchmarking Australian viticultural regions and determine the appropriate standardized methodology. The Agenda covered soil quality datasets already available in viticulture and other industries, the relevance of soil health programs to viticulture, and the selection of soil indicators for viticulture. The Workshop attendees were asked to consider what does industry expect as an outcome from measuring soil quality, what are the five most important soil functions to measure and why, what are the most useful soil indicators and what should industry be measuring?

Table 1.1. Agenda for the National Viticultural Industry Soil Quality Workshop, 621 Burwood Hwy, Knoxfield, Dec 14-15th, 2011. The stated aim was to identify a potential minimal dataset of indicator tests for soil quality which can be used to assist growers make positive changes for production, quality and sustainability.

Wednesday 14 December		
Start	***Topic***	***Presenter***
10.30 AM	Arrival: Coffee and Tea	
10.45 AM	Welcome, Background of Project, Aims of Workshop	Mark Krstic Jacky Edwards
	Industry Soil Quality Data	
11.00 AM	What has been measured? Why? How useful?	Cecil Camilleri, Yalumba
11.20 AM	What has been measured? Why? How useful?	Bethany Collins, Treasury Wines Estate
11.40 AM	McLaren Vale EMS: how was it set up, what was measured, was it useful?	Toby Bekkers. McLaren Vale
12.00 PM	What has been measured? Why? How useful? DPI 04/04	Lexie McClymont
12:20 PM	Discussion session (Industry/research): What does industry expect as an outcome from soil health measurements? (3 priority outcomes)	
12 .45	Lunch	
	Relevance of Soil Health Programs to Viticulture	
1.30 PM	Viticulture	Prof. Bob White
1.45 PM	Grains/pastures	Pauline Mele
2.05 PM	Vegetables/viticulture	Ian Porter
2.25 PM	Discussion session (Industry/research): What are the 5 most important soil functions (processes/constraints) you want to measure and why? (e.g. water logging, salinity, nutrient availability, disease suppression) (Must include at least one physical, chemical and biological)	
3:00 PM	Tea	
	Indicators of soil quality - what has been done to date?	
3.30 PM	Review of soil assessment systems and indicators used worldwide	David Riches/Danni Oliver
4.30 PM	Barossa experience with different labs	Belinda Rawnsley
4.50 PM	Discussion on indicators and how useful? What should the project aim to get industry to measure and why (what outcome)?	
5.30 PM	Finish	
7.00 pm	Dinner (Yarra Valley)	

Thursday 15 December		
Start	***Topic***	***Presenter***
	Selecting soil health indicators	
8.30 AM	ReCap Day 1. Outcomes, soil functions and best bet indicators from the specialist groups	All - discussion
9.00 AM	The minimal dataset? (Physical, chemical and biological groupings) Prioritize potential indicators against desired outcomes?	Syndicate groups (3 mixed discipline tables)
10.00	Feedback from syndicate groups (x 3)	
10.30 AM	Morning Tea	
10.50 AM	Best method for the indicator test	
11.30 AM	Challenge against criteria in syndicate groups eg ease to measure, consistency, thresholds ,availability, price Consider whether future methods covered adequately	
12.00 PM	Further discussion for 'parked' issues (Prof White)	
12.30 PM	Lunch	
1.15 PM	What will the project look like? (Trials, sampling, database, benchmarking)	
3. 15 PM - 3.30 PM	Closing remarks and summary	

The speakers and topics were:

- Cecil Camilleri, Manager Sustainable Wine Programmes, Yalumba: " 'Vitis' Total Quality Environmental Management in Vineyards"
- Bethany Collins, Treasury Wine Estates: "The Fosters Foot Print Initiative"
- Toby Bekkers: "Benchmarking Soil Health: a McLaren Vale Perspective"
- Dr Lexi Clymont, DEPI Victoria: " 'Five sites' – vine and soil relationships"
- Prof Bob White: "Recommendations from GWR 0918 The status of soil health in the viticulture and wine industry – a review"
- Assoc. Prof. Pauline Mele, DEPI Victoria: "Indicators of soil quality – what has been done to date? Grains Industry"
- Assoc. Prof. Ian Porter, DEPI Victoria: "Indicators of soil quality – what has been done to date? Vegetable Industry"
- Dr Belinda Rawnsley, SARDI: "Use of soil biological tests to assess vineyard soil health"
- Danni Oliver, CSIRO: "Selection of soil physical and chemical properties as indicators of soil quality in viticulture"
- David Riches, DEPI Victoria: "Selection of biological soil properties as indicators of soil quality in viticulture"

The Workshop attendees were Toby Bekkers (Bekkers Consultancy), Cecil Camilleri (Yalumba), Bethany Collins (Treasury Wine Estate), Luke Johnston (Adelaide University), Mark Krstic (AWRI), Dean Lanyon (Arris Consulting), Richard MacEwan (DEPI Victoria), Michael McCarthy (SARDI), David McKenzie (Soil Management Consulting), Lexie McClymont (DEPI Victoria), Pauline Mele (DEPI Vic and GRDC Soil Biology Initiative), Bruce Shelley (DEPI Vic State Chemistry Laboratories), Craig Thornton (Wingara), Prof Bob White (University of Melbourne), as well as the team members Jacky Edwards, Ian Porter, Rob Bramley, Danni Oliver, David Riches and Belinda Rawnsley.

1.4 Results:

1.4.1 Expert Workshop

The Workshop discussion sessions can be summarised as follows.

What does industry expect as an outcome from soil health measurements?

- to ensure long-term productive capacity, maximising quality, yield and profit
- to measure and monitor change in response to inputs such as chemicals, fertilisers and water
- to demonstrate responsible environmental stewardship and ensure social and market acceptability
- to minimise soil degradation
- to establish links between wine quality and soil properties
- to identify soil constraints
- grower education and awareness, and
- to enhance biodiversity in the vineyard.

What are the 5 most important soil functions (processes/constraints) you want to measure and why?

- Supply of adequate water by allowing water infiltration and maintaining water-holding capacity
- Provide nutrients through a balance of inorganic and organic soil fractions, and prevention of salinity and sodicity
- Physical support for grapevine through unimpeded root growth and minimal soil compaction
- Gas exchange allowing adequate aeration of the roots
- Mitigation of soilborne pests and diseases through disease suppression, good biological activity and increased organic carbon.

1.4.2 Selection of a minimum dataset for monitoring viticulture soil quality

The minimum dataset chosen comprises tests of physical properties: aggregate stability (dispersion and slaking) and soil consistency (strength); chemical properties: pH, electrical conductivity (EC), exchangeable cations (sodium, magnesium, potassium, calcium), exchangeable sodium percentage (ESP), cation exchange capacity (CEC), total organic carbon and chloride, and biological properties: soil microbial biomass, potentially mineralizable nitrogen (PMN) and labile carbon (Table 1.2).

Table 1.2. Minimum dataset (MDS) chosen for soil monitoring in the viticulture industry, published threshold information, and the soil function addressed by the indicator test.

	INDICATOR	THRESHOLD VALUES*	FUNCTION	METHOD
BIOLOGICAL	Microbial biomass	>300 ug/g	Soil biological activity	Chloroform fumigation extraction (Amato & Ladd 1988)
	Potentially mineralizable nitrogen (PMN)	8-18 mg N/g soil	N supply capacity	Method 7D2 (Rayment & Lyons 2010)
	Labile carbon	> 500 ppm	Soil biology food	Method 6E1 (Rayment & Lyons 2010).
PHYSICAL	Aggregate stability: dispersion	Good < 6 (0-16)	Infiltration, aeration	Aggregate stability: ASWAT slaking and dispersion tests (Field et al. 1997)
	Aggregate stability: slaking	No slaking (0-4)	Infiltration, aeration	Aggregate stability: ASWAT slaking and dispersion tests (Field et al. 1997)
	Soil consistency (strength)	<2	Infiltration, aeration	Air dry soil consistency: Australian soil and land survey field handbook 2009
CHEMICAL	pH	5.5 - 8 (water)	Nutrient availability	pH: 1:5 water, Method 4B4; 1:5 $CaCl_2$, Method 4A1 (Rayment & Lyons 2010)
	EC	< 1.4 dS/m	Salinity	1:5 water, Method 3A1 (Rayment & Lyons 2010)
	Exchangeable cations (Ca, Mg, K, Na)	Ca 60-80% Mg 15-50% K 1-10% Na <6%	Buffering capacity, nutrient availability Na – sodicity, dispersion, soil structure	Method 15D1 (Rayment & Lyons 2010)
	Cation exchange capacity (CEC)			Cation exchange capacity (CEC)= sum of exchangeable cations
	Exchangeable Sodium Percentage			ESP = Na/CEC x 100%
	Total organic carbon	Sand > 1% Loam > 1.8% Clay> 2%	CEC, buffering capacity, microbe food source, energy storage, water holding capacity	Total C Leco – ($CaCO_3$ x 0.12) (Method 6B3, Rayment & Lyons 2010)
	Chloride	< 175 ppm	Salinity	Method 5A (Rayment & Lyons 2010)

*There is a paucity of threshold value information specifically for viticulture. The threshold values shown here have come from a range of sources – expert opinion, reference books, published literature, commercial soil testing laboratories, etc. They are to be taken as guidelines only, and may differ according to region and soil type. The published sources are referenced in Oliver et al. (2013) and Riches et al. (2013).

The rationale for choosing the minimum dataset for a soil monitoring system for Australian viticulture was published by the project team as two review papers in the *Australian Journal of Grape and Wine Research*:

Oliver DP, Bramley RGV, Riches D, Porter IJ, Edwards J (2013) Review: soil physical and chemical properties as indicators of soil quality in Australian viticulture. *Australian Journal of Grape and Wine Research* 19:129-139.

Riches D, Porter IJ, Oliver DP, Bramley RGV, Rawnsley B, Edwards J, White RE (2013) Review: soil biological properties as indicators of soil quality in Australian viticulture. *Australian Journal of Grape and Wine Research* 19: 311-323.

They are summarised here:

Physical

Aggregate stability

A stable surface soil structure is important to promote water infiltration and for resistance to erosion (White 2010). For an aggregate to be stable, the forces between particles must be strong enough to prevent the particle separating as a result of disruptive forces such as those due to the impact of raindrops, heavy machinery or clay swelling (White 2003). Aggregate stability is a property that is sensitive to management changes and affects porosity, field infiltration and saturated water capacity. Measurement by dispersion is sensitive to water content so it should be made when the soil is at its most vulnerable stage. In southern Australia, this corresponds to the end of summer when the unirrigated soil is at its driest.

When a small clod is placed in water the aggregate may slake or disperse. Slaking occurs when aggregates of soil collapse into smaller fragments. Dispersion is more severe and is the separation of soil into single particles. It is caused by high levels of sodium in the soil and results in undesirable hard layers that may impede the penetration of water, air and roots (Anderson et al., 2007). Slaking is measured on a scale from 0 – 4 and dispersion on a scale from 0 - 16. Optimum scores are zero for slaking and less than 6 for dispersion.

Soil consistency

Soil consistency is a measure of soil strength, *i.e.* the soil's ability to resist the loss of structure through compaction, and to resist penetration by plant roots and burrowing soil fauna. A soil with good physical quality should be strong enough to maintain its structure and hold plants upright, but also weak enough to allow extensive penetration by plant roots, soil flora and fauna (Topp et al. 1997). Soil consistency can be measured qualitatively by the force required to crush air-dry aggregates, on a scale from 0 – 7, with an optimum value of less than 2.

Chemical

Soil pH

Soil pH is one of the most important determinants of soil fertility through its influence on the solubility of metal ions, such as Al, Mn, Fe, Cu, Zn and Mo, its effect on the supply of nutrient cations and anions, and its influence on microbes present in soil and their activity. Vines do not perform well when soil pH_w (1:5 soil:water) is <5 due to stunted shoot and root growth (Conradie 1983, White 2009) and at pH_w 4.5 and below root growth ceases (Robinson 1993). The optimum pH_w range for vine growth is 5.5 to 8 (White 2003).

Soil pH is a measure of the intensity of acidity or alkalinity. The data presented in this report are based on soil pH being measured in a soil/solution ratio of 1:5 with water (pH_w) and 0.01M $CaCl_2$ (pH_{Ca}) as the solution. The pH values of most soils are lower when determined in a salt solution than at the same soil/solution ratio in water. Usually pH_{Ca} are 0.5 to 1 unit lower than pH_w measurements.

Total organic carbon

Organic matter (as total organic carbon) is not acquired by plants as a nutrient from the soil, but its cycling is important because of its association with nutrients (nitrogen, phosphorus and sulphur) and the beneficial contributions that it makes to soil chemical, physical and biological properties (Hoyle et al. 2011). Nutrients may be released into the soil in plant available forms as organic materials are decomposed by microorganisms. Total organic carbon also contributes to a soil's cation exchange capacity, maintains soil structure and provides a food source to soil microorganisms. Increasing total organic carbon in the vineyard is achieved through the incorporation of perennial cover crops, manure

and compost and the addition of mulch. However, it can take several years for substantial increases in total organic carbon to be achieved. There is little evidence to show organic matter contributes to yield on irrigated and fertilised crops and there are few threshold values for total organic carbon.

Laboratory estimates of soil carbon are restricted to the quantity of organic materials that accompany soil particles that pass through a 2mm sieve. The data presented in this report are determined by a high-temperature combustion method (Leco furnace method). Inorganic forms of carbon (e.g. charcoal, carbonates and bicarbonates) need to be removed prior to analysis or be measured and a correction made to determine total organic carbon.

Total organic carbon (TOC) = total carbon (C) – [inorganic C (%carbonate) X 0.12]

Recommended optimum values range from > 1% for sandy soils to > 2% for clay soils.

Electrical conductivity (EC)
Salinity is the presence of soluble salts in the plant root zone and crop production is limited when the concentration of soluble salts in the soil solution is high enough to decrease absorption of water by the plants. The response of grapevines to increasing salinity varies depending on the grape cultivar and rootstock used. To measure EC, soils are shaken in deionised water in a soil:solution ratio of 1:5. Electrical conductivity is measured at the same time as pH using a combination electrode. Recommended optimum values are < 1.4 dS/m.

Exchangeable cations (Ca, Mg, K, Na)
Measurement of exchangeable cations (positive ions) allows calcium(Ca^{2+}), sodium (Na^{+}), magnesium (Mg^{2+}) and potassium (K^{+}) to be monitored in regions where there may be concerns about an increasing concentration in soil.

At low salinity exchangeable cations can be determined without a pre-wash. However, a more accurate measurement of exchangeable cations requires leaching of the soil with a pre-wash solution before exchangeable cations can be determined.

Suggested optimum values are 60 – 80% exchangeable Ca^{2+}, 15 – 50% exchangeable Mg^{2+}, 1 – 10% exchangeable K^{+} and less than 6% exchangeable Na^{+}.

Cation exchange capacity
Cation exchange capacity (CEC) is the capacity of the soil, which is predominantly negatively charged, to hold and exchange cations which are positive. The CEC is a major controlling agent of stability of soil structure, nutrient availability for plant growth, soil pH and the soil's reaction to fertilisers and other ameliorants (Hazelton and Murphy 2007). Especially for soils of pH_w <7, the CEC should be measured in a non-buffered solution (at the natural soil pH) because most soils have a pH-dependent component and a CEC measured in a barium chloride-triethanolamine extractant at pH 8.2, for example, will be an over-estimate.

An approximate value for CEC is Effective CEC.

Effective CEC = sum of the most abundant cations in soils i.e. sum (Na^{+}, Ca^{2+}, Mg^{2+}, K^{+})
If pH_w < 5.5 the cation Al^{3+} should be included for calculating Effective CEC.

Exchangeable sodium percentage
Soils high in Na^{+} (>6% ESP in the subsurface) can have structural problems beginning to occur and the soil is termed sodic. High sodicity causes clays to swell excessively when wet and clay particles may separate or disperse and in surface soils crusts may form preventing water penetration.

$$\text{Exchangeable sodium percentage (ESP)} = \frac{100 \times \text{amount of exchangeable sodium } (Na^{+})}{\text{Sum of all exchangeable cations (CEC)}}$$

Sodic soils may have the following problems:

- Very severe surface crusting
- Very low water infiltration and hydraulic conductivity
- Very hard, dense subsoils; low permeability
- High susceptibility to severe gully erosion

- High susceptibility to tunnel erosion (Hazelton and Murphy, 2007)
-

Exchangeable cation data must be in units of cmol/kg. Sometimes data may be given in meq/100g and 1 meq/100g = 1 cmol/kg.

Chloride
Most soil chloride is highly soluble and is found predominantly dissolved in the soil water. At concentrations > 175 ppm, it can cause toxicity symptoms in grapevines.

Biological
Microbial biomass (MB)
Microbial biomass is the living component of soil organic matter excluding plant roots and macrofauna. It is a measure of the microbial population density and is a sensitive indicator of changes in soil quality due to changes in soil management practices. Substrate availability, moisture and temperature influence measurements of soil MB which may affect comparison over time. There is no optimal value for MB but values from vineyards around the world detailed in our review ranged from 167 to 527 ug C/g soil.

Potentially mineralizable nitrogen (PMN)
Although most soils contain a large quantity of organic nitrogen, a proportion of this is chemically or physically stabilised and resistant to microbial degradation. A small proportion is labile and is prominent as a source of nitrogen mineralisation. Measurement of PMN has been suggested as a surrogate for MB since the two are highly correlated and PMN is easier to measure. A realistic estimate of the quantity of N available for mineralisation from soil organic matter is necessary for determining the rate of N fertiliser for optimal crop yield and to prevent any adverse environmental effects due to excess fertiliser. In vineyards there is also the need to balance optimal yield without creating problems with excess vigour. There are few measurements of PMN in vineyard soils, but values between 8 mg and 18 mg N/kg soil/week for cool climate vineyards in Victoria have been reported.

Labile carbon
In soil there are various pools of carbon which differ in their availability for microorganisms to use as a food source. Inert carbon is largely unavailable to microorganisms and is associated with highly weathered soils and historical burning. The labile (bio-available) pool of carbon is primarily influenced by more recent additions of organic matter (originating from plants and/or animals) and has a significant role in microbial nitrogen turnover and supply. The amount of labile carbon influences both the activity and mass of microorganisms (microbial biomass) in soil. The microorganisms' capacity to release plant-available N is influenced by the quality of organic matter inputs. Since labile carbon turns over relatively rapidly, it is considered a more sensitive indicator of changes in soil quality and function than the percentage of total carbon which includes the more inert fractions.

Selection of indicator methodology

Biological:
- Microbial biomass: chloroform fumigation extraction (Amato & Ladd 1988)
- Potentially mineralizable nitrogen: Method 7D2 (Rayment & Lyons 2010)
- Labile carbon: permanganate oxidisable active carbon content (Weil *et al.* 2003, Method 6E1 Rayment & Lyons 2010).

Chemical:
- pH: 1:5 water, Method 4B4; 1:5 $CaCl_2$, Method 4A1 ((Rayment & Lyons 2010)
- Electrical conductivity: 1:5 water, Method 3A1 (Rayment & Lyons 2010)
- Exchangeable cations: ammonium acetate extraction with a pre-wash, Method 15D1 (Rayment & Lyons 2010)
- Cation exchange capacity (CEC): sum of exchangeable cations
- Exchangeable sodium percentage (ESP): Na/CEC x 100%
- Total organic carbon = Total C Leco (Method 6B3, Rayment & Lyons 2010) – ($CaCO_3$ x 0.12)

Physical:
- Aggregate stability: ASWAT slaking and dispersion tests (Field *et al.* 1997)
- Soil consistency: air dry soil consistency test (Australian soil and land survey field handbook 2009).

1.4.3 Standardized soil sampling methods

The timing of soil sampling was chosen to be at approximately 4 weeks post-harvest in order to sample when vineyard activities are less demanding than during the growing season and vintage. This coincides with a second flush of root growth (the first being at budburst) (Freeman and Smart 1976), chosen in order to target maximum soil biological activity (Rawnsley 2008).

Three sampling locations were chosen: undervine, the midrow and an adjacent non-viticultural site for comparison within 50 m of the vineyard, preferably with native vegetation. Sampling locations are to be geo-referenced using a global positioning system (GPS) for repeat sampling. Two depths were chosen: 0-15 cm (surface) and 35-45 cm (subsurface). Biological indicators were omitted from the sub-surface soils because biological activity is concentrated in the top 10 cm. All surface growth and debris is to be removed from the sampling points prior to taking cores.

The sampling protocol is as follows:

Chemical and biological samples (1 kg needed for surface samples, 500 g for subsurface samples):

For chemical and biological analyses, collect soil cores using a 5-7 cm diameter hand auger to minimise damage to roots. For the undervine surface samples, take five cores in line with the nearest dripper to the grapevine trunk but extending approximately 20 cm into the midrow (Figure 1.1). The five cores are to be pooled and mixed in the field.

For midrow surface samples, take five cores directly in the centre of the midrow aligned with the undervine sampling (Figure 1.1). The five cores are to be pooled and mixed in the field.

Sub-surface soils are to be collected from a depth of 35-45 cm from three of the five holes used for collection of surface soil. These three cores are to be pooled and mixed for each of the sampling areas (undervine, midrow and native).



Figure 1.1. Soil sampling from undervine and midrow, with native area in the background



Figure 1.2 . Soil sampling procedure for physical assessments.

Physical samples:
The soils for physical analyses are taken by a different method to preserve the soil structure. The surface of the soil is removed with a shovel and a small trench dug at the designated location. The first vertical face is to be 0-15 cm, a small step and then a vertical face at 35-45 cm. Make slices with the shovel around the target area at one side of the trench and gently lift out the target area. Several small clods should be gently broken off, avoiding any surface area affected by shearing (Figure 1.2). The clods are to be placed into rigid containers or open plastic bags and carefully handled to preserve the soil structure.

During the regional benchmarking (described in chapters 5-8), we found that in many instances (e.g. Murray Darling and Yarra Valley soils) the soil was too difficult to dig to the required depth manually. The procedure was modified to remove soil down to 35 cm with a mechanical auger, then follow the procedure as described above to remove undisturbed clods from the subsurface soil.

Soil storage in field:
Soils for the physical measurements are to be stacked in a single layer if in plastic bags. Do not stack on top of one another to prevent clods being broken up or squashed. Otherwise store representative clods selected in the field in rigid plastic containers for transport back to laboratory.

Soils for biological and chemical measurements are to be immediately stored in a cool place (e.g. esky with ice blocks) to keep as cool as possible.

Soil storage once returned from field (before shipment):
Soils for biological and chemical measurements are to be stored at 4ºC immediately upon return to the laboratory. They are then to be sub-sampled and sent to laboratories for analysis – quantities required will be prescribed by the laboratories. Desired quantities of each sample should be weighed out for biological and chemical analyses and sent to laboratory within 1-5 days after collection.

Soils for physical measurements are to be air-dried, or oven-dried at 40ºC if available, prior to testing for slaking, dispersion and consistency.

1.5 Discussion

There was considerable interest from industry for a soil monitoring system. Several companies and regions had implemented their own versions, but a standardized approach was welcomed. Existing datasets were ad hoc, with sampling methodology varying from year to year so that little was comparable. The reasons for development of a soil monitoring system were determined to be primarily for providing a baseline from which vineyard managers could monitor their impact on the soil quality, and a regional benchmark so that they could compare their soil quality against the average and range for the region. The larger companies expressed a need to be accountable for environmental stewardship and thought a recognized soil monitoring system would help them achieve this.

The original project aim of linking soil quality with quality wine production was considered difficult to achieve and perhaps unrealistic, given previous research in this area (Goodwin *et al.* 2009). However, using a soil monitoring system to inform management to overcome constraints such as salinity was considered to be achievable.

The extensive literature review was published as two companion papers in the Australian Journal of Grape and Wine Research. There have been several requests for reprints of the MDS papers, both from Australia and overseas.

The keen industry interest in being able to have and use such a soil monitoring system is evidenced by the response that the project team has had even before the project is completed. The sampling methodology and MDS was requested by Treasury Wine Estates technical viticulture team in April 2014 to be integrated into their current company-wide soil health monitoring program so that they can contribute to the regional benchmarking databases. Treasury Wine Estates Ltd is one of Australia's largest companies and their interest in the outcomes of this project has been greatly appreciated by the team. Similar requests were received in June 2014 from the Mornington Peninsula Growers Association, Victoria, to help them benchmark their own region (analyses are currently being completed and the data prepared for delivery to the database), and from the viticulturist at Peter Lehmann Wines, so that they can continue to expand the Barossa Valley database.

The Workshop presentations and the two companion papers are attached in Appendix 1: Communication.

Chapter 2: Validation of the minimum dataset for soil monitoring purposes

2.1 Introduction

The purpose of a soil monitoring system is to assess the effect of management practices on soil. Therefore the minimum dataset (MDS) should contain tests that can detect differences in soil properties in response to a change in management practice. A proposed MDS was chosen through extensive literature review and consultation with soil scientists and key industry personnel (Chapter 1). With this in mind, several sites were chosen specifically to test that the chosen MDS was suitable for this purpose. A total of nine commercial vineyard sites in Langhorne Creek (SA), McLaren Vale (SA), Mornington Peninsula (Vic) and Bellarine Peninsula (Vic) were visited and examined in February 2012 to choose the best sites for soil sampling to validate the MDS (Figure 2.1). All four sites in SA had been used previously for long-term trials by SARDI and CSIRO to determine the usefulness of applying mulch and compost undervine. The three vineyard sites on the Mornington Peninsula and two on the Bellarine Peninsula all had histories of mulch application and undervine ground cover but were not formal trial sites.

2.2 Aim

To demonstrate the minimum dataset indicator tests will detect change in soil properties caused by changed management, using long-term trial sites incorporating different soil management practices (e.g. application of mulch, undervine ground cover, viticulture versus non-viticulture).

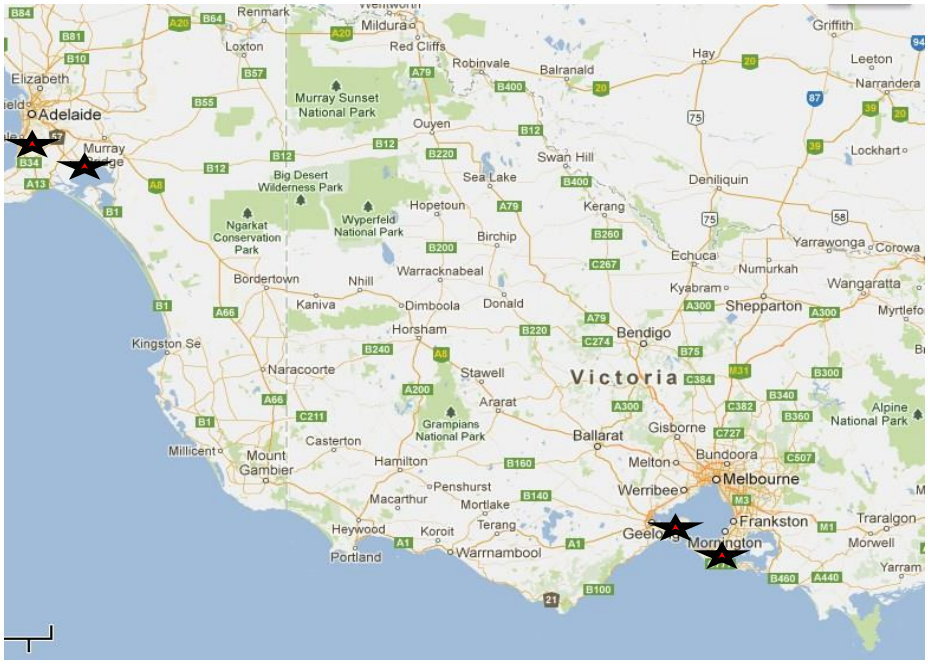


Figure 2.1. Trial sites in commercial vineyards in South Australia and Victoria used to demonstrate whether the chosen minimum dataset could detect changes in soil properties due to changed management practices.

2.3 Method

Nine vineyard sites were chosen to validate the MDS variables under changed management practice (Table 2.1). The sites were chosen on the basis that all had previous history of a changed practice such as compost, mulch application or undervine ground cover, with an unchanged area for comparison. Samples were collected 4 weeks after harvest, March – May 2012, to coincide with a flush of active root growth, as described in Chapter 1. Standardized time of sampling and sampling methodologies determined previously (Chapter 1) were followed. The soil was analysed for the physical, chemical and biological variables comprising the MDS.

Table 2.1 Characteristics of the nine vineyard sites used for the MDS validation study.

Site	*Region*	*Grape cultivar*	*Treatment*	*Soil type*
1	McLaren Vale	Cabernet Sauvignon	Undervine composted forest mulch	Loamy sand over clay loam
2	McLaren Vale	Cabernet Sauvignon	Undervine composted forest mulch	Clay loam over clay
3	Langhorne Creek	Shiraz	Undervine composted grape marc mulch	Clay loam
4	Langhorne Creek	Cabernet Sauvignon	Undervine Nitromulch	Sand over clay
5	Mornington Peninsula	Arneis	Undervine mixed species cover	Duplex sandy loam
6	Mornington Peninsula	Chardonnay	Composted grape marc mulch	Duplex sandy loam
7	Bellarine Peninsula	Pinot Noir	Composted chicken manure + green waste	Brown chromosol (duplex sand over clay)
8	Bellarine Peninsula	Pinot Gris	Composted chicken manure + green waste	Sodosol (sand over clay)
9	Mornington Peninsula	Pinot Noir	Undervine composted green waste mulch	Yellow – grey chromosol

2.3.1 Site details

Sites 1 and 2: McLaren Vale, SA (cv. Cabernet Sauvignon)
This 10 year old vineyard was used previously for trials (GWRDC project No. SAR 04/02, McCarthy *et. al* (2009)) comparing the effects of ripping and compost mulch on growth and yield of Cabernet Sauvignon grown on different functional soil types (Figure 2.2).

For our purposes, we chose to compare the compost mulch treatment with the conventionally managed treatment (i.e. the control). Jeffries Compost™ (forest mulch) had been applied as a mulch undervine at 150 m^3/ha in the spring of 2005. There was increased vigour in all treated vines, due to increased water availability. This effect was still noticeable 7 years post-application and the fruit quality across the whole block had improved from C and D grade to B-grade fruit.

Site 1 was on a loamy sand and Site 2 was on a clay loam (soil 4, P2.6, and soil 3, P2.4, respectively; Figure 2.2). Only two replicates of each treatment per soil type were available for sampling. A replicate consisted of one panel x two adjacent rows (3 vines/panel).

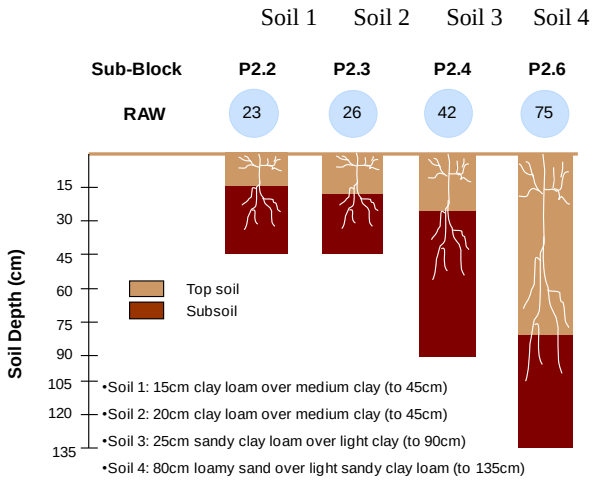


Figure 2.2. Schematic of soil profile description at Sites 1 and 2. For this current trial, soils 3 (P2.4) and 4 (P2.6) were sampled (source: GWRDC SAR 04/02 Final report, M^{c}Carthy *et al*. 2009).

Site 3: Langhorne Creek, SA (cv. Shiraz)
This 20 year old vineyard was used previously for trials comparing the effects of ripping and composted grape marc applied as mulch on growth and yield of Shiraz. The soil type was clay-loam and salinity was an issue across the whole site. For our purposes, we chose to compare the mulch treatment with the conventionally managed treatment (*i.e.* the control). Composted grape marc had been applied as an undervine mulch at 250 m^3/ha in 2002 and was again applied in 2008 across the whole site except the control treatments. Three replicates of each treatment were sampled. A replicate consisted of one panel x two adjacent rows (3 vines/panel).

Site 4. Langhorne Creek, SA (cv. Cabernet Sauvignon)
This 17 year old vineyard was used previously for a trial examining the effect of Nitromulch™ on growth and yield of Cabernet Sauvignon. Nitromulch™ had been applied as a mulch undervine at 100-150 m^3/ha in 2004 with a repeat application in 2006. The application of Nitromulch™ had reportedly significantly increased berry weight compared to the conventionally managed control. The soil type was sand to 40 cm depth over clay.

For our purposes, we compared the differences between application of Nitromulch™ undervine and conventional management (control). Three replicates of each treatment (Nitromulch™ and conventional) were sampled. A replicate consisted of one panel x two adjacent rows (3 vines/panel).

Site 5: Mornington Peninsula (cv. Arneis)
This 30 year old vineyard was previously maintained as bare undervine with herbicide and mowed permanent sward midrows. The soil type was duplex sandy loam with an A2 'concrete' horizon. In 2006 vineyard productivity was considered to have declined and the vineyard floor was full of weeds, so the owners changed management practices to reinvigorate the vineyard. The midrows were alternately planted each year with a mixture of buckwheat, oats, peas, ryecorn and faba beans from 2007 onwards. Composted grape marc was applied as a mulch undervine on some rows and replenished biannually (quantity not recorded); other rows were planted with a mixed species cover crop undervine.

For our purposes, we compared composted grape marc mulch undervine with cover crop undervine. Four replicates per treatment were sampled. A replicate consisted of one panel x two adjacent rows (4 vines/panel). Four replicate samples were also taken from an adjacent area of native vegetation for comparison.

Site 6: Mornington Peninsula (cv. Chardonnay)
This site was at the same property as above, but in a different block. In this instance, half of the block was maintained under the original management practice of mowed permanent sward midrows and bare undervine with herbicide use. The other half had composted grape marc (quantity not recorded) applied across the whole area every two years since 2006 with cover crops sown in the midrow.

For our purposes, we collected soil from four replicates per treatment in each half of the block. A replicate consisted of one panel x two adjacent rows (5 vines/panel). Four replicate samples were also taken from an adjacent area of native vegetation for comparison.

Site 7: Bellarine Peninsula (cv. Pinot Noir)
This 12 year old vineyard had been divided into two in 2008 and one half sold to a neighbour. The soil type was brown chromosol (duplex acid sand over alkaline clay; Figure 2.3).



Figure 2.3. Brown chromosol soil at Site 6: Bellarine Peninsula, Victoria.

One half (the control) was unimproved and maintained as bare earth in the midrow and undervine with cultivation and herbicide use. The other half was treated in 2009 with compost "40:40" (40 m^3 composted chicken manure plus 40 m^3 composted green waste applied across the 5 ha site), with a repeat application in 2010. The midrow was sown with a pasture mix every second year, herbicide was applied undervine, and sheep grazed in the winter. The grower reported a marked improvement in yield and quality within two seasons of treatment with compost.

For our purposes, we compared the bare earth treatment (control) with the compost treatment. Four replicates per treatment were sampled. A replicate consisted of one panel x two adjacent rows (5 vines/panel). Four replicate samples were also taken from an adjacent area of native vegetation for comparison.

Site 8: Bellarine Peninsula (cv. Pinot Gris)
This 15 year old vineyard was bought by the current owners in 2008 and was considered to be struggling. The soil type was sodosol, with 20 cm sandy loam over pale sand to 40 cm, then orange clay below. Ten rows were treated with 50:50 mixture of compost "40:40" applied as a mulch undervine at a rate of 16 m^3/ha in 2008. The remainder of the block was maintained with herbicide undervine. The midrows were permanent sward for both areas.

For our purposes, we compared the herbicide undervine treatment (control) with the compost treatment. Four replicates per treatment were sampled. A replicate consisted of one panel x two adjacent rows (5 vines/panel). Four replicate samples were also taken from an adjacent area of pasture for comparison, as there was no adjacent native vegetation and the previous history of the block was pasture.

Site 9: Mornington Peninsula (cv. Pinot Noir)
This 12 year old vineyard was used previously for a trial comparing the effect of composted green waste applied as an undervine mulch with conventional herbicide undervine. The composted green

waste was applied in 2007, but quantity not recorded. The soil type was yellow/grey chromosol. The block had permanent grass sward in the midrow. Four replicates per treatment were sampled. A replicate consisted of one panel x two adjacent rows (5 vines/panel). Four replicate samples were also taken from an adjacent area of native vegetation for comparison.

2.3.2 Soil sampling

Soil samples were taken using the methods described in Chapter 1.

2.3.3 Soil analyses

The soil samples were all analysed according to the indicator tests determined to comprise the minimum dataset for soil monitoring (Chapter 1):

- biological indicator - microbial biomass (MB)
- chemical indicators – pH, electrical conductivity (EC), exchangeable cations, cation exchange capacity (CEC), exchangeable sodium percentage (ESP), total organic carbon, chloride
- physical indicators – aggregate stability (slaking and dispersion) and soil consistency.

Total nitrogen (Leco method) was also collected as it is provided as part of the tests required to calculate total organic carbon (Leco method). The additional biological indicators - potentially mineralizable nitrogen and labile carbon – were suggested at the expert workshop but their value was not agreed upon by all experts. Therefore, they were included in the analyses of the Victorian soil samples during this validation phase to test whether they added value and should be included in the MDS in the future.

The physical assessments were performed in-house by the project team following the methodology described in Field *et al*. (1997) and the Australian Soil and Land Survey Field Handbook (2009).

The chemical analyses were performed on all surface and subsurface soil samples by CSBP Soil & Plant Analysis Laboratory, Bibra Lake Western Australia, with the exception of total organic carbon. This was derived from total carbon (Leco method) and calcium carbonate content using the formula: Total organic C = Total C – ($CaCO_3$ x 0.12). Exchangeable sodium percentage (ESP) was calculated as exchangeable Na / cation exchange capacity (CEC) X 100%.

2.3.4 Microbial biomass carbon analyses

The preferred method of analysing microbial biomass carbon, i.e. chloroform fumigation extraction (CFE), was not available as a commercial test. Instead, all surface soils were analysed by the substrate induced respiration (SIR) method available at CSBP. There is an assumption that SIR values can be multiplied by 30 to convert them to CFE values, depending on soil type (Anderson and Joergensen,1997). Subsamples of all of the South Australian surface soils and all of the conventional treatment Victorian surface soils were sent to soil scientists at DEPI Victoria – Rutherglen and analysed using the CFE method for comparison with the SIR method.

2.3.5 Statistical analysis

The objective was to test whether there were any significant differences between the treatments with respect to the MDS variables: MB, labile carbon, PMN, organic carbon, total nitrogen, pH_{water}, pH_{CaCl2}, conductivity (EC), chloride, exchangeable cations calcium (Ca), potassium (K), magnesium (Mg) and sodium (Na), CEC and ESP. All variables were tested for at 0 – 15 cm depth; MB, labile carbon, PMN, organic carbon and total nitrogen were not tested at 35-45 cm depth as the organic matter and biologically active fraction is mostly confined within the top soil.

Where replication allowed, datasets for each site were compared to detect differences between treatments and between vineyard positions i.e. undervine, midrow and native. The South Australian sites had undervine and midrow only, as there were no undisturbed areas within close proximity of the vineyard sampling sites for meaningful comparison. Additionally the datasets of all sites within a state were combined and examined for significant differences between treatments and vineyard positions. The datasets for South Australia and Victoria were analysed separately due to differences in trial design.

With respect to the South Australian dataset, the treatments were considered to be conventional midrow (T1), conventional undervine (T2), treated midrow (T3) and treated undervine (T4). There were unequal replications for these treatments, as Site 4 in Langhorne Creek had no treated midrow. For this reason, the site could not be used as a 'block' in the analysis. Three questions were posed: was there any difference between any of the treatments? Was there any difference between the conventional (T1 + T2) and the treated (T3 + T4)? Was there any difference between the conventional undervine (T2) and the treated undervine (T4)?

Similarly, with respect to the Victorian dataset, the treatments were considered to be conventional midrow (T1), treated midrow (T2), native (T3), conventional undervine (T4) and treated undervine (T5). Because all Victorian sites had the same trial design, the site was included as a 'block' in the analysis. Four questions were posed: was there any difference between the conventional undervine (T4) and the treated undervine (T5)? Was there any difference between the conventional (T1 + T4) and the treated (T2 + T5) sites? Was there any difference between the conventional (T1 + T4) vineyard sites and the native (T3)? Was there any difference between the treated (T2 + T5) vineyard sites and the native (T3)?

The MDS variables were analysed using analysis of variance in the GenStat® statistical package (GenStat® release 16.1, Copyright 2008, VSN International Ltd.). For South Australia, the treatment structure was specified as *COMP(Trt;2;cont)* where *COMP* = comparison, *Trt i*s the treatment factor and *Cont* are the two contrasts listed earlier. There was no blocking structure. It was treated as a completely randomised design. For Victoria, the treatment structure was specified as *COMP(Trt;4;cont)* where *COMP* = comparison, *Trt i*s the treatment factor and *Cont* are the four contrasts listed earlier. This was treated as a randomised block design, where the blocking structure was specified as *Site.*

For both Victorian and South Australian data, histogram and quantile plots of residuals, and graphs of residuals against fitted values, were used to check ANOVA distributional assumptions of normality and constant variance.

A separate analysis was performed to examine treatment differences for individual sites independently. ANOVA was used with treatment structure *Trt* and the blocking structure was vineyard row.

Least significant differences (5% level) were used to separate the means, subject to significant F-tests.

There were two methods of microbial biomass (MB) measurement, chloroform fumigation extraction (CFE) and substrate induced respiration (SIR). A subset of the soil was measured by both methods as described above. To determine agreement between the two methods, a regression analysis was employed whereby MB CFE was the response and MB SIR was the predictor. The analysis was carried out using GenStat® 16.1.

The discrete data for the physical indicators were not subjected to statistical analyses. However, where measured, the medians for each trial site have been shown for comparison. With the combined datasets for each state, the categorical data were assigned into classes of low, moderate and high, as follows:

- Consistency (0-7): low (0-1), moderate (2-3), high (4-7);
- Slaking (0-4): low (0), moderate (1-2), high (3-4);
- Dispersion (ASWAT) (0-16): low (0), moderate (1-8), high (9-16).
-

The preferred class is moderate for consistency and low for slaking and dispersion. The number of replicates in each class were graphed for comparison.

2.4 Results

2.4.1 Individual sites

Sites 1 and 2: McLaren Vale, SA (cv. Cabernet Sauvignon)
The original trial design did not allow analysis of variance to be performed, but general differences were observed. At Site 1 (loamy sand), mulch application increased organic carbon, total nitrogen,

exchangeable K, pH and MB SIR undervine in the surface soil (0-15 cm), chloride increased three to six-fold undervine compared to midrow, and 20 to 60-fold in the subsurface soil (35-45 cm) undervine compared to midrow. Exchangeable Na and ESP were increased in the undervine subsoil where mulch had been applied, but not in the midrow. EC was considerably higher in the undervine compared to the midrow subsurface soil (Table 2.2).

Table 2.2. Site 1 McLaren Vale, SA (loamy sand). Means of the MDS for surface (0-15 cm) and subsurface (35-45 cm) soil in the undervine and midrow of the conventional and forest mulch treatments.

Indicator property	***Conventional midrow***	***Conventional undervine***	***Treated midrow***	***Treated undervine***
Surface (0-15 cm)				
MB SIR (µgC/g)	27.41	0.01	6.95	13.57
EC (dS/m)	0.08	0.59	0.10	0.14
pH_{CaCl}	6.90	6.75	6.60	7.30
pH_{water}	7.30	7.15	7.30	7.90
Chloride (ppm)	6.00	18.40	5.70	29.25
Total N (LECO) (%)	0.08	0.08	0.09	0.11
Exch. Ca (meq/100g)	3.17	6.71	4.92	5.47
Exch. K (meq/100g)	0.21	0.16	0.38	0.52
Exch. Mg (meq/100g)	0.46	0.61	0.72	1.56
Exch. Na (meq/100g)	0.05	0.05	0.05	0.05
CEC (%)	3.89	7.53	6.07	7.60
Org C (LECO) (%)	0.86	0.78	1.23	1.28
ESP (%)	1.29	0.87	0.82	0.80
Consistency (0-7)	2	2	2	2
Slaking (0-3)	0	0	1	1
Dispersion (0-16)	3	3	4	4
Subsurface (35-45 cm)				
EC (dS/m)	0.03	0.31	0.03	0.25
pH_{CaCl}	7.30	7.05	6.50	7.05
pH_{water}	8.10	7.75	7.10	7.80
Chloride (ppm)	1.10	61.50	3.30	67.85
Exch. Ca (meq/100g)	2.64	4.16	2.05	5.41
Exch. K (meq/100g)	0.07	0.11	0.10	0.24
Exch. Mg (meq/100g)	0.32	0.70	0.48	1.20
Exch. Na (meq/100g)	0.05	0.05	0.05	0.12
CEC (%)	3.08	5.01	2.68	6.97
ESP (%)	1.62	1.11	1.87	1.70

At Site 2 (clay loam), surface soil organic carbon and total nitrogen were approximately doubled undervine where the forest mulch was applied (Table 2.3). EC, chloride and CEC were also elevated where forest mulch was applied undervine. In the subsurface soil, exchangeable Na and ESP were increased 10-fold and chloride was increased up to 40-fold undervine compared to the midrow, regardless of treatment.

Table 2.3. Site 2 McLaren Vale, SA (clay loam). Means of the MDS for surface (0-15 cm) and subsurface (35-45 cm) soil in the undervine and midrow of the conventional and forest mulch treatments.

Indicator property	***Conventional midrow***	***Conventional undervine***	***Treated midrow***	***Treated undervine***
Surface (0-15 cm)				
MB SIR (µgC/g)	36.98	15.74	26.71	13.41
EC (dS/m)	0.14	0.16	0.16	0.29
pH_{CaCl}	7.70	7.38	7.70	7.53
pH_{water}	8.20	8.05	8.10	8.25
Chloride (ppm)	18.10	25.35	7.50	78.03
Total N (LECO) (%)	0.11	0.12	0.16	0.35
Exch. Ca (meq/100g)	15.46	9.21	15.89	15.58
Exch. K (meq/100g)	0.71	0.17	0.85	1.22

Exch. Mg (meq/100g)	1.55	3.18	1.86	4.82
Exch. Na (meq/100g)	0.05	0.21	0.05	0.23
CEC (%)	17.77	13.66	18.65	21.84
Org C (LECO) (%)	1.50	1.37	1.84	3.87
ESP (%)	0.28	1.59	0.27	1.02
Consistency (0-7)	3	5	5	3
Slaking (0-3)	1	1	1	1
Dispersion (0-16)	1	5	2	1
Subsurface (35-45 cm)				
EC (dS/m)	0.13	0.44	0.11	0.41
pH_{CaCl}	7.80	7.60	7.80	7.70
pH_{water}	8.50	8.50	8.40	8.53
Chloride (ppm)	6.7	211.7	5.1	217.4
Exch. Ca (meq/100g)	22.12	15.91	15.41	15.47
Exch. K (meq/100g)	0.60	0.58	0.48	0.56
Exch. Mg (meq/100g)	2.21	2.22	1.70	2.06
Exch. Na (meq/100g)	0.11	0.97	0.05	1.10
CEC (%)	25.04	19.68	17.64	19.19
ESP (%)	0.44	4.51	0.28	4.51

Site 3: Langhorne Creek, SA (cv. Shiraz)
All of the biological and chemical MDS variables detected significant differences between either vineyard position, treatment or both in the surface soil (Table 2.4). Treatment effects were detected for pH, chloride, total nitrogen, exchangeable K and organic carbon. Organic carbon and total nitrogen were higher where mulch had been applied. There was a significant interaction between treatment and vineyard position for pH, chloride and exchangeable K, which were all increased in the mulch undervine soil, but no interaction for Ca, Mg, Na, ESP or CEC.

Fewer significant differences were detected in the subsurface soil (Table 2.4). pH was decreased by the mulch treatment, ESP increased undervine, and conductivity, chloride and exchangeable Mg increased in the midrow. Exchangeable Na was increased in the mulch undervine treatment, and exchangeable K was decreased in the conventional undervine treatment. This site was already known to have a salinity issue and this has been confirmed with the high exchangeable Na and ESP values, particularly undervine.

Table 2.4. Site 3: Langhorne Creek, SA (cv. Shiraz). Means of the MDS for surface (0-15 cm) and subsurface (35-45 cm) soil in the undervine and midrow of the conventional and grape marc mulch treatments.

Indicator property	***Conventional midrow***	***Conventional undervine***	***Treated midrow***	***Treated undervine***
Surface (0-15 cm)				
MB SIR (µgC/g)	25.1a	16.2b	28.1a	18.0b
EC (dS/m)	0.21a	0.40b	0.17a	0.58b
pH_{CaCl}	6.93b	7.23c	6.43a	7.23c
pH_{water}	7.40b	7.63c	6.97a	7.60c
Chloride (ppm)	44.8a	121.8b	45.7a	194.9c
Total N (LECO) (%)	0.17a	0.15a	0.22b	0.22b
Exch. Ca (meq/100g)	9.43a	10.35b	9.19a	10.93b
Exch. K (meq/100g)	0.55a	0.69b	0.68b	1.02c
Exch. Mg (meq/100g)	1.30a	2.75b	0.79a	2.72b
Exch. Na (meq/100g)	0.05a	0.18b	0.05a	0.15b
CEC (%)	11.33a	13.98b	10.72a	14.82b
Org C (LECO) (%)	1.90a	1.67a	2.16b	2.41b
ESP (%)	0.44a	1.29b	0.46a	0.94b
Consistency (0-7)	6	5	5	5
Slaking (0-3)	1	1	1	0
Dispersion (0-16)	1	3	1	1
Subsurface (35-45 cm)				
EC (dS/m)	0.60b	0.46a	0.97c	0.42a

pH_{CaCl}	7.17a	7.23a	6.93b	6.90b
pH_{water}	7.93a	8.10a	7.53b	7.83b
Chloride (ppm)	292.4b	231.7a	452.0c	201.2a
Exch. Ca (meq/100g)	12.6	11.32	11.84	11.56
Exch. K (meq/100g)	0.88b	0.68a	0.85b	0.93b
Exch. Mg (meq/100g)	8.96a	6.59b	8.34a	7.11b
Exch. Na (meq/100g)	2.47a	2.60a	2.04a	3.55b
CEC (%)	24.47	21.19	23.07	23.15
ESP (%)	10.09a	11.87b	8.84a	15.33b

Yellow highlighting and different letters following values in rows indicate significant differences using Fisher's LSDs at 5%.

Site 4. Langhorne Creek, SA (cv. Cabernet Sauvignon)
At this site, the midrow was between the two treatments and was not treated with mulch. Only one MDS variable detected a significant difference and that was for vineyard position where EC was higher in the subsurface soil of the undervine than midrow (Table 2.5). Some trends were observed in the surface soil, where MB SIR, total nitrogen and organic carbon were twice as high in the mulch treatment and MB SIR was seven times higher in the midrow, but due to high standard error, these differences were not significant.

Table 2.5. Site 4: Langhorne Creek, SA (cv. Cabernet Sauvignon). Means of the MDS for surface (0-15 cm) and subsurface (35-45 cm) soil in the undervine and midrow of the conventional and composted Nitromulch treatments.

Indicator property	***Conventional Midrow***	***Conventional undervine***	***Treated undervine***
Surface (0-15 cm)			
MB SIR (µgC/g)	20.4	2.2	4.6
EC (dS/m)	0.09	0.14	0.29
pH_{CaCl}	6.87	6.77	6.93
pH_{water}	7.37	7.30	7.47
Chloride (ppm)	17.3	72.2	119.4
Total N (LECO) (%)	0.11	0.12	0.23
Exch. Ca (meq/100g)	3.27	4.97	5.66
Exch. K (meq/100g)	0.27	0.62	0.40
Exch. Mg (meq/100g)	0.44	1.32	1.51
Exch. Na (meq/100g)	0.74	1.47	2.61
CEC (%)	4.7	8.4	10.2
Org C (LECO) (%)	1.23	1.17	2.62
ESP (%)	11.1	22.3	25.5
Consistency (0-7)	1	1	1
Slaking (0-3)	0	1	0
Dispersion (0-16)	2	2	1
Subsurface (35-45 cm)			
EC (dS/m)	0.04a	0.23b	0.13ab
pH_{CaCl}	6.50	6.57	6.97
pH_{water}	7.17	7.10	7.60
Chloride (ppm)	15.7	51.2	22.9
Exch. Ca (meq/100g)	1.20	6.08	1.89
Exch. K (meq/100g)	0.24	0.30	0.21
Exch. Mg (meq/100g)	0.19	1.65	0.64
Exch. Na (meq/100g)	0.44	1.12	0.63
CEC (%)	2.07	9.14	3.37
ESP (%)	17.57	18.89	17.58

Yellow highlighting and different letters following values in rows indicate significant differences using Fisher's LSDs at 5%.

Site 5: Mornington Peninsula (cv. Arneis)
At Site 5, several MDS variables detected significant differences between vineyard positions (Table 2.6). The undervine treatment did not significantly change the MDS compared to the conventional undervine. pH was significantly lower in the native soil than the vineyard soils. Labile carbon was significantly higher in the surface midrow soil. Chloride was five to seven times higher and the exchangeable cation Ca was significantly higher in the vineyard surface soil compared to the native soil.

In the subsurface soil EC, pH, chloride, exchangeable Ca and Mg were all significantly higher in the undervine soil than the midrow and native soil.

Table 2.6. Site 5: Mornington Peninsula, VIC (cv. Arneis). Means of the MDS for surface (0-15 cm) and subsurface (35-45 cm) soil from conventional (herbicide undervine), treated (undervine ground cover) and native treatments.

Indicator property	***Conv. midrow***	***Native***	***Conv. undervine***	***Treated undervine***
Surface (0-15 cm)				
MB SIR (µgC/g)	16.0	14.6	9.3	9.8
Labile C (%)	0.10a	0.08b	0.08b	0.08b
PMN (mg N/g)	58.6	83.4	26.1	41.0
EC (dS/m)	0.14b	0.08a	0.20c	0.20c
pH_{CaCl}	6.40b	4.10a	6.60b	6.60b
pH_{water}	7.25b	4.85a	7.43b	7.53b
Chloride (ppm)	25.3a	44.8ab	61.0b	65.3b
Total N (LECO) (%)	0.27	0.29	0.24	0.24
Exch. Ca (meq/100g)	7.01b	1.80a	6.53b	6.38b
Exch. K (meq/100g)	0.33	4.46	0.54	0.55
Exch. Mg (meq/100g)	1.22	1.10	1.35	1.46
Exch. Na (meq/100g)	5.28	3.33	0.08	4.01
CEC (%)	13.8	10.7	8.5	12.4
Org C (LECO) (%)	4.05	4.77	3.78	3.76
ESP (%)	37.3	19.3	1.0	26.8
Consistency (0-7)	1	2	2	2
Slaking (0-3)	0	0	0	0
Dispersion (0-16)	0	2	0	0
Subsurface (35-45 cm)				
EC (dS/m)	0.06a	0.03a	0.14b	0.15b
pH_{CaCl}	5.25b	4.40a	6.13c	5.73bc
pH_{water}	6.25b	5.35a	7.00c	6.63bc
Chloride (ppm)	15.25a	11.10a	77.90b	84.45b
Exch. Ca (meq/100g)	1.00a	0.34a	4.08b	3.40b
Exch. K (meq/100g)	2.20	3.90	2.30	0.19
Exch. Mg (meq/100g)	0.38a	0.32a	1.01b	1.02b
Exch. Na (meq/100g)	2.58	2.24	1.88	3.46
CEC (%)	6.16	6.79	9.26	8.07
ESP (%)	50.85	34.23	18.82	41.66

Yellow highlighting and different letters following values in rows indicate significant differences using Fisher's LSDs at 5%.

Site 6: Mornington Peninsula (cv. Chardonnay)
On analysis, the soil type in the conventional treatment plots were found to have a higher clay content than the compost treatment plots, so the physical indicators were not measured. The results at this site need to be considered with caution since the treatment effects are confounded by soil type differences as well.

The significant differences detected by the MDS variables were all related to vineyard position rather than treatment (Table 2.7). Undervine surface soil had significantly less organic carbon, labile carbon and PMN than the midrow and native soil. EC, pH, chloride and exchangeable Ca were significantly lower in the native than the vineyard surface soil. Exchangeable Mg was significantly higher undervine than in the midrow or native surface soil.

In the subsurface, exchangeable Ca was lower in the native soil and EC was significantly higher in the undervine position. pH was below recommended levels for grapevine growth in the native and conventional subsurface soil, but not in the treated soil, but this has been confounded by the clay content differences mentioned above, so may not be a treatment effect. Exchangeable K was significantly higher and exchangeable Mg significantly lower in the treated plots, but again this could be due to the soil type difference.

Table 2.7. Site 6: Mornington Peninsula, VIC (cv. Chardonnay). Means of the MDS for surface (0-15 cm) and subsurface (35-45 cm) soil from conventional (permanent sward midrow and herbicide undervine), treated (compost and midrow cover crop) and native treatments.

Indicator property	*Conv. midrow*	*Treated midrow*	*Native*	*Conv. undervine*	*Treated undervine*
Surface (0-15 cm)					
MB SIR (µgC/g)	17.9	15.2	14.6	10.8	5.4
Labile C (%)	0.10c	0.09bc	0.08bc	0.07ab	0.07ab
PMN (mg N/g)	85.6bc	44.7ab	83.4bc	39.3ab	26.0a
EC (dS/m)	0.14c	0.11b	0.08a	0.11b	0.10ab
pH_{CaCl}	6.08b	6.18bc	4.10a	6.23bc	6.43c
pH_{water}	6.65b	7.08c	4.85a	7.03c	7.18c
Chloride (ppm)	26.0ab	15.0a	44.8b	20.4ab	33.9b
Total N (LECO) (%)	0.35d	0.26b	0.29c	0.23a	0.21a
Exch. Ca (meq/100g)	9.05d	7.10c	1.80a	6.61c	5.64b
Exch. K (meq/100g)	0.26	0.16	4.46	0.32	0.12
Exch. Mg (meq/100g)	1.40bc	0.89a	1.10ab	1.65c	1.35bc
Exch. Na (meq/100g)	2.42	2.66	3.32	1.72	2.24
CEC (%)	13.13	10.81	10.69	10.29	9.35
Org C (LECO) (%)	4.62c	3.33b	4.77c	2.91ab	2.51a
ESP (%)	18.4	24.6	31.1	16.7	24.0
Subsurface (35-45 cm)					
EC (dS/m)	0.05ab	0.04ab	0.03a	0.07b	0.07b
pH_{CaCl}	4.08a	5.35c	4.40b	4.15ab	5.83d
pH_{water}	5.00a	6.33c	5.35b	5.05a	6.73d
Chloride (ppm)	3.90	4.40	11.10	13.18	25.90
Exch. Ca (meq/100g)	1.52c	0.88b	0.34a	1.00b	1.96c
Exch. K (meq/100g)	0.16a	6.81b	3.90ab	0.15a	8.46b
Exch. Mg (meq/100g)	1.21c	0.34a	0.32a	0.83b	0.63ab
Exch. Na (meq/100g)	2.96	4.27	2.24	5.36	2.20
CEC (%)	5.85	12.30	6.79	7.34	13.25
ESP (%)	44.84	37.67	34.23	72.84	15.65

Yellow highlighting and different letters following values in rows indicate significant differences using Fisher's LSDs at 5%.

Site 7: Bellarine Peninsula (cv. Pinot Noir)
Most of the MDS variables detected significant differences in treatment or vineyard position at both soil depths (Table 2.8). The conventional surface soil had significantly lower pH, CEC, labile carbon, EC, chloride, exchangeable Ca and K than the treated surface soil. Vineyard position differences were evident, with higher chloride, EC and exchangeable Mg in the native soil and lower organic carbon and exchangeable K in the midrow soil. Labile carbon was significantly lower in the conventional midrow soil than the other surface soils.

In the subsurface, pH_{water} was significantly higher in the conventional undervine and midrow than their treated counterparts. Other treatment effects occurred only in midrow soil. Chloride, EC, pH and exchangeable K were significantly higher in the conventional midrow than the treated midrow. Vineyard position differences were also evident, with the midrow significantly higher in CEC, EC and pH, and the undervine significantly lower in chloride and exchangeable cations Ca, K and Mg.

Table 2.8. Site 7: Bellarine Peninsula, VIC (cv. Pinot Noir). Means of the MDS for surface (0-15 cm) and subsurface (35-45 cm) soil from conventional (bare ground undervine and midrow), treated (compost "40:40") and native treatments.

Indicator property	*Conv. midrow*	*Treated midrow*	*Native*	*Conv. undervine*	*Treated undervine*
Surface (0-15 cm)					
MB SIR (µgC/g)	2.97	3.35	1.92	3.27	3.23
Labile C (%)	0.03a	0.04b	0.04b	0.04b	0.05b
PMN (mg N/g)	36.58	38.83	52.97	36.41	37.45
EC (dS/m)	0.09ab	0.07a	0.13b	0.10ab	0.35c
pH_{CaCl}	4.48a	6.00c	4.65a	4.58a	5.45b
pH_{water}	5.48a	6.95c	5.50a	5.53a	6.15b
Chloride (ppm)	22.0a	12.5a	85.5b	29.4a	69.8b
Total N (LECO) (%)	0.15	0.16	0.19	0.20	0.20
Exch. Ca (meq/100g)	1.64a	4.38b	1.94a	2.36a	4.37b
Exch. K (meq/100g)	0.29a	0.36ab	0.45b	0.34ab	0.80c
Exch. Mg (meq/100g)	0.57a	0.94b	1.21c	0.68a	1.01bc
Exch. Na (meq/100g)	1.82	1.72	4.48	1.32	2.71
CEC (%)	4.32	7.40	8.07	4.69	8.89
Org C (LECO) (%)	1.47a	1.62ab	2.65c	2.12bc	1.90ab
ESP (%)	42.1	23.2	55.5	28.1	30.5
Consistency (0-7)	4	4	3	3	4
Slaking (0-3)	1	0	0	0	0
Dispersion (0-16)	1	2	2	1	0
Subsurface (35-45 cm)					
EC (dS/m)	0.26c	0.08a	0.14b	0.06a	0.10ab
pH_{CaCl}	6.18d	5.48c	4.98b	4.78ab	4.58a
pH_{water}	7.15d	6.48c	5.98b	5.78b	5.35a
Chloride (ppm)	71.0b	16.4a	82.0b	23.5a	33.5a
Exch. Ca (meq/100g)	3.47b	2.42ab	3.11b	1.27a	1.33a
Exch. K (meq/100g)	0.68b	0.34a	0.65b	0.19a	0.18a
Exch. Mg (meq/100g)	5.54c	3.44b	3.83bc	0.62a	0.69a
Exch. Na (meq/100g)	2.59	1.06	0.86	1.98	1.61
CEC (%)	12.27c	7.27abc	8.44bc	4.06ab	3.81a
ESP (%)	21.1	14.0	9.7	22.9	30.6

Yellow highlighting and different letters following values in rows indicate significant differences using Fisher's LSDs at 5%.

Site 8: Bellarine Peninsula (cv. Pinot Gris)
At Site 8, there was no native vegetation area for comparison, but the vineyard had previously been pasture and there was still pasture in the adjacent paddock.

Most of the MDS variables detected significant differences in the surface depth (Table 2.9). PMN, chloride, EC, organic carbon and total nitrogen were all significantly higher in the pasture than in the vineyard, but exchangeable Ca and microbial biomass were higher in the vineyard than in the pasture. pH was significantly higher undervine than in the midrow or the pasture. Organic carbon, total nitrogen, EC, exchangeable Ca and Mg were all significantly higher in the treated compared to conventional vineyard soil, but MB SIR was significantly lower in the compost-treated than the conventional vineyard soil, which was contrary to expectations.

In the subsurface, the only significant difference detected was that of pH, which was lower in the pasture than in the vineyard.

Table 2.9. Site 8: Bellarine Peninsula, VIC (cv. Pinot Gris). Means of the MDS for surface (0-15 cm) and subsurface (35-45 cm) soil from conventional (permanent sward), treated (compost "40:40") and pasture treatments.

Indicator property	***Conv. midrow***	***Treated midrow***	***Pasture***	***Conv. undervine***	***Treated undervine***
Surface (0-15 cm)					
MB SIR (µgC/g)	5.99bc	3.01ab	1.91a	7.49c	2.63ab
Labile C (%)	0.041a	0.042a	0.046ab	0.036a	0.055b
PMN (mg N/g)	37.04ab	39.92ab	62.7c	27.28a	46.89b
EC (dS/m)	0.04a	0.06bc	0.07c	0.05ab	0.10d
pH_{CaCl}	4.82ab	5.43bc	4.63a	5.43b	6.03c
pH_{water}	5.83ab	6.30bc	5.58a	6.30bc	6.85c
Chloride (ppm)	7.60a	10.47a	32.55b	12.12a	12.12a
Total N (LECO) (%)	0.12a	0.15a	0.17ab	0.12a	0.21b
Exch. Ca (meq/100g)	1.55ab	2.30c	1.07a	1.95bc	3.61d
Exch. K (meq/100g)	3.91	0.11	0.25	2.33	0.26
Exch. Mg (meq/100g)	0.26a	0.41ab	0.51b	0.39ab	1.16c
Exch. Na (meq/100g)	4.99	1.42	2.84	1.30	0.90
CEC (%)	10.70	4.22	4.66	5.97	5.93
Org C (LECO) (%)	1.24a	1.54ab	1.90bc	1.05a	2.34c
ESP (%)	34.9	23.3	50.1	30.0	16.0
Consistency (0-7)	2	2	2	2	2
Slaking (0-3)	0	0	0	0	0
Dispersion (0-16)	2	1	3	2	2
Subsurface (35-45 cm)					
EC (dS/m)	0.02	0.03	0.04	0.03	0.04
pH_{CaCl}	5.33b	5.60b	4.43a	5.35b	5.40b
pH_{water}	6.15b	6.38b	5.38a	6.18b	6.20b
Chloride (ppm)	3.7	6.9	17.5	6.1	6.6
Exch. Ca (meq/100g)	0.79	0.83	0.65	0.77	1.34
Exch. K (meq/100g)	1.91	2.31	0.12	2.56	0.15
Exch. Mg (meq/100g)	2.48	2.46	0.33	0.21	0.32
Exch. Na (meq/100g)	2.30	2.03	1.58	1.57	0.40
CEC (%)	7.5	7.6	2.7	5.1	2.2
ESP (%)	11.8	15.8	50.5	25.4	14.7

Yellow highlighting and different letters following values in rows indicate significant differences using Fisher's LSDs at 5%.

Site 9: Mornington Peninsula (cv. Pinot Noir)
At this site, the majority of the MDS variables were able to detect significant differences (Table 2.10). In the surface soil, treatment effects were seen with exchangeable Na, which was significantly lower in the conventional than the treated and native soil. PMN and chloride were significantly higher and pH lower in the native compared to vineyard soil. Organic carbon and total nitrogen were significantly lower in the midrow than undervine and native soil, whereas labile carbon was significantly higher in the midrow than undervine and native soil. Exchangeable Mg and EC were significantly higher in undervine than midrow and native soil. Exchangeable Ca was lowest in the native soil, intermediate in the midrow and highest undervine.

In the subsurface, pH was significantly lower in the native soil. EC and chloride levels were significantly higher undervine than midrow, which in turn were significantly higher than native soil. Exchangeable Mg was significantly higher in the native and treated undervine soil.

There were no treatment effects in the midrow.

Table 2.10. Site 9: Mornington Peninsula, VIC (cv. Pinot Noir). Means of the MDS for surface (0-15 cm) and subsurface (35-45 cm) soil from conventional (herbicide undervine), treated (undervine compost mulch) and native treatments.

Indicator property	***Conv. midrow***	***Treated midrow***	***Native***	***Conv. undervine***	***Treated undervine***
Surface (0-15 cm)					
MB SIR (µgC/g)	27.73	16.28	23.70	36.87	19.74
Labile C (%)	0.017a	0.016a	0.010	0.007b	0.022b
PMN (mg N/g)	27.9a	34.1a	112.5b	39.2a	34.9a
EC (dS/m)	0.07a	0.06a	0.07a	0.10b	0.09b
pH_{CaCl}	6.2b	6.2b	4.6a	6.3b	6.6b
pH_{water}	7.0b	7.1b	5.6a	7.2b	7.5b
Chloride (ppm)	13.43a	14.45a	37.40b	16.63a	12.90a
Total N (LECO) (%)	0.18a	0.15a	0.27b	0.27b	0.27b
Exch. Ca (meq/100g)	3.79b	3.63b	2.37a	5.90c	6.60c
Exch. K (meq/100g)	1.80	1.67	0.19	0.24	0.19
Exch. Mg (meq/100g)	0.82a	0.84ab	0.97b	1.37c	1.40c
Exch. Na (meq/100g)	2.13a	6.69b	3.73b	1.69a	3.34b
CEC (%)	8.53	12.83	7.26	9.19	11.54
Org C (LECO) (%)	2.51a	2.20a	3.92b	3.38b	3.32b
ESP (%)	24.2	53.3	34.6	12.6	23.0
Consistency (0-7)	2	3	3	2	1
Slaking (0-3)	0	0	0	0	0
Dispersion (0-16)	2	0	0	2	0
Subsurface (35-45 cm)					
EC (dS/m)	0.07b	0.08b	0.04a	0.13c	0.13c
pH_{CaCl}	5.88b	5.70b	4.67a	5.55b	5.63b
pH_{water}	6.88b	6.68b	5.63a	6.45b	6.48b
Chloride (ppm)	32.50b	46.98b	12.37a	98.58c	107.50c
Exch. Ca (meq/100g)	0.70	0.59	1.05	1.12	3.04
Exch. K (meq/100g)	1.96	2.54	0.11	1.33	2.63
Exch. Mg (meq/100g)	0.56a	0.36a	1.38b	0.38a	1.74b
Exch. Na (meq/100g)	4.15	1.98	0.20	2.67	2.43
CEC (%)	7.37	5.46	2.37	5.50	9.83
ESP (%)	45.92	27.60	7.17	44.65	22.19

Yellow highlighting and different letters following values in rows indicate significant differences using Fisher's LSDs at 5%.

2.4.2 South Australian combined dataset

To determine if the MDS variables showed significant differences between treated and untreated areas, data generated from both sites in SA were combined (Tables 2.11 and 2.13). Significant differences were detected in the surface soil (0-15 cm) for MB CFE, organic carbon and total nitrogen.

The treated undervine soil had significantly higher MB, organic carbon and total nitrogen than the conventional undervine soil. Additionally, the treated (undervine + midrow) had significantly higher MB than the conventional (undervine + midrow). This result was encouraging given that the organic matter (mulch and compost) had been applied several years ago.

No other indicators demonstrated significant differences between treatments. There were no significant differences detected at the subsurface soil layer (35-45 cm).

The graphical presentation of physical property classes did not indicate any major differences between treatment or vineyard position, but it did indicate that the South Australian soils trended towards high consistency (5-7) (Figure 2.7).

2.4.3 Victorian combined dataset

To determine if the MDS variables showed significant differences between treated and untreated areas, data generated from all sites in VIC were combined (Tables 2.12 and 2.14). Significant differences were detected in the surface soil (0-15 cm) for the biological indicators MB SIR, PMN and labile carbon, and the chemical indicators organic carbon, total nitrogen, pH (both), EC, chloride and exchangeable cations Ca, K and Mg. Significant differences were detected in the sub-surface soil (35-45 cm) for pH, EC and exchangeable Na.

There was significantly higher labile carbon in the treated undervine soil compared to the conventional undervine soil, but the opposite was observed for MB SIR.

PMN, organic carbon (LECO) and total nitrogen (LECO) were all significantly higher in the native soil compared with the vineyard soil.

pH was significantly lower in the native soil compared with the vineyard soil, and lower undervine than midrow.

Chloride was significantly higher in the treated undervine compared with conventional undervine, and in the native compared to vineyard soil.

Conductivity (EC) was significantly higher in the treated compared with conventional vineyard soil.

Exchangeable Mg was significantly higher in the treated undervine compared to conventional undervine. Differences in exchangeable Ca were highly significant between native and viticulture soil, being higher in the vineyard. Exchangeable K was significantly higher in the native soil compared with the treated soil.

In the sub-surface soil layer (35-45 cm), EC and exchangeable Na were significantly higher in the conventional vineyard soil compared to the native soil, pH was again higher in the vineyard than the native soil, and pH_{CaCl} was significantly higher in the treated vineyard soils compared to conventional, but this difference was not significant with $pH_{water.}$

The graphical presentation of physical property classes indicated that the treated midrow surface soils had more replicates in the high class for consistency than the other treatments, but there were no discernible differences between treatments in slaking or dispersion (Figure 2.8).

Table 2.11 Analysis of soil properties at South Australian sites 1 to 4, showing significant differences between treated and untreated soil whereby A: conventional undervine – treated undervine and B: conventional (undervine + midrow) – treated (undervine + midrow).

Contrast		*MB CFE*	*MB SIR*	*Org C (LECO)*	*Tot N (LECO)*	*pH_{CaCl}*	*pH_{water}*	*EC*	*Chloride*	*ExCa*	*ExK*	*ExMg*	*ExNa*	*CEC*	*ESP*
0-15 cm		µgC/g	µgC/g	%	%			dS/m	ppm	meq/100g	meq/100g	meq/100g	meq/100g	%	%
A	Mean	-103	-3.2	-1.15	-0.097	-0.18	-0.23	-0.016	-37	-0.8	-0.12	-0.54	-0.34	-1.8	-1
	se	52.2	5.18	0.26	0.03	0.19	0.19	0.10	27.0	1.90	0.15	0.48	0.47	2.25	6.2
	P	0.059	NS	**	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B	Mean	-106	-0.8	-0.78	-0.08	0.05	-0.01	-0.016	-21	-1.7	-0.17	-0.31	-0.04	-2.2	2
	se	42.3	4.19	0.21	0.02	0.15	0.16	0.08	21.9	1.54	0.119	0.39	0.383	1.82	5.0
	P	**	NS	**	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
35-45 cm															
A	Mean					-0.04	-0.10	0.05	6	0.7	-0.09	0.1	-0.24	0.5	-1.1
	se					0.26	0.30	0.12	64.0	3.02	0.12	1.56	0.61	4.58	6.43
	P					NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B	Mean					-0.02	0.01	-0.151	-75	-0.9	-0.11	-0.8	-0.19	-2.0	1.9
	se					0.20	0.24	0.10	51.8	2.45	0.12	1.26	0.49	3.71	5.21
	P					NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Significance is denoted by NS, not significant, *P<0.05, **P<0.01, based on comparisons for all pairs using Fisher's LSDs at 5%. Significant properties are highlighted in yellow. A negative value indicates treated had a higher value than conventional.

Table 2.12. Analysis of soil properties at Victorian sites 5 to 9, showing significant differences between treated and untreated areas whereby A: conventional undervine – treated undervine, B: conventional (undervine + midrow) – treated (undervine + midrow), C: conventional (undervine + midrow) – nonviticulture, and D: treated (undervine + midrow) – native.

Contrast		*MB SIR*	*labC*	*PMN*	*Org C (LECO)*	*Tot N (LECO)*	*pH_{CaCl}*	*pH_{water}*	*EC*	*Chloride*	*ExCa*	*ExK*	*ExMg*	*ExNa*	*CEC*	*ESP*
0-15 cm		µgC/g	%	mgN/g	%	%			dS/m	ppm	meq/100g	meq/100g	meq/100g	meq/100g	%	%
A	Mean	5.6	-0.008	-3.7	-0.12	-0.015	-0.41	-0.35	-0.057	-11.4	-0.68	0.38	-0.199	-1.48	-2.0	-6.8
	se	2.77	0.004	5.65	0.27	0.02	0.16	0.16	0.02	5.45	0.44	0.72	0.09	0.89	1.28	7.00
	P	*	*	NS	NS	NS	*	*	**	*	NS	NS	*	NS	NS	NS
B	Mean	5.1	-0.004	2.7	0.09	0.004	-0.43	-0.43	-0.024	-5.0	-0.37	0.52	-0.090	-0.68	-0.62	-2.4
	se	2.02	0.003	4.12	0.20	0.01	0.12	0.12	0.01	3.98	0.32	0.53	0.07	0.65	0.94	5.10
	P	NS	NS	NS	NS	NS	**	**	*	NS	NS	NS	NS	NS	NS	NS
C	Mean	2.6	-0.002	-39.1	-0.94	-0.032	1.35	1.35	0.016	-26.7	2.96	-0.97	-0.008	-1.32	0.7	-8.6
	se	2.40	0.003	4.89	0.24	0.01	0.14	0.14	0.01	4.72	0.38	0.63	0.08	0.77	1.11	6.06
	P	NS	NS	**	**	*	**	**	NS	**	**	NS	NS	NS	NS	NS
D	Mean	-2.5	0.002	-41.8	-1.03	-0.036	1.78	1.78	0.04	-21.6	3.33	-1.49	0.083	-0.63	1.3	-6.2
	se	2.45	0.003	4.99	0.24	0.01	0.14	0.14	0.01	4.82	0.39	0.64	0.083	0.79	1.13	6.19
	P	NS	NS	**	**	**	**	**	NS	**	**	*	NS	NS	NS	NS
35-45 cm																
A	Mean						-0.24	-0.18	-0.013	-7.7	-0.57	-1.02	-0.27	0.67	-1.2	12
	se						0.17	0.17	0.015	9.23	0.41	0.98	0.53	0.70	1.55	8.4
	P						NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B	Mean						-0.25	-0.21	0.009	-1.8	-0.20	-1.37	0.12	0.59	-0.9	11
	se						0.12	0.13	0.01	6.73	0.30	0.72	0.39	0.51	1.13	6.1
	P						*	NS	NS	NS	NS	0.059	NS	NS	NS	NS
C	Mean						0.68	0.64	0.031	5.5	0.49	-0.47	0.11	1.31	1.4	8
	se						0.15	0.15	0.013	7.99	0.35	0.85	0.46	0.61	1.34	7.3
	P						**	**	*	NS	NS	NS	NS	*	NS	NS
D	Mean						0.93	0.85	0.022	7.3	0.69	0.91	-0.01	0.72	2.3	-3
	se						0.15	0.15	0.014	8.16	0.36	0.87	0.47	0.62	1.37	7.4
	P						**	**	NS	NS	NS	NS	NS	NS	NS	NS

Significance is denoted by NS, not significant, *P<0.05, **P<0.01, based on comparisons for all pairs using Fisher's LSDs at 5%. Significant properties are highlighted in yellow. A negative value indicates treated had a higher value than conventional.

Table 2.13. Means of the MDS variables for surface (0-15 cm) and subsurface (35-45 cm) soils from conventional and treated undervine and midrow positions in the South Australian sites 1 to 4.

Indicator property	*Conventional midrow*	*Conventional undervine*	*Treated midrow*	*Treated undervine*
Surface (0-15 cm)				
MB CFE (µgC/g)	405.3	286.9	515.4	389.7
MB SIR (µgC/g)	25.1	9.4	23.6	12.6
Ammonium N (ppm)	4.75	2.60	5.00	4.80
Nitrate N (ppm)	12.2	8.4	26.2	14.0
Phosphorus (ppm)	35.0	65.4	42.2	118.6
Potassium (ppm)	267	348	376	477
Sulphur (ppm)	25	191	29	132
Org C (W-B) (%)	1.220	1.104	1.564	2.053
EC (dS/m)	0.139	0.318	0.155	0.333
pH_{CaCl}	7.000	7.030	6.720	7.210
pH_{water}	7.475	7.520	7.260	7.750
Chloride (ppm)	26	69	30	106
Total N (LECO) (%)	0.129	0.117	0.184	0.214
Exch. Ca (meq/100g)	7.09	7.90	9.68	8.72
Exch. K (meq/100g)	0.424	0.616	0.654	0.734
Exch. Mg (meq/100g)	0.90	1.93	0.99	2.47
Exch. Na (meq/100g)	0.31	0.54	0.05	0.87
CEC (%)	8.73	10.98	11.37	12.79
Org C (LECO) (%)	1.39	1.19	1.81	2.33
ESP (%)	4.5	7.5	0.5	8.3
Subsurface (35-45 cm)				
Ammonium N (ppm)	2.12	2.30	2.20	5.35
Nitrate N (ppm)	2.12	2.30	1.30	1.75
Phosphorus (ppm)	5	111	6	163
Potassium (ppm)	210	197	256	218
Sulphur (ppm)	78	178	207	58
Org C (W-B) (%)	0.567	0.673	0.722	0.705
EC (dS/m)	0.261	0.359	0.608	0.312
pH_{CaCl}	7.01	7.05	7.02	7.09
pH_{water}	7.74	7.78	7.62	7.88
Chloride (ppm)	117	140	273	135
Exch. Ca (meq/100g)	8.1	9.5	10.6	8.8
Exch. K (meq/100g)	0.502	0.435	0.626	0.525
Exch. Mg (meq/100g)	3.75	3.09	5.44	3.02
Exch. Na (meq/100g)	1.11	1.33	1.25	1.57
CEC (%)	13.5	14.3	17.9	13.9
ESP (%)	10.64	10.36	5.71	11.46

Table 2.14. Means of the MDS variables for surface (0-15 cm) and subsurface (35-45 cm) soils from native, conventional and treated undervine and midrow positions in the Victorian sites 5 to 9.

Indicator property	*Conv. midrow*	*Treated midrow*	*Native*	*Conv. undervine*	*Treated undervine*
Surface (0-15 cm)					
MB SIR (µgC/g)	14.17	9.59	11.31	13.59	7.97
Labile C (%)	0.056	0.055	0.052	0.045	0.053
PMN (mg N/g)	49.04	39.91	80.09	32.88	36.62
Ammonium N (ppm)	7.2	5.4	8.7	4.3	4.9
Nitrate N (ppm)	15.9	11.7	3.8	10.5	34.9
Phosphorus (ppm)	102.1	103.9	12.8	106.7	134.9
Potassium (ppm)	181	176	162	251	328
Sulphur (ppm)	9.38	7.75	11.59	14.39	21.22
Org C (W-B) (%)	1.952	1.877	2.662	2.055	2.200
EC (dS/m)	0.0918	0.0833	0.0852	0.1105	0.1675
pH_{CaCl}	5.571	6.017	4.352	5.826	6.237
pH_{water}	6.416	6.928	5.203	6.692	7.046
Chloride (ppm)	17.6	16.3	49.0	27.0	38.4
Total N (LECO) (%)	0.2101	0.1882	0.2408	0.2075	0.2221
Exch. Ca (meq/100g)	4.57	4.63	1.64	4.64	5.32
Exch. K (meq/100g)	1.31	0.65	1.98	0.72	0.34
Exch. Mg (meq/100g)	0.836	0.818	0.964	1.077	1.276
Exch. Na (meq/100g)	3.33	3.22	3.55	1.14	2.62
CEC (%)	10.05	9.32	8.14	7.58	9.55
Org C (LECO) (%)	2.70	2.39	3.57	2.56	2.68
ESP (%)	30.42	28.52	32.33	17.00	23.78
Subsurface (35-45 cm)					
Ammonium N (ppm)	1.95	1.14	2.09	3.25	3.65
Nitrate N (ppm)	2.57	1.50	1.45	2.29	6.27
Phosphorus (ppm)	7.7	4.8	5.3	18.2	19.7
Potassium (ppm)	92.3	57.4	88.7	78.2	74.9
Sulphur (ppm)	12.26	11.52	5.27	16.87	21.04
Org C (W-B) (%)	0.526	0.419	0.780	0.878	0.858
EC (dS/m)	0.0915	0.0606	0.0580	0.0857	0.0985
pH_{CaCl}	5.330	5.581	4.572	5.180	5.420
pH_{water}	6.274	6.516	5.536	6.079	6.264
Chloride (ppm)	24.9	20.7	28.6	43.4	51.2
Exch. Ca (meq/100g)	1.47	1.30	1.06	1.62	2.19
Exch. K (meq/100g)	1.36	3.09	1.79	1.29	2.30
Exch. Mg (meq/100g)	2.05	1.54	1.23	0.63	0.90
Exch. Na (meq/100g)	2.90	2.39	1.48	2.68	2.01
CEC (%)	7.79	8.33	5.56	6.22	7.40
ESP (%)	34.7	24.9	28.0	36.7	24.7

Microbial biomass (CFE) was determined for only a subset of the Victorian samples, so is not included in the table.

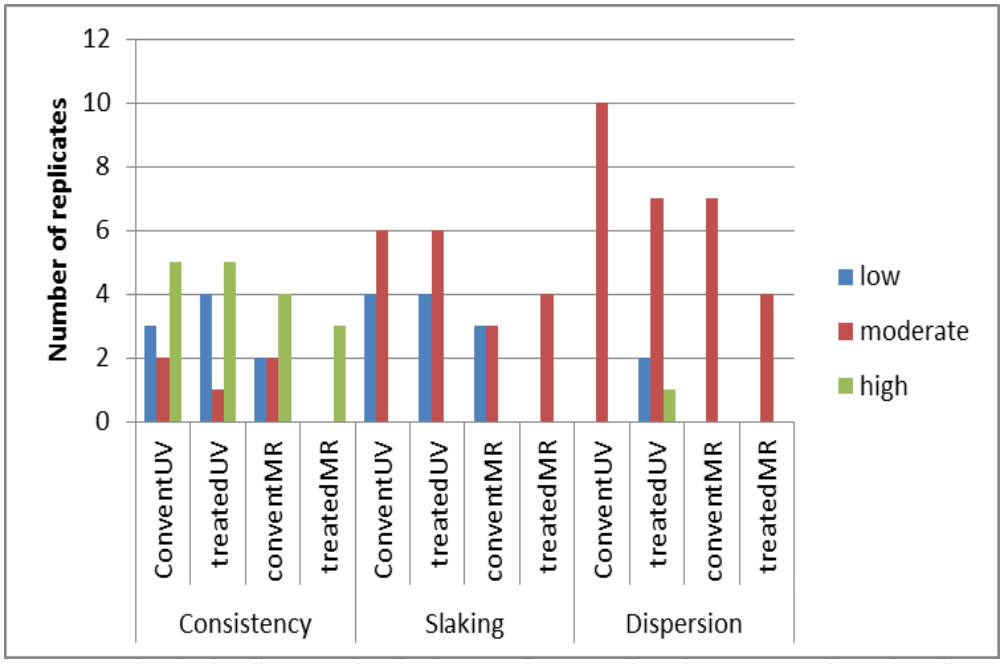


Figure 2.7. Physical soil properties in the South Australian dataset: number of replicates in each class. Classes: Consistency (0-7): low (0-1), moderate (2-3), high (4-7); Slaking (0-4): low (0), moderate (1-2), high (3-4); Dispersion (ASWAT) (0-16): low(0), moderate (1-8), high (9-16).

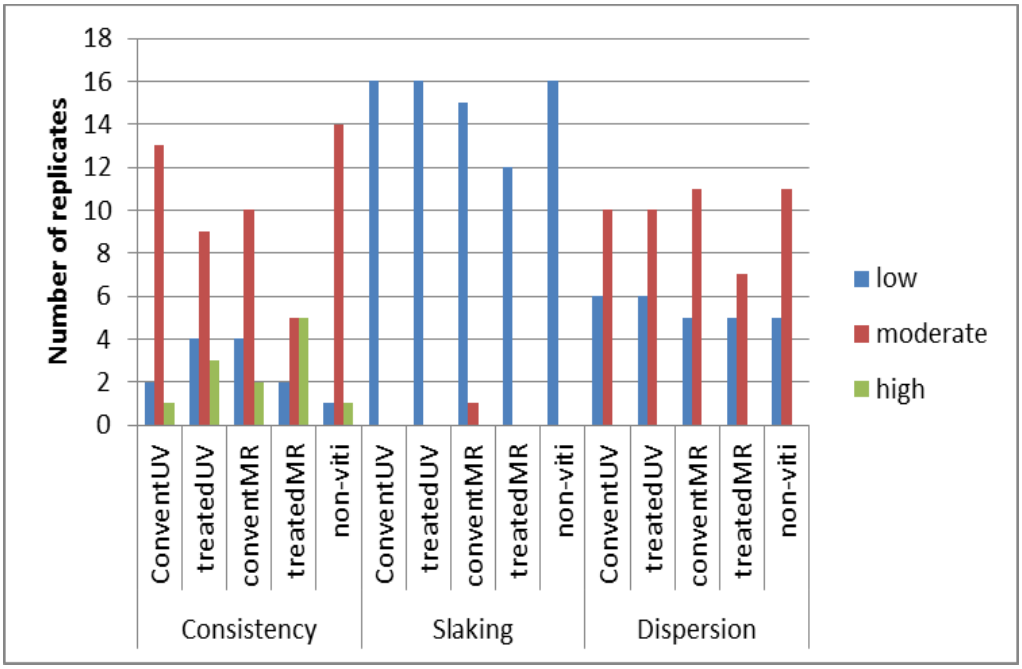


Figure 2.8. Physical soil properties in the Victorian dataset: number of replicates in each class. Classes: Consistency (0-7): low (0-1), moderate (2-3), high (4-7); Slaking (0-4): low (0), moderate (1-2), high (3-4); Dispersion (ASWAT) (0-16): low(0), moderate (1-8), high (9-16).

2.4.4 Comparison of the two methods of measuring microbial biomass carbon: microbial biomass CFE and microbial biomass SIR

In order to test whether the commercially available method of measuring microbial biomass (substrate induced respiration (MB SIR)) was an acceptable substitute for microbial biomass measured by chloroform fumigation extraction (MB CFE), subsamples of the same surface soils were analysed by both methods. There was no evidence of a strong relationship between the two measures of microbial biomass carbon. Therefore, a conversion factor was deemed not to be applicable to the viticulture soil datasets.

Regression analysis of the South Australian dataset:

$$MB\ CFE = 274.9 + 6.52\ MB\ SIR$$
$$P<0.001,\ R^2 = 0.38$$

Regression analysis of the Victorian dataset:

$$MB\ CFE = 284.0 + 6.73\ MB\ SIR$$
$$P=0.003,\ R^2 = 0.19$$

2.5. Discussion

The soil indicator tests that were chosen as a minimum dataset (MDS) for soil monitoring of Australian viticulture soils, plus potentially mineralizable nitrogen (PMN), labile carbon and total nitrogen (LECO), were tested for their ability to detect differences in soil properties as a result of changed management practice. The changed management practices included (i) change from native vegetation or pasture to viticulture, (ii) bare soil to application of various composts and manures, (iii) bare soil to undervine mulch or undervine cover crop, and (iv) bare soil to permanent sward or cover crops in the midrow.

All of the soil tests were able to detect a significant difference in at least one instance (*i.e.* treatment or vineyard position at surface or subsurface depth) and at some sites, many of them detected significant differences. The MDS proved useful to detect changes in soil properties as a result of modified soil management practices at individual vineyard sites. It must be stated that these results need to be treated with a degree of caution as the trials were designed for other purposes and we selected particular areas from within those designs for our own purpose in this study.

For example, Sites 3 and 4 were two vineyards in Langhorne Creek, South Australia. At Site 3, all of the MDS variables detected significant differences between treatment (conventional and mulch) or vineyard position (undervine and midrow) in the surface soil. Even though the mulch had been applied several years earlier, total nitrogen and organic carbon were significantly higher in the treated areas than the conventional areas. The indicators of salinity and sodicity, conductivity, chloride, exchangeable sodium and ESP, were all significantly higher in the undervine soil than in the midrow soil, regardless of treatment. This site was known to have salinity issues and these results support that. In the subsurface soil, ESP was still significantly higher in the undervine than the midrow, but the reverse was observed with conductivity and chloride, which were higher in the midrow than undervine. At Site 4, conductivity at depth (35-45 cm) was the only variable that detected a significant difference, namely that the midrow subsurface had higher conductivity than undervine. The soil types were different at each site. Site 3 was clay loam whereas Site 4 was a duplex soil with sand over clay. This information should be useful to inform management decisions at each site.

In addition to examining each vineyard individually, the datasets per state were combined to look at the overall consistency of the MDS indicators. Few significant differences were evident for the South Australian dataset, but site was not able to be used a block in the analysis to account for differences in soil type between vineyards. In the Victorian dataset where soil type differences could be accounted for by blocking, all indicators detected significant differences between

treatment or vineyard position in surface soil properties, and several of them detected significant differences in subsurface soil properties. These results provide confidence that the MDS is capable of tracking changes in soil properties due to changed management practices and is therefore a valuable tool for soil monitoring purposes.

The soil biological test chosen as the best option for the MDS was microbial biomass measured using the chloroform fumigation extraction method. Unfortunately, this method proved to be not commercially available at present. Criteria used to choose the MDS included that the tests must be commercially available to growers and relatively inexpensive. An alternative method of measuring microbial biomass, substrate induced respiration, met with these criteria, but when compared with the chloroform extraction method, there was a very poor relationship between the two measures. Microbial biomass analysis was unavailable by either method for our second season of benchmarking (see Chapters 5, 6 and 8). So therefore we recommend that microbial biomass measured by substrate-induced respiration is not included in the MDS, but should the chloroform extraction become available commercially, it should be included.

Labile carbon and potentially mineralizable nitrogen (PMN) were two additional measures of soil biological activity that were tested in the Victorian trial sites. Although indirect measures of biology rather than the direct measure of microbial biomass, both proved useful to detect significant differences between treatments and vineyard position at the Victorian sites. Similarly, total nitrogen calculated as part of the LECO test for total carbon proved useful to detect differences. Therefore, our chosen MDS was amended to include labile carbon, PMN and total nitrogen.

Chapter 3: Industry endorsement and choosing a delivery model for an Australian soil monitoring system

3.1 Introduction

The key focus of the first year of the project was to review current indicator tests to identify those suitable for a minimum dataset (MDS) that can inform and monitor changes in vineyard management. The project team drew on available expertise and datasets within the viticultural research community and scientists engaged in soil health-related work being conducted outside the wine industry. The chosen MDS was then tested at sites within commercial vineyards to validate whether they could detect changes in soil properties in response to changes in management practice.

In addition to choosing and testing a MDS for monitoring soil quality in viticulture, a suitable data repository and delivery system to industry needed to be chosen. This chapter outlines the process taken.

3.2 Aims

To engage with key viticulturists to review the direction of the project and determine the activities and outcomes for the subsequent project years 2 and 3.
To identify a suitable delivery model and an appropriate database for an Australian viticulture soil monitoring system for use after the project.

3.3 Method

A Project Review Workshop was factored into the project at the end of Year 1 to allow industry to examine progress and suggest amendments. The workshop was held on 4th June 2012 in Adelaide to present examples of soil monitoring systems currently in use and to ensure that key industry stakeholders could review the direction of the project and endorse the activities and outcomes for the subsequent project years 2 and 3. The Workshop agenda is presented in Table 3.1.

The speakers and topics were:

- Jacky Edwards “Introducing GWRDC DPI 1101”
- Damien Griffante “Entwine – what is it?”
- Sally van der Zijpp “Sustainable Winegrowers New Zealand” (in absentia, presented by Rob Bramley)
- Pauline Mele “A web-based soil quality monitoring tool: www.soilquality.org.au “
- Ian Porter “The Cornell Soil Health Program”
- Toby Bekkers “McLaren Vale Sustainable Winegrowing Australia”
- Project team “Project progress to date and where to from here?”

The Workshop attendees were Richard Hamilton (Hamilton Viticulture), James Hook (DJ Growers), Goia Small (Treasury Wine Estates), Kerry de Garis (Constellation Wines), Andrew Clarke (Yering Station), Toby Bekkers (McLaren Vale Consulting), Damian Griffante (Entwine), Wendy Meech (soil surveyor and consultant), Amy Richards (Treasury Wine Estates), Mardi Longbottom (Australian Wine Research Institute), Hugh Hull (Geelong Wine Growers), Dean Lanyon (Arris Consulting), Pauline Mele (DEPI Victoria), Matthew Holdstock (Australian Wine Research Institute), Mike McCarthy (SARDI), Mark Krstic (AWRI), Colin Heinze (Taylors), Ashley Keegan (Food & Beverage Co.), Chris Brodie (Wingara), Dave Hansen (Treasury Wine Estates), Craig Thornton (Wingara), as well as a representative from GWRDC, Adrian Loschiavo, and the team members Jacky Edwards, Ian Porter, Rob Bramley, Danni Oliver, David Riches and Belinda Rawnsley.

Table 3.1. Agenda of the Project Review Workshop, Plant Research Centre, Waite Institute, Adelaide, June 4, 2012, held to review the direction of the project and determine the activities and outcomes for the subsequent project years 2 and 3, including identifying a preferred delivery model.

Start	***Topic***	***Presenter***
9.00	Arrival: Coffee and Tea	
	Setting the Scene	
9.30	Welcome, Background of Project to date	Jacky Edwards
9.45	Entwine and soil quality management	Damien Griffante
10.05	New Zealand Sustainable Winegrowers	Rob Bramley on behalf of Sally van der Zijpp
10:25	Questions and discussion	Facilitated
10.40	Coffee and Tea	
Successful Industry Programs: What's been done on soil quality parameters?		
11.00	Soilquality.org.au website and how it is used	Pauline Mele
11.15	Cornell Soil Health Program	Ian Porter
11.30	McLaren Vale Generational Farming Program	Mike McCarthy
11:45	Discussion on usefulness of programs for industry including what benefit it provides industry (e.g. 1. Environmental stewardship, 2. Improving vineyard performance, 3. Soil sustainability)	Facilitated
12.30	Lunch	
The Proposed Model and What to do Now		
1.30	What data has been collected in the project and how useful?	Ian Porter / Belinda Rawnsley
1.45	Practicalities for industry	Facilitated
2.15	How will industry use the information	Facilitated
2.45	The Project (what is planned going forward?)	Jacky Edwards
2:55	Reflection and where to from here	Facilitated
3:30	Close	

3.4 Results

The Workshop talks are presented in Appendix 1.

The Workshop discussion sessions can be summarised as follows:

Workshop participants emphasised that it can be a challenge for growers to collect good quality data. Any system needs to be simple and packaged well. Companies prioritise issues to be addressed based on the degree of the constraints; the auditor focuses on these. In order for industry uptake, soil quality management needs to be linked to a benefit, not just a compliance requirement. Soil testing costs should be minimised.

Industry standards for benchmarking soil quality are lacking. Sampling methodology should be standardized and timed to coincide with peak root growth to capture biological activity, yet avoid intensive workload times such as the growing season and vintage.

Industry participants generally agreed that a suite of soil measurements for on-going monitoring would be useful for the industry, with the following stipulations:

1. Need detailed guidelines about how (including location, depth and frequency) and when sampling is to be done
2. Need detailed guidelines about how soil measurements are to be done
3. Clarity needed about regional thresholds
4. Soil measurements should be kept simple and inexpensive

Some participants expressed the need for guidance and information about what the numbers mean, and what are the thresholds that indicate constraints. There were private consultants in attendance and it was clarified that this role was outside the scope of this project. There was a clear expectation that the project team would deliver the system, but after that, consultants and advisers would work with growers to conduct soil sampling and analyses, and provide the interpretation of results and how to make the most of the information to inform vineyard management.

Industry comments:

- Keep parameters simple and consistent
- Provide information to the broader industry e.g. suitable for a range of large-scale and boutique growers, consultants
- Grape and wine quality measurements are separate from this project and too difficult to measure and correlate so keep to soil quality indicators
- Baseline measurements wanted
- Practical and simple measurements are important and the project has started this, well done
- The information will be useful for monitoring over time and managing constraints of individual vineyards
- Concise format to work with
- Getting information out to growers and adoption is critical
- Environmental management is in place, constraints have major influence on decision-making
- Good to see soil quality website. Can see this linked in with wine industry so all at one site
- The chemical factors are well understood by growers, but the physical and biological are not.

Participant feedback about the Project:

Participants were interested and impressed. They wanted simple, easy to access, inexpensive tests. Simplicity and practicality were stressed as being very important. They were pleased to see the development of a basic set of indicators and standardized methodology, with consistency in the approach. They were pleased with the progress, keen for the project to continue and get such a system out to industry. They identified that it would be challenging to provide a system robust enough to serve both small vineyards and large corporate vineyards and all the interest levels of industry. They thought the McLaren Vale story provided a good example of how to engage with small growers. The soilquality.org.au website was highly regarded and was voted as a suitable host for an Australian viticulture soil monitoring system. The team was advised to concentrate resources on developing regional databases of soil properties, and not to attempt correlating soil variables with vine parameters or wine quality.

3.5 Discussion

Data collected from the nine paired sites were presented to demonstrate how this information could be applied by growers and their consultant advisers, and a number of delivery models were presented and discussed. The overwhelming feedback was that industry were impressed with what was presented, that they really liked the soilquality.org.au web-based delivery model and believed that such a service tailored for viticulture would be utilised. It was noted that there is a definite need for standardized, robust soil tests that can be used by growers and consultants, as there is too much confusion at present on what tests are reliable. The participants debated whether the outputs of this project could be incorporated into the Entwine system, but due to the lack of any specific requirements in Entwine around soil management, it was unlikely that this was practical.

The direction for Years 2 and 3 of the project was to concentrate on collecting benchmark soil property data of key regions to populate a database for future use. Participants gave a strong message that significant project resources should not be directed into collecting wine or vine performance data, as this would dilute the emphasis on developing regional soil databases.

It was decided that www.soilquality.org.au would be approached to host the viticulture soil monitoring system and that this would be delivered as part of AWGA project DPI 1102 led by Dr Pauline Mele. On 23 October 2012, a follow-up Workshop titled “A soil quality web-based monitoring & decision support tool for the Grape & Wine industry” was conducted in Melbourne as part of DPI 1102 to engage industry members and the project team with Dan Murphy and Andrew Wherrett, the convenors of the soilquality website, and explore expanding their system to incorporate a Grape and Wine module. Subsequently, a data spreadsheet was developed and circulated to our project team for collating MDS datasets in a format compatible with regional benchmarking using the soilquality.org.au delivery system (see Appendix 5).

Chapter 4: Using the minimum dataset to identify and manage a known or unknown constraint e.g. salinity

4.1 Introduction

In 2013 and 2014, demonstration trials and a number of paired sites were set up to see if the MDS could identify known and any unknown constraints to soil quality and grapevine performance in the vineyard. Prior to and during this project, salinity has been recognised as an increasing problem in Yarra Valley soils, so two field sites were set up to determine if the MDS could help provide information to assist management of salinity and to obtain economic data of the impact of salinity in the Yarra Valley. Additionally, through a series of paired sites set up during the benchmarking studies, the MDS was used to see if it could identify the key major constraint to vineyard production across the Yarra Valley. The project also linked with visits by experts, such as Dr Mike McCarthy, organised by the Yarra Valley Wine Growers Association and AWRI to raise awareness and provide advice (Figure 4.1).

In this chapter, we discuss three studies based in the Yarra Valley of how the soil indicators in the minimum dataset (MDS) can help growers identify and manage a constraint, such as salinity.



Figure 4.1. Yarra Valley grapegrowers attending a field day featuring Dr Mike McCarthy, SARDI, who advised on how to identify and manage salinity in the vineyard.

4.2 Aim

To demonstrate the use of the MDS soil indicators to identify and manage an unknown constraint *i.e.* salinity.

4.3 Case Study 1: Using the MDS to identify an unknown constraint.

4.3.1 Method

In order to obtain a representative sample of vineyard soils for benchmarking the Yarra Valley region (see Chapter 8), participating growers were asked to nominate either a single site representative of their vineyard, or paired sites where we could compare the soil properties from a high performing section of a vineyard with those from a poor performing section of the same vineyard. In nearly all cases growers were also unaware of what soil quality constraint was contributing to the poorer productivity. As a result, in 2013 and 2014 we collected soils from 30 paired sites within the Yarra Valley region. The combined dataset was analysed to examine

whether there were any significant differences between soil properties from the poor and good sites that might identify a constraint in common that was affecting vine performance.

Soil sampling
Soil samples were collected from two paddock positions per site: undervine and in the adjacent midrow The soil sampling methodology has been described in Chapter 1. The soils were analysed for the MDS as described previously. In 2013, the soil biological analyses, microbial biomass (MB CFE), labile carbon and PMN, were conducted by the University of Western Australia. In 2014, the University of Western Australia was no longer offering the MB and PMN testing and there was no other commercial laboratory accredited to do the tests from a region with quarantine issues, such as the Yarra Valley (phylloxera and potato cyst nematode). In 2014, labile carbon was analysed by a commercial laboratory. All chemical analyses were conducted by the same commercial laboratory in both years, and physical assessments were performed in-house by project team members.

Statistical analysis
The objective was to test whether there were any significant differences between the poor and good sites with respect to the MDS variables: MB, labile carbon, PMN, organic carbon, total nitrogen, pH_{water}, pH_{CaCl2}, conductivity (EC), chloride, exchangeable cations calcium (Ca), potassium (K), magnesium (Mg) and sodium (Na), CEC, ESP, slaking, dispersion and consistency.

The MDS variables from the 30 paired sites were analysed using analysis of variance in the GenStat® statistical package (GenStat® release 16.1, Copyright 2008, VSN International Ltd.). The treatment structure was specified as *Trt*PadPos* where the factors were *Trt:* poor or good, and *PadPos:* undervine or midrow. The blocking structure was vineyard. Physical variables were analysed using the Friedman Rank Test where *Trt*PadPos* was combined as a single factor giving four distinct classes: good UV, poor UV, good MR, poor MR.

Least significant differences (5% level) were used to separate the means, subject to significant F-tests.

Histogram and quantile plots of residuals, and graphs of residuals against fitted values, were used to check ANOVA distributional assumptions of normality and constant variance.

4.3.2 Results and Discussion
The MDS variables were able to detect significant differences between a number of soil properties from the good and poor sites in the Yarra Valley dataset (Table 4.1). In general, the constraint at the site was unknown prior to testing. Mean conductivity (EC), chloride, exchangeable sodium and ESP were either significantly or highly significantly elevated in the poor sites compared to the good sites in both the surface (0-15 cm) and sub-surface (35-45 cm) soil. In general, slaking was significantly higher in the surface soils from undervine. These properties are indicators of salinity and sodicity and although at some sites the values exceeded the threshold values, the mean values for both the poor and good sites presented in Table 4.1 are within the acceptable range for viticulture (eg. Cl < 175 ppm, ESP < 6%). The poor sites in this study comprise visually healthy vines producing fruit which was considered by the growers to be appropriate for wine production; however a future study is needed to determine if some of this fruit could be affecting wine quality. Grower experience told them that these areas were consistently under-performing in relation to other areas within the block. Analysis of the combined dataset clearly identified that a significant number of the poor performing areas have increased salinity and sodicity compared with the high-performing areas. The results also provide the participating growers with an early warning to take some corrective action before the situation worsens. This study of paired sites demonstrates the usefulness of the MDS for identifying a constraint such as salinity.

Table 4.1. Mean values for surface (0-15 cm) and sub-surface (35-45 cm) soil properties measured at 30 Yarra Valley paired sites in 2013 and 2014 and results of tests of the significance[A] of the between-pair difference (analysis of variance; Friedman's test for physical data). Good = area identified by grower as consistently high-performing, Poor = area identified by grower as consistently under-performing

Property	Units	Pair	0-15 cm		35-45 cm	
			Undervine	Midrow	Undervine	Midrow
EC	dS/m	Good	0.12	0.08	0.07	0.06
		Poor	0.19	0.11	0.10	0.09
			*	*	*	*
pH ($CaCl_2$)		Good	5.8	5.8	4.7	4.6
		Poor	5.8	5.7	4.7	4.6
			NS	NS	NS	NS
pH (H_2O)		Good	6.5	6.5	5.6	5.4
		Poor	6.5	6.4	5.4	5.4
			NS	NS	NS	NS
Cl	mg/kg	Good	70.8	24.0	52.5	25.7
		Poor	147.9	49.8	101.8	83.9
			*	*	**	**
Total N	%	Good	0.25	0.26		
		Poor	0.24	0.26		
			NS	NS		
Total OC	%	Good	3.15	3.21		
		Poor	3.13	3.41		
			NS	NS		
Exch. Ca	meq/100g	Good	6.20	6.11	2.14	1.73
		Poor	6.04	5.91	1.80	1.58
			NS	NS	NS	NS
Exch. K	meq/100g	Good	0.27	0.20	0.11	0.12
		Poor	0.31	0.23	0.12	0.12
			NS	NS	NS	NS
Exch. Mg	meq/100g	Good	1.73	1.56	1.35	1.80
		Poor	1.92	1.79	1.54	1.86
			NS	NS	NS	NS
Exch. Na	meq/100g	Good	0.07	0.05	0.10	0.11
		Poor	0.09	0.09	0.15	0.14
			*	*	**	**
CEC	meq/100g	Good	8.0	7.8	3.6	3.7
		Poor	8.2	7.9	3.6	3.6
			NS	NS	NS	NS
ESP	%	Good	0.88	0.71	2.74	2.99
		Poor	1.21	1.04	3.96	4.06
			**	**	**	**
Labile C	mg/kg	Good	388	439		
		Poor	406	418		
			NS	NS		

Property	Units	Pair	0-15 cm		35-45 cm	
			Undervine	Midrow	Undervine	Midrow
PMN		Good	30.87	43.38		
		Poor	30.98	46.32		
			NS	NS		
MB (SIR)		Good	176	211		
		Poor	146	236		
			NS	NS		
Consistency	0-7	Good	2.5	2.4	2.5	2.4
		Poor	2.6	2.4	2.5	2.7
			NS	NS	NS	NS
Dispersion	0-16	Good	2.6	2.3	2.5	2.6
		Poor	2.7	2.3	2.4	2.5
			NS	NS	NS	NS
Slaking	0-4	Good	2.4	2.4	2.4	2.4
		Poor	2.9	2.4	2.4	2.7
			**	NS	NS	NS

[A]Significance is denoted by NS, not significant, * P < 0.05, ** P < 0.01 based on Fisher's LSDs at 5%. Yellow highlighting indicates significant differences.

4.4 Case Study 2. Using the MDS to select appropriate action to manage a constraint

4.4.1 Background

A rehabilitated site previously affected by salinity and an adjacent site monitored during this project gave the industry a unique opportunity to monitor the impact of remedial treatments to solve a salinity issue compared to a site without any remedial action. It also enabled detailed economic data to be obtained to identify the cost of a major soil constraint. i.e. salinity, to the industry in the Yarra Valley.

Prior to the project in 2008, salinity was identified in a Cabernet Sauvignon vineyard near Yarra Glen as a constraint impacting vine performance. The soil was a grey clay loam. There were two affected blocks of grapevines adjacent to each other in the vineyard, Block A and Block B, and the decision was made to remediate Block B in autumn 2009. Feather drains were installed across the block, draining to the lowest point of the block into a channel filled with compost and mole drains (Figure 4.2). This allowed the salt to wash out and flow away from the site. Block A was left unchanged.



Figure 4.2. Installing feather drains in Block B, Yarra Valley.

In order to track the effectiveness of the drain installation, soils were sampled from across both blocks in April 2010, 2012 and 2014, and analysed for the basic suite of chemical tests by a commercial laboratory. Table 4.2 presents the values for conductivity (EC), chloride, exchangeable sodium and exchangeable sodium percentage (ESP).

Table 4.2 Values for soil salinity properties measured from two adjacent vineyard blocks in the Yarra Valley in April 2010, 2012 and 2014. Block B had been remediated with the installation of drains whereas Block A had not. Note: these results were obtained from the grower adviser and exchangeable sodium values for 2014 were not provided.

	April 2010		***April 2012***		***April 2014***	
Soil property	**Block A (poor)**	**Block B (good)**	**Block A (poor)**	**Block B (good)**	**Block A (poor)**	**Block B (good)**
EC (dS/m)	0.73	0.35	0.68	0.23	0.86	0.15
Chloride (mg/kg)	798	133	701	179	1010	10
Exch. Na (meq/100g)	2.08	0.75	1.26	0.42	*	*
ESP (%)	8.8	3.9	6.0	2.1	12.0	2.4

Both blocks had similar levels of EC, chloride, exchangeable sodium and ESP prior to the drain installation (data not provided). It is clear that these properties were all considerable lower in Block B than Block A after the installation of the drains, and more significantly, from 2012 to 2014, the chloride continued to decrease in Block B, but together with ESP, increased in Block A. This posed the question on what management action would be cost-effective in Block A, and also whether the loss in production supported the installation of similar drainage for the salinity issue.

Our soil sampling methodology and MDS were used to provide information to help inform this decision.

4.4.2 Method

The salinity was evident as a gradation down the slope of Block A. Vines at the lower end of the block were severely affected, whereas those at the top end of the block appeared visually healthy. We chose to monitor three panels along a row running the full length of the block. The health of the vines in Panel A were apparently unaffected and healthy; the vines in Panel B were

just beginning to show signs of salt damage, and the vines in Panel C were badly affected by salt (Figure 4.3). Each panel consisted of 5 vines. Fruit was harvested in 2013 and 2014. Bunch numbers and weights were recorded, as were the numbers of bunches that had been dropped prior to harvest due to elevated salt levels (2013 only). Berry samples were collected and analysed for pH, TA (2013 only), Brix (2014 only), sodium and chloride. Four weeks after harvest, soils were sampled from two depths undervine and in the midrow of each panel and analysed for the MDS as described (Chapter 1). A native area just outside the vineyard boundary was also sampled in 2013 for comparative purposes, but not repeated in 2014.

4.4.3 Results and Discussion

Table 4.3. Fruit data (bunch numbers, yield, average bunch weight, pH, Brix, sodium and chloride content) from Cabernet Sauvignon, Block A, Yarra Valley, at harvest 2013 and 2014,

	2013			*2014*		
	Panel A Healthy	Panel B Moderate	Panel C Severe	Panel A Healthy	Panel B Moderate	Panel C Severe
Fruit						
Bunches harvested	134	87	82	135	144	88
Bunches dropped	0	10	9	n/a	n/a	n/a
Yield (kg/panel)	13.92	5.68	4.48	9.92	10.99	4.44
Average bunch weight (g)	103.9	65.4	54.6	73.5	76.3	50.5
Juice						
pH	3.5	3.3	3.3	3.7	3.8	3.5
Brix (%)				23.1	22.3	21.5
TA	7.22	6.05	6.05			
Na (ppm)	34	36	41	29	32	100
Cl (ppm)	0	332	540	106	510	810

Impact on yield and berry quality

Yield was severely impacted by salinity over the two seasons (Table 4.3). Panel B, although showing only slight visual symptoms of salt damage, had similar numbers of bunches dropped and similar yields to the severely-affected vines in Panel C in 2013. The yield and average bunch weight of panels B (moderate) and C (severe) were less than half that of the healthy panel in 2013. In 2014, the yield and bunch weight of vines in panel C (severe) were still less than Panel A (healthy), but Panel B (moderate) was comparable with the healthy panel in this year.

Berry quality was also affected (Table 4.3). In 2013, pH and TA were reduced in Panels B and C (salt-affected). In 2014, pH was reduced in Panel C (severe) and there was a gradual reduction in Brix from Panel A (healthy) through to Panel C (severe). In both years, there was a gradual increase in sodium and steep increase in chloride from Panel A (healthy) through to Panel C (severe). Although yield and bunch weight for Panel B (moderate) were higher in 2014, chloride levels in the juice of all fruit almost doubled from 2013 to 2014.

Differences in soil properties

Only the MDS properties that were affected by salinity and sodicity are presented here (Table 4.4). The others, such as soil pH (data not shown), were relatively uniform across the site. There was no replication and therefore no analysis was conducted. A nearby native site was sampled in 2013 for comparison.

All of the salinity and sodicity indicators (electrical conductivity, sodium, chloride and ESP) were much higher in the severely affected vines (Panel C) than the healthy vines in Panel A, as expected. Of particular interest were the undervine and midrow chloride levels in the surface (0-15 cm) soils. The accepted threshold for soil levels that produce acceptable fruit quality for chloride in viticulture is 175 ppm. Panel C (severe) had extremely high levels of chloride in both

the midrow and undervine, more than seven times the threshold level. Panel A (healthy) had comparatively low levels of chloride in both midrow and undervine, but the undervine chloride was still above the threshold level. Panel B (moderate), which appeared relatively healthy although yield was reduced, had chloride levels comparable with the Panel C (severe) undervine, but much lower levels in the midrow.

There were also differences evident in electrical conductivity, sodium, chloride and ESP between 2013 to 2014. In the undervine surface soil, Panel C (severe) did not change. Panel B (moderate) levels reduced slightly, perhaps due to rain flushing the system. Panel A (healthy) levels, however, increased in 2014. The midrow levels of electrical conductivity and chloride dropped in 2014, but sodium levels doubled. In the subsurface (35-45 cm), chloride appeared to be increasing undervine, but not in the midrow. Panel A (healthy) undervine soil increased in chloride, sodium and ESP from 2013 to 2014. This is evidence that the 'good' area (Panel A) is becoming affected by salt, even though it is not yet visually affecting the vines or reducing yield.

Use of the MDS demonstrated that soils can be monitored to detect an increasing trend in salinity before there is a noticeable impact on vine performance. Direct measures from the vines, such as petiole and berry analyses (data not shown), provide an insight into how much of the salt is being taken up by the vine. The MDS is more informative about where the salt is in the soil. For example, it was surprising to find in 2013 that the surface soil chloride level undervine in the moderate panel (B) was just as high as in the severe panel (C). The midrow chloride levels were very different, however, and helped explain why vines in the severe panel (C) were dying, yet vines in the moderate panel (B) were only beginning to show signs of salt damage. Grapevine roots are not restricted to the undervine but are able to grow into the midrow where the salinity was much less severe in the moderate panel (C). The chloride level in the midrow of the severe panel (C) was just as high as the undervine level.

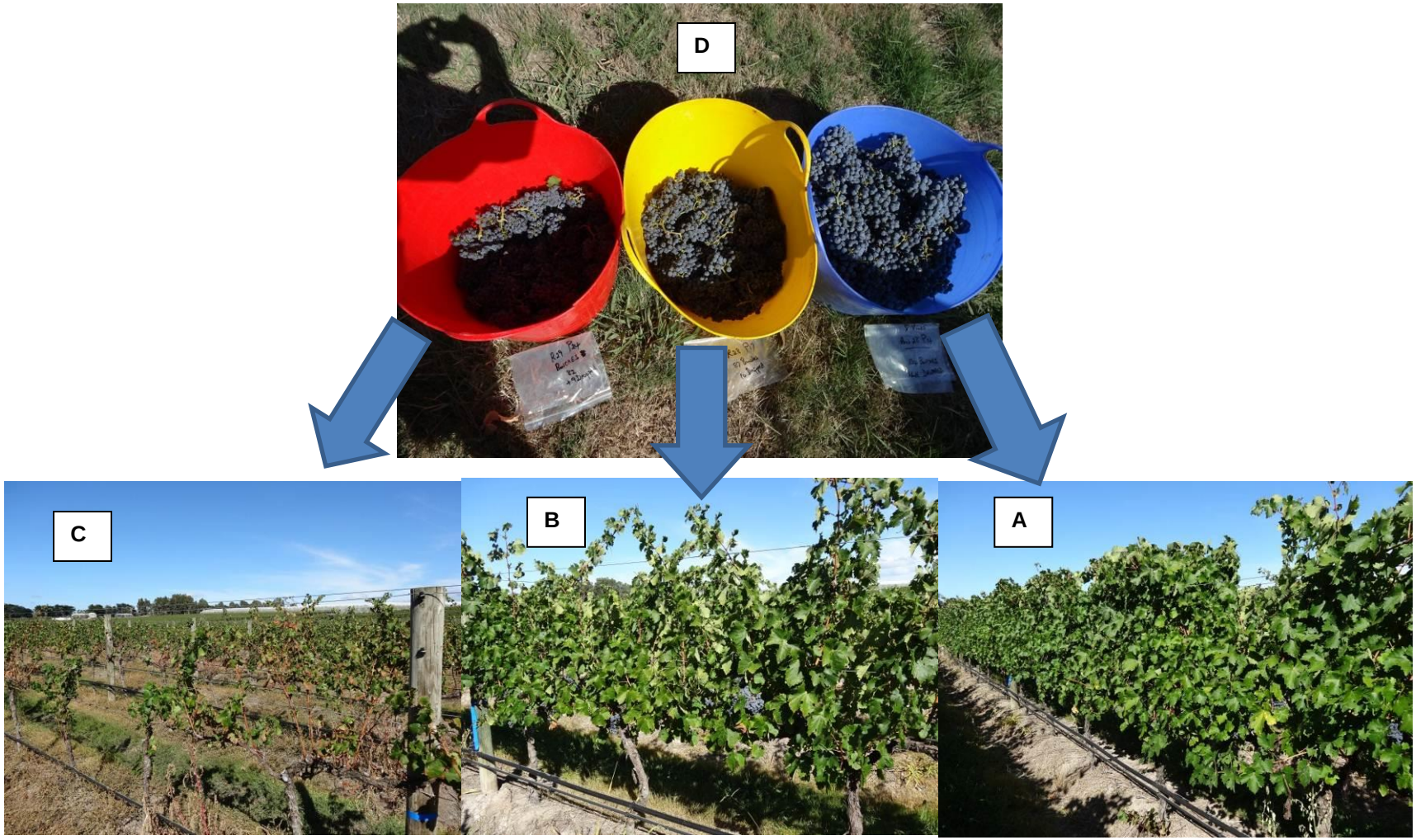


Figure 4.3. Three panels along the same row chosen to monitor the effect of salinity in Block A, Yarra Valley. A: Panel A, healthy vines unaffected by salinity; B: Panel B, vines starting to show signs of salt damage; C: Panel C, vines showing severe salt damage; D = respective harvests per panel in 2013.

Table 4.4. Selected soil properties from the MDS for the soils sampled from salt-affected Cabernet Sauvignon Block A, Yarra Valley. Sampling depths were surface (0-15 cm) and subsurface (35-45 cm). Sampling times were 4 weeks post-harvest in 2013 and 2014. UV = undervine; MR = midrow. (Native) refers to nearby native site.

	pH $CaCl_2$	*pH H_2O*	*EC dS/m*	*CEC meq/100g*	*Cl mg/kg*	*Exch. Ca meq/100g*	*Exch. K meq/100g*	*Exch. Mg meq/100g*	*Exch. Na meq/100g*	*ESP %*
0-15 cm										
2013										
(Native)			(0.10)		(90)				(<0.1)	(1.1)
Panel A (Healthy) UV	6.7	7.3	0.32	10.4	178	9.0	0.3	1.1	<0.1	0.5
Panel B (Moderate) UV	6.3	6.7	1.18	10.0	1355	6.7	0.3	2.6	0.4	3.6
Panel C (Severe) UV	6.5	6.8	1.18	12.8	1383	9.6	0.3	2.6	0.3	2.7
2014										
Panel A (Healthy) UV	6.3	6.8	0.46	9.0	416	7.5	0.2	1.2	0.1	0.6
Panel B (Moderate) UV	5.9	6.3	0.73	8.5	731	5.5	0.2	2.5	0.2	2.5
Panel C (Severe) UV	6.1	6.5	1.01	12.2	1261	8.6	0.3	3.1	0.3	2.3
2013										
Panel A (Healthy) MR	6.4	7.1	0.10	6.5	39	5.5	0.1	0.8	<0.1	0.8
Panel B (Moderate) MR	6.4	6.8	0.29	6.2	273	5.1	0.1	1.0	<0.1	0.8
Panel C (Severe) MR	6.6	6.9	1.12	10.2	1526	6.7	0.3	2.8	0.5	2.7
2014										
Panel A (Healthy) MR	6.4	7.0	0.07	7.2	5	6.0	0.1	1.0	0.1	0.7
Panel B (Moderate) MR	6.2	6.8	0.07	7.0	42	5.4	0.1	1.4	0.1	0.7
Panel C (Severe) MR	6.0	6.5	0.58	7.7	727	4.7	0.2	2.7	0.2	2.8
35-45 cm										
2013										
(Native)			(0.05)		(69)				(<0.1)	(2.1)

Panel A (Healthy) UV	5.3	6.1	0.14	3.3	99	2.4	0.1	0.8	<0.1	1.5
Panel B (Moderate) UV	4.5	5.1	0.39	2.4	492	1.0	0.1	1.3	0.1	5.4
Panel C (Severe) UV	4.7	5.2	0.66	5.6	704	2.7	0.2	2.3	0.4	7.8
2014										
Panel A (Healthy) UV	4.5	5.1	0.16	2.5	139	1.4	0.1	0.9	0.1	2.0
Panel B (Moderate) UV	4.4	5.1	0.34	2.9	436	1.1	0.1	1.5	0.1	4.6
Panel C (Severe) UV	4.8	5.4	0.60	5.6	914	2.9	0.2	2.2	0.3	4.5
2013										
Panel A (Healthy) MR	4.5	5.1	0.12	3.3	78	1.8	0.1	1.4	<0.1	1.5
Panel B (Moderate) MR	4.6	5.2	0.28	3.3	303	1.4	0.1	1.6	0.2	5.2
Panel C (Severe) MR	4.9	5.3	0.83	4.8	1319	2.1	0.2	2.0	0.5	11.4
2014										
Panel A (Healthy) MR	4.4	5.1	0.09	3.5	23	2.0	0.1	1.4	<0.1	1.4
Panel B (Moderate) MR	4.5	5.1	0.30	3.9	331	1.7	0.1	2.0	0.1	3.3
Panel C (Severe) MR	4.5	5.0	0.91	4.5	1012	1.8	0.2	2.3	0.3	5.6

4.5 Case Study 3: Using the MDS to monitor management of a constraint

4.5.1 Aim

To monitor the effects of applying calcium in the form of gypsum and hot lime to alleviate salinity in a Pinot Noir vineyard

4.5.2 Method

A salt-affected Pinot Noir site near Coldstream showed increasing salinity in the soil profile as the vineyard sloped downhill towards a dam. The top of the vineyard furthest from the dam was unaffected. The soil type was duplex clay loam (Figure 4.4). A trial was designed to investigate whether calcium incorporated into the soil would displace the sodium and improve vine health and grape quality. The trial also evaluated timing of the lime applications to determine the effect of winter rains on their ability to flush out the salt. Two forms of calcium were trialled: gypsum ($CaSO_4$) and hot lime (CaO). (A third treatment, chicory, a deep-rooted salt tolerant cover crop, was originally included but despite two attempts at establishment, did not grow.)



Figure 4.4. Soil profile of the Pinot Noir vineyard, Yarra Valley.

Trial design and treatments

The trial was established as a replicated block design, with apparently unaffected 'no salt' plots within the same rows but outside the replication (Figure 4.5). Each replicate plot consisted of three consecutive panels of 5 vines per panel plus the associated midrows on either side of the vines. There were four replicates per treatment. The hot lime and gypsum treatments were broadcast and rotary-hoed into the midrows (Figure 4.6). The incorporated soil was delved undervine in 2014. There were two applications: the first in early spring of 2012 just after budburst and the second was post-harvest in the autumn 2013. The timing of the second application was to allow autumn and winter rains to flush the displaced salt out of the system.

The treatments were no salt (outside the blocking structure), untreated salt-affected control, hot lime applied twice, gypsum applied twice. The rates of application were 2.5 t/ha hot lime (applied as 9 kg per plot) and 6.0 t/ha gypsum (applied as 21.6 kg/plot). The same rate was applied at each application.



Figure 4.5. Trial design for Pinot Noir salt-affected vineyard, Yarra Valley. Blue = chicory, which did not establish and was excluded from the sampling; Pink = gypsum; Yellow = hot lime; White (U) = untreated salt-affected control. The no salt controls were in the top half of each row. MR= midrow..



Figure 4.6 Gypsum and hot lime treatments being applied to the salt-affected Pinot Noir vineyard, Yarra Valley, in spring 2012.

Soil sampling
Baseline measurements from the surface depth (0-15 cm) undervine were taken for electrical conductivity, exchangeable sodium, chloride and ESP in early October 2012 prior to treatment application. Repeat samples were collected and analysed in 2014 in order to monitor change in salinity over the time of the trial in both parts of the vineyard in the absence of any treatment.

Soils were sampled and analysed from all trial plots except the no salt plots at budburst in September 2013. This time was chosen to see whether the treatments had altered the salinity either undervine or midrow prior to the new growing season. Soils were sampled and analysed from all trial plots at the end of the trial in April 2014 four weeks after harvest. Surface soils only were sampled due to difficulties found with sampling the heavy clay subsoil.

Additionally, soils were sampled from a single plot from the no salt and untreated salt areas at both depths (0-15 cm and 35-45 cm) from undervine and midrow as part of the Yarra Valley benchmarking in May 2013 and April 2014.

Vine performance
Petioles were sampled and analysed for calcium, chloride and sodium at flowering (November 2013) and veraison in both seasons (February 2013 and 2014) to monitor the uptake of these cations by the vines. A sample consisted of 100 petioles taken from the vines in the centre panel of the plot.

In March 2013 and 2014, the centre panel of each trial plot was harvested and yield data recorded (bunch number and weight). Berry samples were analysed for potassium, sodium and chloride to monitor uptake of these cations into the berries. Ten bunches per plot were crushed and fermented with yeast, and the resultant fermented juice analysed for potassium, sodium and chloride to monitor uptake into the wine.

Statistical analysis
The objective was to test whether there were any significant differences between the treatments with respect to the MDS variables relating to salinity i.e. electrical conductivity, exchangeable cations, ESP, chloride, and pH. The MDS variables were analysed using analysis of variance in GenStat® v. 16.1.

Histogram and quantile plots of residuals, and graphs of residuals against fitted values, were used to check ANOVA distributional assumptions of normality and constant variance.

Least significant differences (5% level) were used to separate the means, subject to significant F-tests.

4.5.3 Results and Discussion

Changes in vineyard soil properties
In the period from 2012 to 2014, the undervine surface soil chloride of both no salt and salt plots increased significantly (P<0.01) to levels well exceeding the desirable threshold of 175 ppm in soil, with an equivalent decrease in exchangeable sodium and ESP. The conductivity (EC) values in the untreated salt plots also demonstrated a highly significant increase. The increase in electrical conductivity and chloride indicate that the salinity issue is becoming worse in this vineyard, but the decrease in exchangeable sodium suggests that sodicity is becoming less important (Table 4.5).

Table 4.5. Mean values for the soil salinity and sodicity indicators from the MDS (conductivity (EC), chloride (Cl), exchangeable sodium (Exch. Na) and exchangeable sodium percentage (ESP)) in surface (0-15 cm) soil sampled undervine from no salt and untreated salt plots in 2012 and 2014 and results of tests of the significance[A] of the between-year difference (analysis of variance).

	Year	*EC dS/m*	*Cl mg/kg*	*Exch. Na meq/100g*	*ESP %*
No salt	2012	0.095	29	2.36	18.23
No salt	2014	0.243	315	0.15	1.44
		NS	**	**	**
Salt unamended	2012	0.121	67	2.44	18.63
Salt unamended	2014	0.340	405	0.15	1.74
		**	**	**	**

[A]Significance is denoted by NS, not significant, * P < 0.05, ** P < 0.01 based on Fisher's LSDs at 5%.

Table 4.6. Values of the soil salinity and sodicity indicators from the MDS (conductivity (EC), chloride (Cl), exchangeable sodium (Exch. Na) and exchangeable sodium percentage (ESP)) measured in the no salt and untreated salt sites from the Pinot Noir salt-affected vineyard during the 2013 and 2014 Yarra Valley soil benchmarking. Soil was sampled at two soil depths, 0-15 cm and 35-45 cm, from undervine and midrow. The regional average values are included for comparison.

	No salt				*Salt*					
	Undervine		*Midrow*		*Undervine*		*Midrow*		*Region average*	*Region average*
Property	*2013*	*2014*	*2013*	*2014*	*2013*	*2014*	*2013*	*2014*	*UV*	*MR*
0-15 cm										
EC dS/m	0.11	0.24	0.06	0.04	0.12	0.14	0.10	0.05	0.18	0.14
Cl mg/kg	90	315	45	39	133	405	108	53	152	104
Exch. Na meq/100g	0.10	0.15	<0.01	<0.01	0.17	0.15	<0.01	<0.01	0.09	0.08
ESP %	1.6	1.4	1.0	1.1	3.4	1.7	1.0	1.1	1.2	1.1
35-45 cm										
EC dS/m	0.07	0.09	0.06	0.09	0.15	0.33	0.09	0.11	0.11	0.10
Cl mg/kg	47	224	61	108	54	172	119	218	94	104
Exch. Na meq/100g	<0.01	0.10	0.18	0.21	0.23	0.18	0.25	0.61	0.13	0.13
ESP %	3.1	2.8	5.0	4.8	8.8	5.4	8.5	11.8	3.5	3.8

The benchmarking data indicated that undervine levels of electrical conductivity, chloride and exchangeable sodium are increasing across the whole vineyard site at both depths (Table 4.6). For the midrow, in the no salt section of the vineyard all variables remained stable in the surface soil at levels below the regional average, but the chloride levels at depth increased. In the salt affected site, midrow surface levels, although higher than the no salt site, were still comparable to or lower than the regional average, but at depth conductivity, chloride and exchangeable sodium were all higher than the regional average.

Table 4.7 Means of MDS variables (pH, conductivity, chloride, exchangeable cations) measured in the untreated salt control, gypsum and hot lime treatments from the Pinot Noir trial in September 2013 (budburst). Two way analysis of variance was used to detect significant differences in variables analysed in samples taken from either undervine or the midrow at two soil depths.

	Undervine			**Midrow**			
Soil Property	**Untreated**	**Gypsum**	**Hot Lime**	**Untreated**	**Gypsum**	**Hot Lime**	**Sig[A]**
0-15 cm							
pH ($CaCl_2$)	5.9	5.8	5.9	5.7	5.7	6.9	Int
EC dS/m	0.171	0.220	0.139	0.156	0.730	0.229	Trt, Pos
Chloride mg/kg	91	77	75	82	94	132	NS
Exch. Ca meq/100g	10.18	10.04	10.10	8.93	11.61	14.15	Trt
Exch. K meq/100g	0.28	0.22	0.35	0.11	0.12	0.19	Pos
Exch. Mg meq/100g	4.16	3.67	3.99	3.60	2.44	3.46	Trt, Pos
Exch. Na meq/100g	0.60	0.51	0.54	0.39	0.36	0.48	NS
ESP (%)	4.1	3.8	3.6	3.0	2.8	2.9	NS
35-45 cm							
pH ($CaCl_2$)	4.4	4.4	4.4	4.3	4.3	4.3	Pos
EC[B] dS/m	0.128	0.151	0.107	0.078	0.154	0.109	NS
Chloride mg/kg	156	130	116	73	94	82	NS
Exch. Ca meq/100g	1.78	2.19	1.84	1.81	2.85	2.11	Trt
Exch. K meq/100g	0.07	0.08	0.05	0.12	0.18	0.13	Pos
Exch. Mg meq/100g	2.40	2.38	2.23	2.61	4.21	3.53	Pos
Exch. Na meq/100g	0.75	0.70	0.64	0.53	0.75	0.76	NS
ESP (%)	15.0	13.4	11.5	8.0	9.1	11.7	Pos

[A]Significance at 5%: Int = two way interaction, Trt = treatment main effect, Pos = position main effect. NS = no significant interaction or main effect.

Despite gypsum and hot lime having some effects on electrical conductivity and exchangeable cations calcium and magnesium in soil, they had no significant effect on the key factors of chloride, exchangeable sodium and ESP (Table 4.7). There was a trend towards reduced ESP in the subsurface for the hot lime treatments applied undervine. There was a significant increase (main effect) in electrical conductivity in the surface soil caused by gypsum, and, as expected, the calcium-based treatments increased exchangeable calcium. It was also notable that there was a decrease in exchangeable potassium undervine compared to the midrow for the three treatments.

By the end of the trial, the double application of gypsum had elevated electrical conductivity but reduced ESP compared to the untreated salt areas in the surface depth undervine (Table 4.8), indicating that this treatment had increased salinity but reduced sodicity. There were no significant improvements in measures of soil salinity in any of the treatments.

Table 4.8. Mean values of soil salinity indicators (electrical conductivity (EC), chloride (Cl), exchangeable cations, exchangeable sodium percentage (ESP)) from soil sampled from the surface depth (0-15 cm) undervine from the treated plots in April 2014 in the Pinot Noir salt-affected vineyard in the Yarra Valley. The treatments were no salt, untreated salt, gypsum (applied twice), hot lime (applied twice).

	No salt	*Untreated salt*	*Gypsum*	*Hot Lime*
EC dS/m	0.243 a	0.340 b	0.728 c	0.276 ab
Cl mg/kg	315 a	405 b	420 b	378 ab
Exch. Ca meq/100g	6.70 a	6.00 a	7.71 a	7.24 a
Exch. K meq/100g	0.37 a	0.24 a	0.23 a	0.26 a
Exch. Mg meq/100g	2.93 a	3.03 a	2.35 a	3.05 a
Exch. Na meq/100g	0.15 a	0.15 a	0.11 a	0.16 a
ESP %	1.44 a	1.74 b	1.02 a	1.52 ab

Values in rows with different letters are significantly different from each other (P<0.05).

Effects on the grapevines

The desired levels (ppm) of sodium, chloride and calcium for Pinot Noir petioles provided with the results of the analyses by a commercial laboratory were Na < 300ppm, Cl < 2000 ppm and Ca < 1100 at flowering and Na < 300ppm, Cl < 2000 ppm and Ca <1350 at veraison. The calcium levels were all within the acceptable range (data not shown).

At veraison 2013, the sodium levels in the petioles sampled from the no salt vines were below the threshold level, but all the other treatments were well above (Figure 4.7). All exceeded the threshold for chloride.

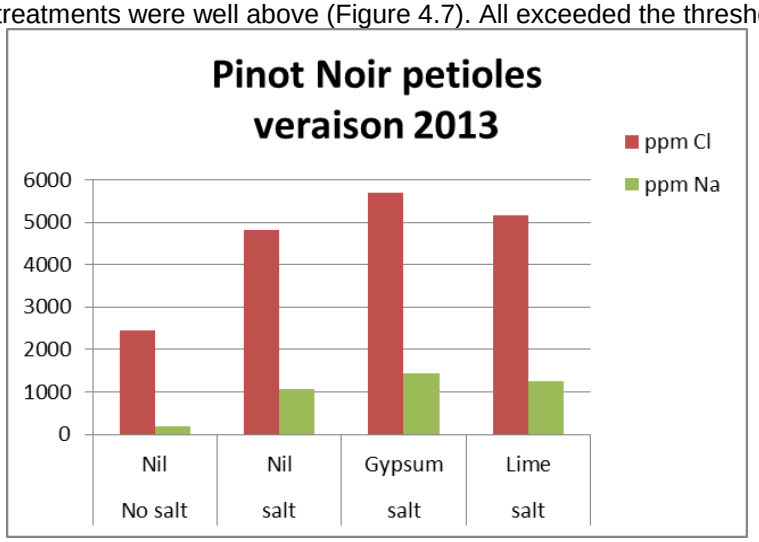


Figure 4.7. Levels of chloride and sodium in petioles sampled at veraison 2013 from Pinot Noir vines. The treatments were no salt, salt affected control (salt nil), salt-affected treated with gypsum and salt-affected treated with hot lime.

At flowering 2013, all treatments were below the thresholds for sodium and chloride (data not shown), but by veraison 2014 they had greatly exceeded these in all treatments, with the gypsum and hot lime treatments having much higher chloride levels than the untreated salt control (Figure 4.8).

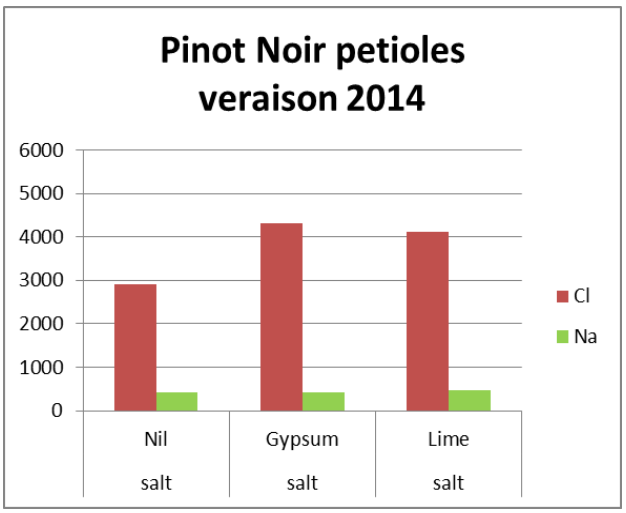


Figure 4.8. Levels of chloride and sodium in petioles sampled at veraison 2014 from Pinot Noir vines. The treatments were salt affected control (salt nil), salt-affected treated with gypsum and salt-affected treated with hot lime.

In the first season, the gypsum applications caused significant increase in sodium and chloride levels in berries, and all the salt-affected plots had significantly higher chloride in the fermented juice than the no-salt plots (Table 4.9). By the end of the second season (2014), sodium levels were significantly higher in the berries from all the salt-affected plots regardless of treatment, but there were no other differences detected. The yields were much lower in 2014 than 2013 for all plots, reflective of conditions everywhere across the Yarra Valley in 2014.

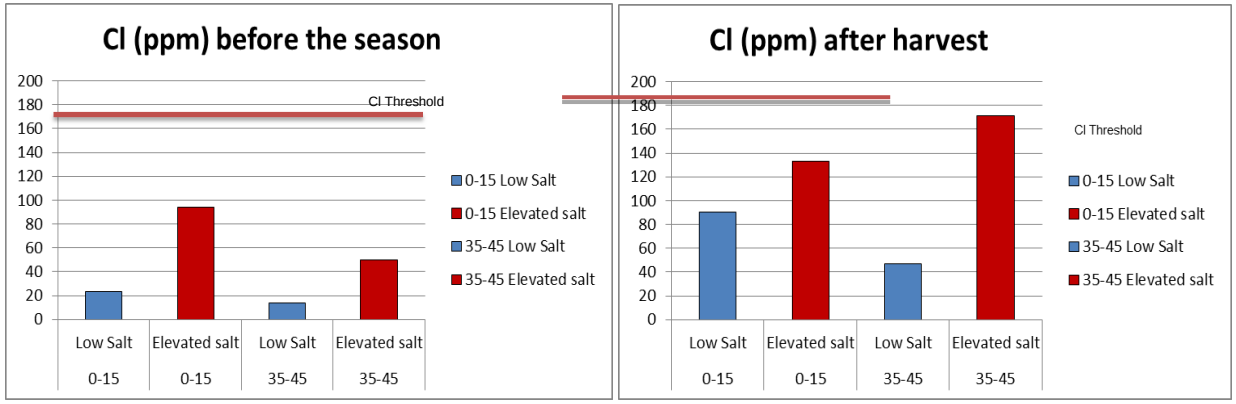
Table 4.9. Mean vine and grape characteristics (yield, bunch number, potassium, sodium and chloride levels in berries and fermented juice) per treatment at harvest 2013 and 2014.

Treatment	Panel bunch no.	Panel yield kg	Berry K ppm	Berry Na ppm	Berry Cl ppm	Fermented juice K ppm	Fermented juice Na ppm	Fermented juice Cl ppm
2013								
No salt	171	21.1	2025	33a	18a	1432	15	52a
Salt control	149	18.6	1706	123ab	191b	1486	169	430b
Gypsum	151	13.7	1604	235b	395c	1410	190	551b
Hot lime	110	16.6	1748	115a	222b	1732	152	448b
(L.s.d.)	(88)	(9.7)	(366)	(115)	(163)	(616)	(187)	(338)
2014								
No salt	174	11.8	1857	18a	90	1766	24	83
Salt control	164	10.8	1780	28b	164	1883	29	221
Gypsum	172	10.7	1680	29b	134	1293	36	166
Hot lime	190	11.5	1628	31b	160	1297	38	253
(L.s.d.)	(41)	(5.9)	(185)	(7)	(84)	(671)	(11)	(165)

L.s.d. = Fisher's least significant difference at 5%. Highlighted values with different letters in the same row (per year) are significantly different .

The trial also showed the importance of standardised sampling time on the ability to detect a soil constraint. When the site was sampled before the season in spring when there is plenty of rain to flush the system, the chloride levels were well below the threshold values and the salinity issue would not have been detected (Table 4.10). When sampled after harvest before the autumn rains, the levels of chloride detected in soil were approaching the thresholds for salinity issues to be affecting vine performance.

Table 4.10 Impact of soil sampling time on chloride concentration (ppm) in soil in respect to the threshold for the effect on vine growth

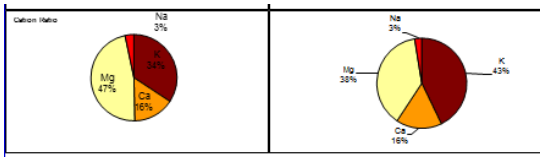


No salt

Results [ppm]:

NUTRIENT		DESIRABLE		RESULT	STATUS
		High	Low		
Ammonium -	NH4	100	15	2.753	
Nitrate -	NO3	700	225	115.8	Low
hosphorus -	P	350	100	501.8	Elevated
Sulphur -	S	250	100	131.8	Satisfactory
Potassium -	K	3500	1500	1905	Satisfactory
Calcium -	Ca	1350	575	862.5	Satisfactory
Magnesium -	Mg	2750	1700	2608	Optimum
Boron -	B	4.00	2.00	0.503	Low
olybdenum -	Mo	0.04	0.02	0.03	Satisfactory
Copper -	Cu	2.5	0.8	0.583	Low
Iron -	Fe	5.0	1.8	1.785	Marginal
Manganese -	Mn	6.0	2.0	34.6	Excessive
Zinc -	Zn	10.00	4.0	10.05	Optimum
Sodium -	Na	300	50	185.8	Marginal
Chloride -	Cl	2000	20	2443	Moderately salin
brix	%	14	10	0	-

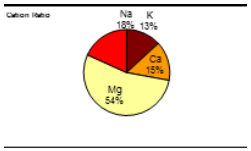
Analysis Results



High salt

NUTRIENT		DESIRABLE		RESULT	STATUS
		High	Low		
Ammonium -	NH4	100	15	3.813	
Nitrate -	NO3	700	225	98.5	Low
hosphorus -	P	350	100	438	Elevated
Sulphur -	S	250	100	220.3	Optimum
Potassium -	K	3500	1500	764.8	Low
Calcium -	Ca	1350	575	857.5	Satisfactory
Magnesium -	Mg	2750	1700	3131	Optimum
Boron -	B	4.00	2.00	0.628	Low
olybdenum -	Mo	0.04	0.02	0.028	Satisfactory
Copper -	Cu	2.5	0.8	0.528	Low
Iron -	Fe	5.0	1.8	1.538	Low
Manganese -	Mn	6.0	2.0	34.87	Excessive
Zinc -	Zn	10.00	4.0	7.985	Satisfactory
Sodium -	Na	300	50	1061	Elevated
Chloride -	Cl	2000	20	4823	Highly saline
brix	%	14	10	0	-

Analysis Results



High salt/CaO

NUTRIENT		DESIRABLE		RESULT	STATUS
		High	Low		
Ammonium -	NH4	100	15	2.038	
Nitrate -	NO3	700	225	90	Low
hosphorus -	P	350	100	363.8	Optimum
Sulphur -	S	250	100	247.3	Optimum
Potassium -	K	3500	1500	657	Low
Calcium -	Ca	1350	575	838.8	Satisfactory
Magnesium -	Mg	2750	1700	3174	Optimum
Boron -	B	4.00	2.00	0.58	Low
olybdenum -	Mo	0.04	0.02	0.02	Marginal
Copper -	Cu	2.5	0.8	0.528	Low
Iron -	Fe	5.0	1.8	1.56	Low
Manganese -	Mn	6.0	2.0	26.18	Excessive
Zinc -	Zn	10.00	4.0	7.755	Satisfactory
Sodium -	Na	300	50	1434	Elevated
Chloride -	Cl	2000	20	5693	Highly saline
brix	%	14	10	0	-

Analysis Results

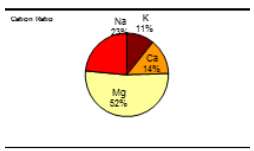


Figure 4.9 Analysis of Na and Cl in petiole sap nutrient levels at veraison from soils not affected by salt (left), soils affected by salt (middle) and soils amended with calcium treatments (right). CaO = hot lime (calcium oxide); gypsum data equivalent to hot lime (not shown).

The calcium treatments, gypsum and lime, were trialled to see if they would slow or reverse the increasing salinity seen at a Pinot Noir vineyard in the Yarra Valley. Hot lime was selected to provide an immediate impact on pH and release calcium in the soil in order to free the bound sodium salt, which in turn would be flushed from the system if adequate rain was available to the vines. Gypsum was applied to break up the subsoil structure and provide better drainage to disperse the sodium salt from the subsoil. Two applications of each was applied; the first at the start of the 2012-13 growing season, and the second after harvest in 2013. The first application was applied after winter rains and for treatments to work effectively considerable spring rains were needed to flush out the sodium salt. The spring was particularly dry and the sodium salt remained in the soils. This was confirmed by an increase in the sodium and chloride levels in the sap of petioles taken at veraison in 2013 from grapevines in both calcium treatments compared to those from the unamended treatment (Figure 4.9). In 2014, treatments were applied before winter and in this instance there was no elevated salt levels at veraison in either of the calcium treatments in the following crop which indicated that winter rains may have leached some of the salt, but that this was not adequate to remediate the site.

The results from this trial plus consultation with maps and soil experts, Dr Mike McCarthy and Prof. Robert White, suggest that there may be an aquifer bringing salt into the site from further up the hill from cleared land. If this is the case then the treatments being applied are unlikely to be suitable to assist long-term management of the salt problem. It has been suggested to the grower that a better treatment is to provide a drain at the top of the site to divert the flow of salty water from the aquifer.

Even though the calcium treatments had negative impacts on the vines in 2013, evidenced in levels of chloride and sodium in petioles, berries and wine juice, the results showed that the treatments were able to free up the sodium and chloride in the soil. For areas where adequate rain or supplementary irrigation could be applied, these treatments may have been suitable for remediation of the salt problem.

By the end of the trial, there were few differences detected in the soil salinity properties of chloride, exchangeable sodium, conductivity and exchangeable sodium percentage, except for elevated electrical conductivity in the gypsum treatment. Since we suspect that the salt is being carried into the site from an aquifer, this result is not unexpected.

The objective of this trial had been to demonstrate the use of the MDS for monitoring the management of a constraint, in this instance salinity. The soil properties chosen were well suited to this purpose and certainly helped to understand the impact of adding gypsum and lime to this vineyard. The grower is now quite aware of the difficult issues they are facing with regards to salinity at this site and future monitoring and remedial action will continue based on these results. The economic information from Case Study 2 will be relevant to the appropriate actions taken.

4.6 Simple economic model from Case Study 2 to inform decision making of a constraint

The major question posed by Case Study 2 was whether a simple economic model could be developed to determine the benefit/cost of managing a serious soil constraint, ie. salinity in a vineyard. The minimum data set and the model were used to demonstrate to growers what actions could be taken to identify correct management depending on the degree of salinity (as shown by the minimum dataset). The model used economic values for the actual region as shown in Table 4.11 below. Growers were then able to consider the options and, depending on yield and net returns, calculate the number of years required to recover the cost of any management action to remediate the site. The advantage of the site chosen in the Yarra Valley was that an adjacent site had already instigated the highest cost management option which proved very effective and provided a real case study for growers to observe effects (see section 4.4).

The Model: In this model for salinity, the minimum dataset was used to establish the extent of the salinity (ie. chloride, sodium and EC values) in soil undervine, in the mid row and at an adjacent native site (see page X). Three sites were chosen in the same vineyard block - one virtually unaffected by salinity (Site A), another with no vine symptoms but reflecting the moderate (or threshold) value for salinity and another highly saline where vine growth was markedly affected (Fig. 4.3). Additionally at these sites, yields and wine quality information was gathered from a representative panel from where soils had been sampled to be able to determine the potential loss in production to the vineyard (loss by value of grape tonnage) and the winery (loss by income per bottle of wine). These loss estimates in gross income were then used to calculate how much could be spent on remedial management strategies to remediate the site (Tables 4.11 and Table 4.12).

The yields of fruit from the affected panels (moderate (Panel B) and severe (Panel C)) in Block A were compared with that of Panel A, assumed to be unaffected, for 2013. The difference between healthy and moderate, and healthy and severe, was used to calculate the lost potential fruit yield per panel. Differences in fruit quality measures, such as pH and TA were noted, but potential downgrading of fruit was not factored into the calculation. However, the information could be used by growers to determine if there would be a further cost penalty at harvest. The wine quality information also showed the negative effect of salinity on fruit quality.

The prices used in the model were realistic for Cabernet Sauvignon fruit grown at this site in the Yarra Valley for 2013, *i.e*. $2000/tonne at the farm gate. If this was different for another grower, they could easily calculate the potential/actual losses on their own property by substituting their own price per tonne with that used in the simple model. Similarly, the potential losses caused by salinity at the three different sites were calculated based on the winery's average yield of 700 litres of wine per tonne of fruit marketed at $8 per bottle, adjusted for the yield losses at Panels B and C compared with the yield from Panel A.

During discussions with growers and consultants throughout the project, the only successful management action at this highly affected salinity site was to install an extensive drainage system costing approximately $16,000/ha. The grower indicated that he had avoided such remedial action due to the high initial cost, but the model data showed that he would return the initial high cost of investment in a relatively short timeframe. For example, a conservative estimate of low yield for Cabernet Sauvignon in the Yarra Valley is two tonne/ha, an average yield 5t/ha, and a good yield 10t/ha. If remediation corrected the salinity issue and improved the site back to average yields of 5t/ha, this would return an extra $6,500/ha and take 3 seasons to recover the initial set up cost for the drainage.

Table 4.11 Projected loss in income from salt-affected areas of Block A compared with the unaffected area, based on price for Cabernet Sauvignon fruit and wine from that vineyard in 2013.

Salinity Level within the vineyard	*Panel yield (kg)*	*Fruit pH*	*Fruit TA*	*Potential yield loss (as % A)*	*$ value of potential fruit loss @ $2000/tonne*	*$ value of potential wine loss @ 700L/tonne & $8/bottle*
Panel A (Healthy)	13.92	3.50	7.22	-	-	-
Panel B (Moderate)	5.68	3.28	6.06	59.2%	$1180/tonne	$4420/tonne
Panel C (Severe)	4.48	3.28	6.05	67.8%	$1356/tonne	$5061/tonne

According to a local viticultural consultant, these different management options have been used to manage salinity in the duplex soils of the Yarra Valley region in Victoria. These costs were shown to industry during the development of the simple economic model for managing salinity (Table 4.12).

Table 4.12 Some possible management options for managing salinity issues in vineyards

Management Action	**Approximate cost per hectare**
Drip irrigate with calcium nitrate – calcium thiosulphate	$ 200 -500
Deep-rip the midrows and plant cover crops	$1200
Add a calcium amendment such as gypsum or lime	$350 - 800
Deep-rip the midrows and add compost into the subsurface	$2-3000
Install mole drains plus feather drains per row (or 2nd row) to get rid of the salt	$16,000

Section 4.4 showed that at an adjacent site to the above trial site, the grower had decided to go to the expense of installing an extensive drainage network and completely solved the salinity issues at the site. The soil characteristics had returned to normal very quickly and the vineyard had been returned to good yields. The long term study conducted in Case Study 3, however, has demonstrated that the cheaper options of using lime or gypsum may not be very effective for managing salinity. To date, there has been no improvement in soil salinity and grape yield and quality, despite three years of calcium amendments. In response to the simple economic model and the information obtained from this study, the affected grower is now reconsidering installing improved drainage at this site.

Chapter 5: Benchmarking indicators of soil quality at regional scale – McLaren Vale

5.1 Introduction

The minimum dataset of indicators for soil quality, described in previous chapters, is intended to provide growers with a basis for assessing soil condition and, through repeat sampling, a means of assessing how soil condition is impacted by their management practices. However, because soils vary at scales ranging from a few metres to the continental, an appropriate local basis is needed for meaningful interpretation of the data. Key questions include:

- How do measured soil properties at a specific location compare to those in the region more broadly?
- What magnitude of change in soil properties over time is required for this change to be attributed to viticultural management and/or used to assess a change in soil condition that might warrant remediation ?

Using McLaren Vale as a case study, this work sought to address these questions; other chapters describe similar studies undertaken in other regions. To address the first question, and mindful of the constraint placed on soil sampling and analysis by the funding available, we sought to provide the beginnings of a regional database of soil quality indicators that McLaren Vale growers could use to assess their soil condition against a regional average. Notwithstanding the possibility that the average condition is sub-optimal, the knowledge that soil condition in a particular vineyard is below the norm for the region was considered to be a likely strong motivator for soil improvement.

The answer to the second question is potentially impacted by laboratory error and an important element of this work was therefore to assess the typical error associated with commercial soil analysis. Knowing that the soil properties in the minimum dataset are unlikely to change substantially in a single year, repeat sampling of a limited number of sites was also seen as a useful means of addressing this second question. Additionally, on the assumption of insignificant change in soil condition, the regional database could be expanded through sampling over both years of the study without seasonal effects needing to be considered. Of course, this assumption needed to be tested.

5.2 Method

5.2.1 Site selection

A total of fifty vineyard locations (30 in 2013 and 20 in 2014) were selected across McLaren Vale for soil sampling, four weeks after harvest had finished; 10 of the sites sampled in 2013 were repeat sampled in 2014 making a total of 30 locations sampled each year. The vineyards were chosen, in consultation with the McLaren Vale Grape Wine and Tourism Association, to cover the range of soil types in the region, as identified in the 1:50,000 soil map for McLaren Vale obtained from Primary Industries and Regions, South Australia (PIRSA), as well as the range of viticultural management approaches (conventional, organic, etc.) used in the region. The locations of the vineyards, along with the 15 generalised soil groups for the whole McLaren Vale region, are shown in Figure 5.1, whilst Table 5.1 details how both the total area in McLaren Vale planted to vines and our sampling sites, are spread amongst these soil types. Details of the area of McLaren Vale planted to vines were obtained from the Phylloxera and Grape Industry Board of South Australia. Of the sites sampled, 40 were under conventional management (including low input conventional) and 10 were under organic management (both certified and uncertified); of these 5 were biodynamic.

5.2.2 Soil sampling

For each sampled vineyard, soils were collected at a single location, georeferenced using a differentially corrected global positioning system (dGPS; accurate to +/- 50 cm) and also at a nearby (within approximately 30 m) native or non-viticultural location if one existed. In some cases, selection of a native/non-viticultural location was not possible.

The sampling location within the vineyard was selected as being representative of the block after discussion with the grower. Note that because the focus of this kind of sampling and analysis activity is to detect changes in soil properties over time, we did not seek to collect a composite sample from throughout the vineyard, but rather focussed on the single geo-referenced location on the assumption that changes in soil condition at this location would be indicative of changes in the vineyard as a whole. Importantly however, and mindful of the use of dGPS, any repeat sampling could be location specific and so much less subject to the error attributed to spatial variability than would be the case for repeat sampling based on composite

sampling. Typically, the sampling locations were at least 3-4 rows from the edge of a block and an equivalent distance (2-3 panels) along the row.

At each sampling location, an 'undervine' site was selected 20 cm towards the midrow from the dripper closest to the trunk and a midrow site was selected in the centre of the midrow but in line with the undervine site. For each of the undervine, midrow and native samples, a hole (30 cm diameter) was hand-augered and clods for physical analyses were sampled from towards the centre of the hole and stored in rigid plastic jars. In the laboratory, clods were checked to ensure that there was no shearing of the sides which can affect physical analyses. Approximately 1 kg of soil was taken from the surface (0-10 cm) and sub-surface (35-45 cm) for chemical and biological analyses. Soils were transported back to Adelaide each day and stored at 4°C upon return. In 2014 the sampling for biological analyses was changed and 5 cores (approximately 7 cm diameter) were sampled (as indicated in Figure 5.2), bulked and stored on ice before transport back to Adelaide. Sampling for the chemical and physical analyses in 2014 was as for 2013 sampling.

5.2.3 Soil analyses

Soils were sub-sampled and sent to a commercial laboratory for chemical analyses and to the University of Western Australia for biological analyses. Physical analyses were determined by project staff at the Waite laboratory.

The analyses were:

Physical (determined by project staff)

- Aggregate stability (dispersion and slaking)
- Soil consistency

Chemical (determined by CSBP, Kwinana, WA)
(those indicated by # are not part of the minimum dataset recommended by the project but were extra analyses determined by the laboratory as part of the suite of analyses offered)

- Soil pH (water and $CaCl_2$)
- Soil carbon (Leco)
- Electrical conductivity
- Exchangeable cations (Ca, K, Mg and Na)
- Cation exchange capacity (if soil pH <5.5)
- Calcium carbonate #
- Ammonium nitrogen #
- Nitrate nitrogen #
- Colwell extractable phosphorus and potassium #
- Sulphur #
- Walkley and Black organic carbon #

Biological (determined by University of WA in 2013; % determined by AgVita, Tas, and PMN by Nutrient Advantage, Vic, in 2014)

- Microbial biomass
- Potentially mineralizable nitrogen
- Labile carbon (%)

Effective cation exchange capacity (ECEC) and exchangeable sodium percentage (ESP) were calculated from the exchangeable cations. Total organic carbon (OC) was calculated from the Leco total carbon measurement. In all cases, standard Australian soil analysis methods were used (Rayment and Lyons, 2011). Further details are given in the booklet provided to collaborating growers (Appendix 1).

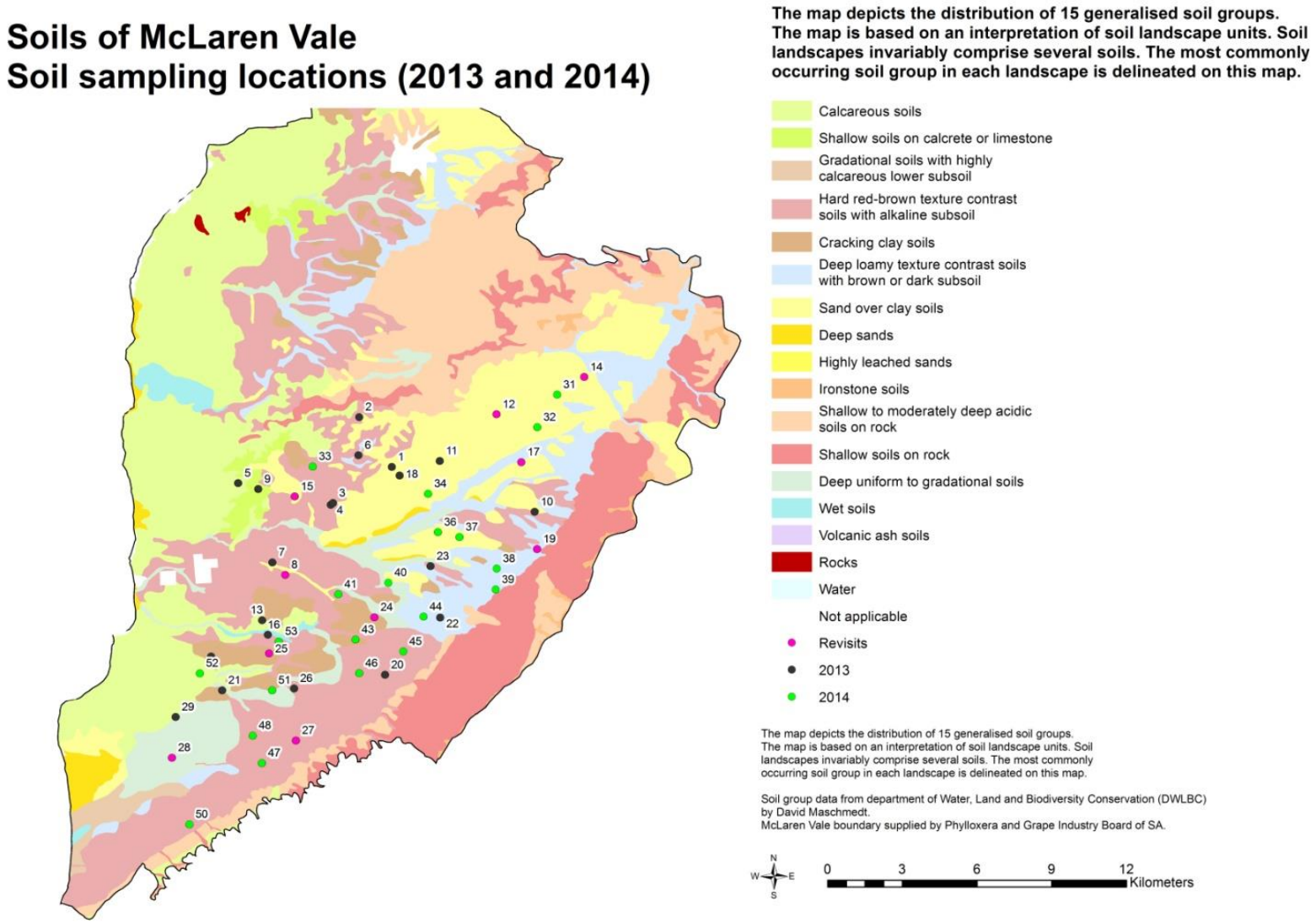


Figure 5.1. Map of McLaren Vale soil sampling locations used in 2013 and 2014 and the major soil groups which are planted to vines. Note that 'revisits' (pink dots) indicates sites sampled in both years of the study.

Table 5.1. Distribution of major soil groups for the whole McLaren Vale area, the area planted to vines and the distribution of sampling sites amongst soil types (McLaren Vale Grape Wine and Tourism Association)

Major Soil Group	McLaren Vale Total Area		Area Planted to Vines		No. sites
	Area (ha)	Proportion of total (%)	Area (ha)	Proportion of total (%)	
Hard red-brown texture contrast soils with alkaline subsoil	9263	21.5	2871	38.4	21
Sand over clay soils	5958	13.8	1679	22.5	12
Deep uniform to gradational soils	2093	4.9	817	10.9	3
Cracking clay soils	1433	3.3	691	9.2	5
Deep loamy texture contrast soil with brown or dark subsoil	3317	7.7	655	8.8	6
Calcareous soils	8335	19.3	365	4.9	3
Shallow to moderately deep acidic soils on rock	6128	14.2	211	2.8	
Shallow soils on calcrete or limestone	514	1.2	80	1.1	
Ironstone soils	274	0.6	32	0.4	
Shallow soils on rock	4150	9.6	27	0.4	
Deep sands	501	1.2	21	0.3	
Gradational soils with highly calcareous lower subsoil	368	0.9	17	0.2	
Wet soils	361	0.8	9	0.1	
Rock	37	0.1		0.0	
NA	397	0.9		0.0	

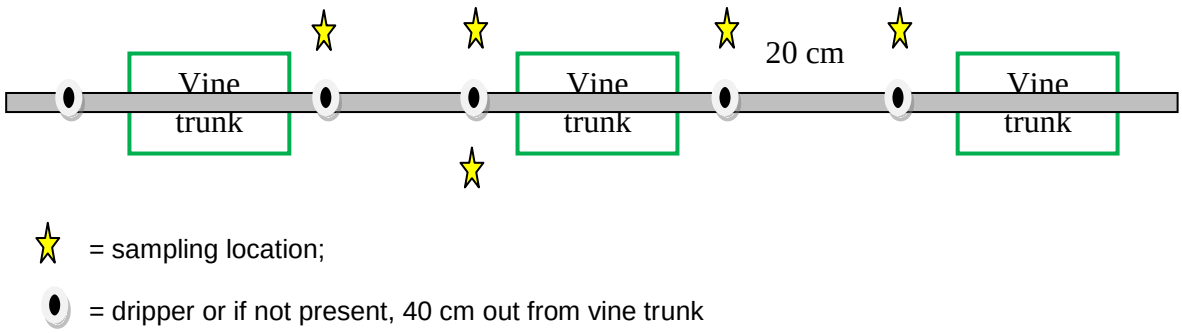


Figure 5.2. Diagrammatic representation of soil sampling for biological samples in 2014.

5.3 Results and Discussion

Given the volume of data generated in this project, we illustrate our results throughout using the example of soil pH (1:5 soil:water) measured in surface (0-10 cm) soil samples only. The entire dataset is summarised in Figure 5.6 and Table 5.8 at the end of this chapter. Note that although 0-15 cm had been chosen as the sampling depth for surface soils (Chapter 1), the McLaren Vale growers had already collected a wealth of soil information using 0-10 cm as the sampling depth and wished to remain consistent.

5.3.1 Regional distribution of soil property values

Results obtained in 2013

Figure 5.3 illustrates the distribution of soil pH in surface samples collected and analysed in 2013. Following the 2013 sampling, all the growers who had allowed us to sample their vineyards were sent a booklet (Appendix 1 provides an example) containing figures illustrating the regional distribution of values for each measured soil property, along with a summary table containing the data for their own site (e.g. Table 5.2). Note that it was not the objective of this project to provide detailed interpretations of these analyses in terms of desirable soil management options that might be implemented in response to them. Rather, we simply sought to establish a regional distribution of soil property values and to enable collaborating growers to see where their soils sat within that regional distribution with a view to considering whether any remedial action might be warranted. Growers were encouraged to seek expert advice separately if they felt that it was warranted.

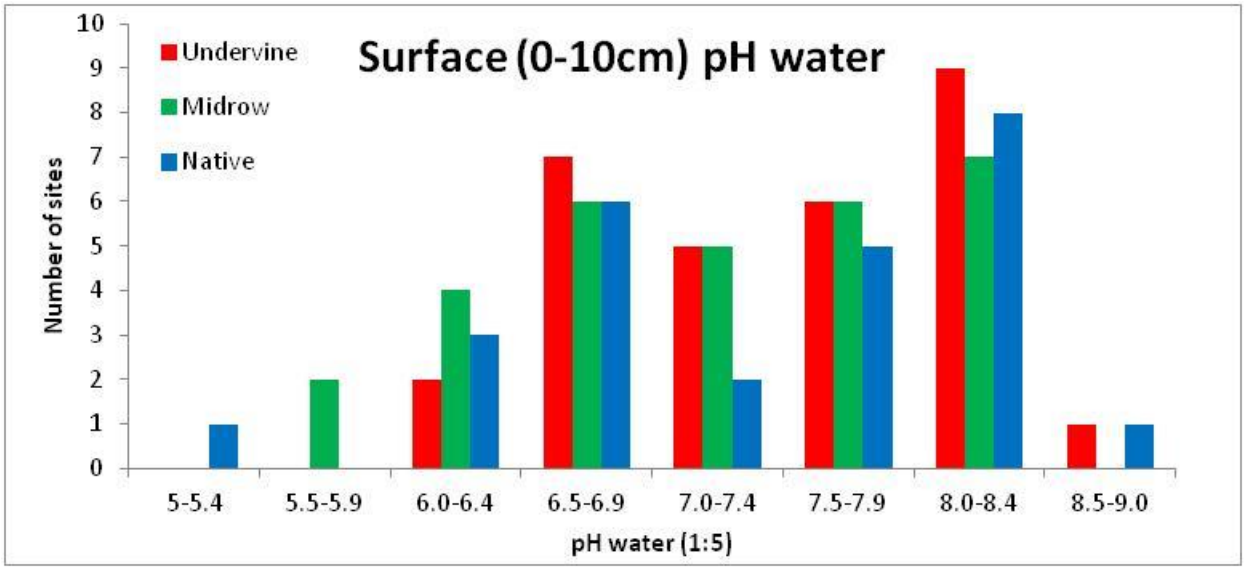


Figure 5.3. Distribution of soil pH (in water) amongst undervine, midrow and native soils sampled from 30 sites throughout McLaren Vale in 2013.

Table 5.2. Example of data presented to growers in 2013; comparison between the surface soil pH at an individual location and in the region as a whole.

Location	Undervine	Midrow	Native
Regional Average	7.5	7.2	7.4
Sampling site	6.7	7.1	7.5

As can be seen from Figure 5.3 and Table 5.2, surface soil pH in the region is approximately normally distributed, albeit with a suggestion of a somewhat bimodal distribution as a consequence of McLaren Vale having some calcareous and saline soils leading to several sites recording pH values above 8. Nonetheless, the regional mean for the undervine samples is 7.5 and in this example (Table 5.2), the grower value is 6.7. Since this value is within the range (pH 5.5 - 8) considered desirable for growing grapes, this grower would probably not be encouraged to consider remedial action even though the pH of their sample is somewhat below the regional mean. However, the fact that the undervine and midrow samples in this example have lower pH than the native site, and the undervine sample has a lower pH than the mid row, could possibly reflect the acidifying effects of N fertilizer use; careful monitoring coupled to expert advice would be needed to inform this.

Results obtained in 2014

Growers who participated in the 2014 sampling were provided with a booklet similar to that provided in 2013 (Appendix 1).

A key component of the 2014 sampling was the repeat analysis of soils taken from 10 sites that had been sampled in 2013. Our assumption was that, in the absence of deliberate actions aimed at changing soil condition, soil properties were unlikely to change markedly in just one year. Thus, such a repeat sampling would allow us to determine whether we had robustly characterised the distribution of soil property values in 2013 as a basis for enabling growers to assess how their own soils compared with regional mean values. Figure 5.4 shows the comparison between measures of surface soil pH made in 2013 and 2014 at 10 sites plotted against the site numbers. Inspection suggests little difference between the years beyond what might be expected due to laboratory error (see below). A paired sampled t-test of these data (Table 5.3) confirms that for these 10 sites, there are, on average, no significant differences between the values obtained in the two years.

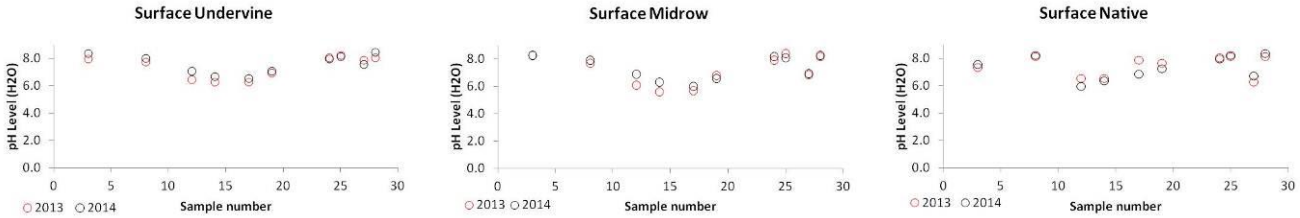


Figure 5.4. Comparison between soil pH (1:5 soil:water) measured in surface samples (0-10 cm) in 2013 and 2014 at 10 sites in McLaren Vale.

Table 5.3. Results of a paired sample t-test for surface (0-10 cm) soil pH (1:5 soil:water) measured at 10 McLaren Vale sites in 2013 and 2014.

location in vineyard	pH mean		P value	significance of difference
	2013	2014		
Undervine	7.4	7.6	0.061	NS
Midrow	7.2	7.4	0.110	NS
Native	7.5	7.4	0.398	NS

Accordingly, Figure 5.5 shows an update to the regional distribution of surface soil pH values (c.f. Figure 5.3) based on the data collected over the two years of the study - that is, from 50 sampling locations – with the summary statistics presented in Table 5.4. We conclude that, in the case of surface soil pH measured in water, Figure 5.5 and Table 5.4 provide a robust basis for McLaren Vale growers to assess how the pH of their surface soil compares to that of their regional peers.

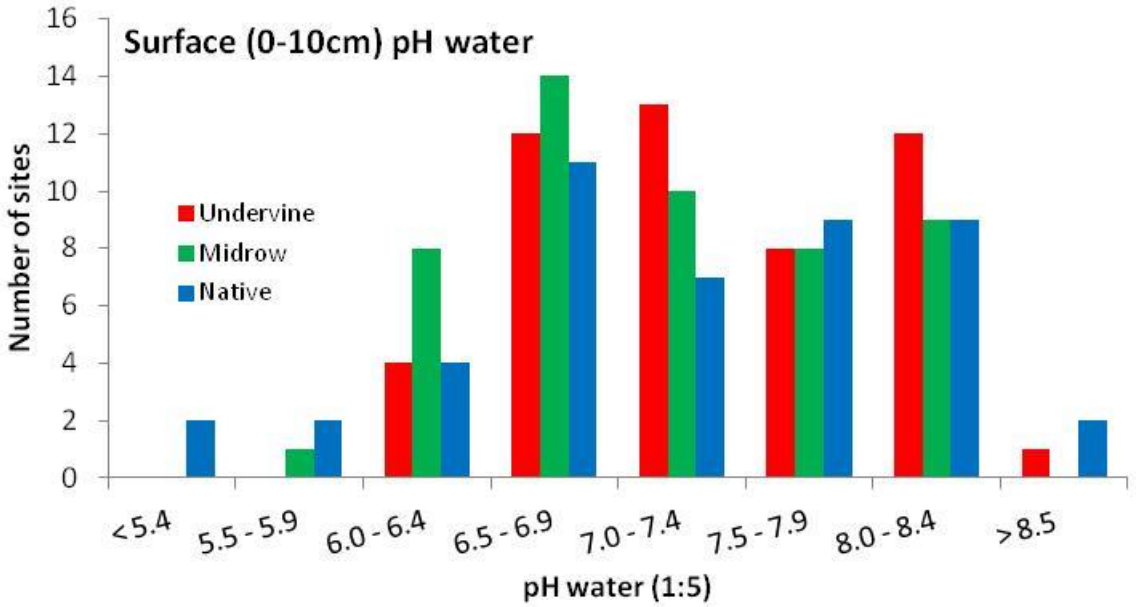


Figure 5.5. Distribution of soil pH (in water) amongst undervine, midrow and native soils sampled from 50 sites throughout McLaren Vale in 2013 and 2014.

Table 5.4. Mean and range of surface (0-10 cm) soil pH (1:5 soil:water) measured at 50 McLaren Vale sites in 2013 and 2014.

	pH		
	Midrow	**Native**	**Undervine**
min	5.9	5.2	6.3
max	8.3	8.6	8.6
average	7.1	7.2	7.3

Table 5.5 summarises a similar analysis to that presented in Table 5.3 for the entire suite of soil properties presented. Whilst there are a small number of analytes which do show significant difference between the sampling years, there are no instances of where the same analyte shows a between year significant difference in both the surface and sub-soil. We therefore conclude that in general, it is reasonable to use the data collected over the two years of the study to establish a regional distribution of soil properties against which growers can assess the condition of their soils compared to a regional average.

Table 5.5. Mean values for surface (0-10 cm) and sub-surface (35-45 cm) soil properties measured at 10 McLaren Vale sites in 2013 and 2014 and results of tests of the significance[A] of the between-year difference (paired sample t-tests).

Property	Units	Year	0-10 cm			35-45 cm		
			Undervine	Midrow	Native	Undervine	Midrow	Native
NH_4-N	mg/kg	2013	2.52	4.77	3.60	1.15	1.35	0.89
		2014	2.80	3.50	3.53	2.30	2.30	2.48
			NS	NS	NS	NS	*	*
NO_3-N	mg/kg	2013	20.27	13.90	11.83	2.95	3.15	2.56
		2014	8.20	14.03	9.35	4.20	3.60	2.50
			*	NS	NS	NS	NS	NS
Colwell P	mg/kg	2013	101.4	53.2	33.6	20.7	13.4	5.2
		2014	111.6	58.1	34.1	24.1	12.8	14.0
			NS	NS	NS	NS	NS	NS
Colwell K	mg/kg	2013	486.3	493.8	519.0	173.5	150.6	218.7
		2014	521.6	423.7	441.6	201.7	156.0	269.6
			NS	NS	NS	NS	NS	NS
Sulphur	mg/kg	2013	27.88	22.15	11.14	39.83	22.14	11.63
		2014	14.52	7.83	9.19	24.48	12.84	14.74
			NS	NS	NS	*	NS	NS
Organic C	%	2013	2.06	2.17	3.03	0.66	0.68	0.79
		2014	2.35	2.30	2.88	0.67	0.60	0.86
			*	NS	NS	NS	NS	NS
EC	dS/m	2013	0.30	0.19	0.19	0.24	0.10	0.15
		2014	0.17	0.10	0.13	0.24	0.10	0.16
			*	**	*	NS	NS	NS
pH ($CaCl_2$)		2013	6.9	6.6	7.0	7.3	7.1	7.0
		2014	7.0	6.6	6.7	7.0	6.9	6.7
			NS	NS	*	NS	NS	**
pH (H_2O)		2013	7.4	7.2	7.5	8.1	7.8	7.8
		2014	7.6	7.4	7.4	7.7	7.7	7.4
			NS	NS	NS	*	NS	**
Cl	mg/kg	2013	193.2	59.9	85.4	137.6	15.1	68.9
		2014	113.4	21.5	76.0	222.6	24.6	107.7
			NS	*	NS	NS	NS	NS
Total N	%	2013	0.28	0.26	0.33			
		2014	0.22	0.22	0.26			
			NS	NS	NS			
Total C	%	2013	2.47	2.66	3.34			
		2014	2.69	2.59	3.28			
			NS	NS	NS			
$CaCO_3$	%	2013	1.81	2.74	0.99			
		2014	2.55	2.30	0.82			
			NS	NS	NS			
Total OC	%	2013	2.25	2.33	3.22			
		2014	2.39	2.32	3.18			
			NS	NS	NS			

Property	Units	Year	0-10 cm			35-45 cm		
			Undervine	Midrow	Native	Undervine	Midrow	Native
Exch. Ca	meq/100g	2013	11.02	11.81	12.25	10.32	11.73	10.57
		2014	13.25	14.14	14.04	12.61	12.35	12.11
			**	*	NS	NS	NS	NS
Exch. K	meq/100g	2013	0.89	0.81	0.92	1.11	0.43	1.25
		2014	1.35	1.14	1.10	0.60	0.44	0.76
			*	*	NS	NS	NS	NS
Exch. Mg	meq/100g	2013	2.03	1.44	2.18	2.66	2.72	2.47
		2014	2.70	1.62	2.20	2.95	2.23	2.61
			NS	NS	NS	NS	*	NS
Exch. Na	meq/100g	2013	0.15	0.06	0.11	1.16	2.06	1.01
		2014	0.18	0.06	0.09	0.37	0.07	0.27
			NS	NS	NS	*	NS	NS
ECEC	meq/100g	2013	14.1	14.1	15.5	15.3	17.0	15.3
		2014	17.5	17.0	17.4	16.5	15.1	15.7
			**	*	NS	NS	NS	NS
ESP	%	2013	1.43	0.99	0.71	12.25	14.64	7.82
		2014	0.99	0.72	0.58	3.66	1.47	2.71
			NS	NS	NS	NS	NS	NS
Labile C	mg/kg	2013	469	491	496			
		2014	284	314	396			
			**	**	NS			
PMN	mg N/kg	2013	21	31	33			
		2014	26	42	56			
			NS	NS	*			

[A]Significance is denoted by NS, not significant; * $P < 0.05$; ** $P < 0.01$. Significant properties are highlighted in yellow.

Histograms derived from the two years of sampling (c.f. Figure 5.5) are presented for all soil properties in Figure 5.6

5.3.2 Laboratory error and assessing change through time

A key reason for establishing the minimum dataset for soil quality characterisation is so that growers can use it to assess the impact of their management over time on soil condition. However, given the error associated with any form of soil analysis, the question arises as to what magnitude of change in soil property values constitutes a 'real' change that might require attention by way of ameliorative action ?

The usual approach to addressing this question is to use replication to enable calculation of error and thus, the difference between measured values in relation to that error. However, the cost of soil analysis is a significant impediment to the use of replicated analysis. One solution to this would be for laboratories to publish details of the error associated with their analysis. Alas, they do not do this, whilst the laboratory accreditation system used by the Australasian Soil and Plant Analysis Council (ASPAC; http://www.aspac-australasia.com/) uses coefficients of variation (CV) to determine laboratory performance – see for example http://www.aspac-australasia.com/index.php/documents/upload-documents/doc_download/232-annual-review-soil-07-08. Note also that "laboratories" are not accredited per se; rather, they are accredited for individual soil tests, and that ASPAC do not assess (or report) laboratory proficiency for all possible analytes or methods.

Table 5.8 details the results of the repeat analyses that we did on 10% of the samples submitted for analysis in 2013 in terms of the values of the means and coefficients of variation for our replicate analysis. CVs greater than 15% have been highlighted on the basis of this being a workable 'cut-off' above which we would have concerns as to the accuracy of the analysis. As can be seen, there is both a marked site to site variation in the CV and also a concerning number of repeat analyses for which the CV is greater than 15%; the range of values of the CV obtained for the soil properties that are in our minimum dataset are summarised in Table 5.6. As Table 5.6 shows, whilst our 2013 dataset contains apparently robust measures of soil pH, laboratory performance with respect to the other analytes of interest leaves something to be desired. The most recent ASPAC report on the proficiency of laboratory performance (http://www.aspac-australasia.com/index.php/documents/upload-documents/doc_download/232-annual-review-soil-07-08) does little to suggest that our data are any worse than the norm.

Whilst the CV associated with a suite of analyses is a useful indication of its precision, it is difficult to interpret in the context of soil change. Accordingly, also shown in Table 5.6 are values of the least significant difference between means calculated from the repeat analyses undertaken in both 2013 and 2014. Whilst this is a limited dataset for which to calculate such a value, it does provide an estimate for the minimum difference that a grower should expect in order to assess the change in soil property values over time. Thus, for example, a McLaren Vale grower concerned at a possible change in soil pH over a five year period would need to have measures of soil pH (in water) that were different by more than 0.26 pH units to be confident that a real change had actually occurred. Of course, interpretation of the seriousness of that change in relation to the absolute value of the soil pH is something which we would advise the grower to base on expert consultant advice. It should also be noted that the CV values and LSD values calculated here are specific to the commercial laboratory used in this study and may not be applicable to all commercial laboratories. However, given the recommendation to use appropriately accredited laboratories for monitoring of soil quality over time, the CV and LSD values calculated here are expected to be broadly representative of similarly accredited laboratories.

The analysis underpinning Table 5.6 and Table 5.8 leads to an important recommendation which arises from this work. Clearly, interpretation of both the magnitude and importance of changes in soil condition is problematic if it is to be based on a limited program of soil analysis. On the assumptions that commercial analytical laboratories are unlikely to make available information regarding their own laboratory performance, it is recommended that for industry to take advantage of the type of work illustrated by this McLaren Vale study, soil analytical programs be coordinated by either national and/or regional industry associations (in this case McLaren Vale Grape Wine and Tourism Association – perhaps as part of its Sustainable Winegrowing program) and/or with the support of soil monitoring initiatives such as www.soilquality.org or perhaps via a national industry-based scheme such as the Entwine scheme operated by the Winemakers Federation of Australia; currently, Entwine does not canvass the issue of soil quality.

Table 5.6. Repeatability[A] of laboratory analyses carried out in triplicate for the soil properties in our minimum dataset.

Property	Units	CV range (%)	No. tests	No. tests with CV>15%	LSD	No. tests
pH (H_2O)		0-5	17	0	0.26	36
pH ($CaCl_2$)		0-7	17	0	0.27	36
EC	dS/m	3-55	17	8	0.05	36
Total C	%	1-60	9	1	1.20	19
Exch. Ca	meq/100g	2-137	17	5	2.11	36
Exch. Mg	meq/100g	3-129	17	6	0.81	36
Exch. K	meq/100g	1-85	17	5	0.94	36
Exch. Na	meq/100g	0-166	17	4	1.68	36
Microbial BC	mg/kg	6-56	9	7		19
Pot. Min N	mg N/kg	3-39	9	2	150.5	19
Labile C	mg/kg	4-26	9	3	108.8	19

[A]CV data are derived from 2013 analyses only (n = 17; 9 topsoils and 8 subsoils). LSD data derive from both 2013 and 2014 (n = 19; 10 topsoils and 9 subsoils).

5.3.3 Effect of sample location and management practice on soil quality

At the outset, and given interest in organic compared to conventional management, especially in McLaren Vale, we had hoped to be able to examine the effects of the type of viticultural management on soil quality. However, given the constraints placed on a study such as this by the budget available for soil analysis, coupled with the paramount need to cover the diversity of soil types present in the McLaren Vale region (Figure 5.1, Table 5.1), we had insufficient samples to evaluate management type effects on soil quality. As indicated, 40 sites were under some form of conventional management, 5 were biodynamic and 5 were otherwise organic – which broadly reflects the proportionate industry use of these types of management practices in the district.

However, it is well known that, especially in vineyards using drip irrigation, soil differences between the undervine and midrow often occur. The use of a co-located 'native' site also offered the opportunity to assess the possible effects of viticultural management on soil quality – recognising that a majority of vineyards were likely used for some other form of agriculture prior to being planted to vines.

Table 5.7 presents the results of an analysis of the effects of sample location in terms of comparison between undervine, midrow and native sampling positions. As can be seen, the only significant effects are with performance, it is recommended that for industry to take advantage of the type of work illustrated by this McLaren Vale study, soil analytical programs be coordinated by either national and/or regional industry associations (in this case McLaren Vale Grape Wine and Tourism Association – perhaps as part of its Sustainable Winegrowing program) and/or with the support of soil monitoring initiatives such as www.soilquality.org or perhaps via a national industry-based scheme such as the Entwine scheme operated by the Winemakers Federation of Australia; currently, Entwine does not canvass the issue of soil quality.

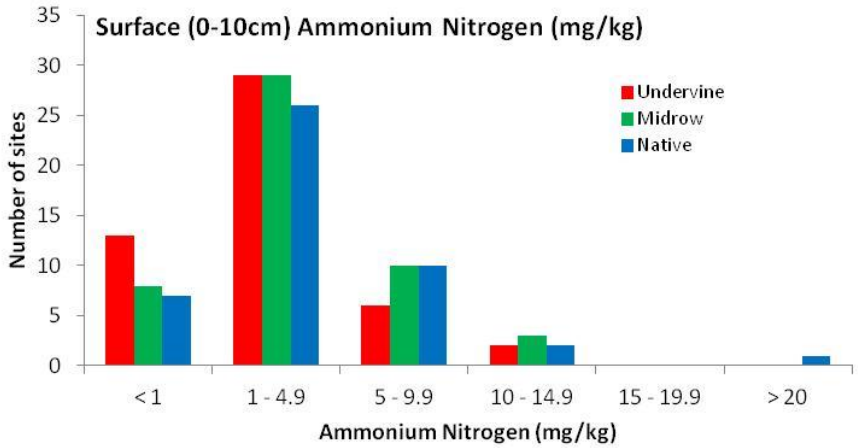
Table 5.7. Oneway analysis of variance of soil properties analysed in samples taken from either undervine, the midrow or from an adjacent (within approx. 30 m) native site. This analysis was done on all samples collected in 2013 and 2014.

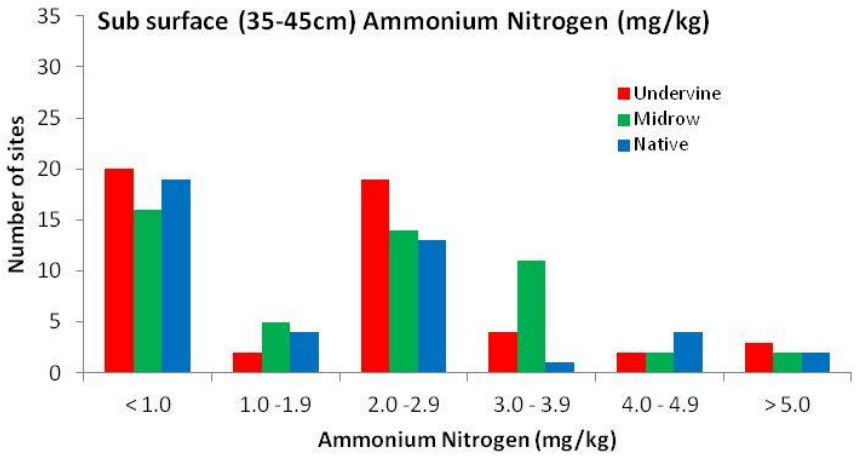
	Surface soils (0-10 cm)				Sub Surface soils (35-45 cm)			
Soil Property	**Undervine**	**Midrow**	**Native**	**Sig[A]**	**Undervine**	**Midrow**	**Native**	**Sig[A]**
pH ($CaCl_2$)	6.8a	6.5a	6.6a	NS	6.7a	6.5a	6.6a	NS
pH (H_2O)	7.3a	7.1a	7.2a	NS	7.5a	7.3a	7.4a	NS
EC[B] dS/m	0.23b	0.13a	0.17a	***	0.23b	0.10a	0.23b	**
Total C %	2.76a	2.78a	3.65b	*				
Total OC %	2.59a	2.59a	3.54b	**				
ECEC[C] meq/100g	13.7a	13.0a	14.1a	NS	15.0a	14.7a	15.9a	NS
Exch. Ca meq/100g	10.47a	10.57a	10.74a	NS	10.19a	10.49a	11.15a	NS
Exch. K meq/100g	1.00a	0.83a	0.88a	NS	0.85a	0.74a	1.05a	NS
Exch. Mg meq/100g	2.09ab	1.58a	2.32b	*	3.20a	2.83a	2.90a	NS
Exch. Na meq/100g	0.11ab	0.06a	0.13b	*	0.81a	0.62a	0.76a	NS
ESP[D] %	1.02a	0.75a	1.04a	NS	6.26a	5.37a	4.99a	NS
MBC[E] mg/kg dry soil	180a	192a	228a	NS				
Labile C mg/kg	420a	424a	458a	NS				
PMN (mg N/kg)	32a	34a	45a	NS				
ASWAT[G] not moulded	0a	0a	1a	NS	4a	4a	4a	NS
ASWAT moulded	2a	2a	2a	NS	2a	3a	3a	NS
Slaking score	2a	2a	2a	NS	1a	1a	1a	NS
Hardness	3a	3a	3a	NS	4a	4a	4a	NS

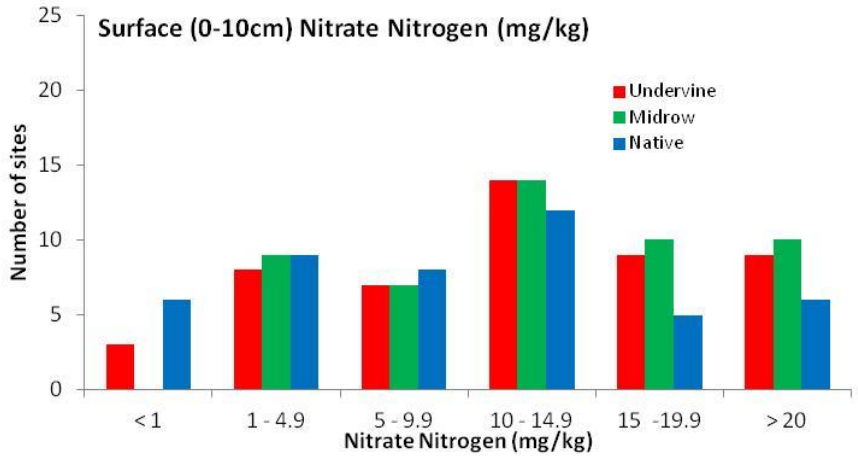
[A]Significance is denoted by NS, not significant, * P < 0.05, ** P < 0.01 based on comparisons for all pairs using the Tukey-Kramer HSD test. Values not connected by the same letter are significantly different. Significant differences are highlighted in yellow.

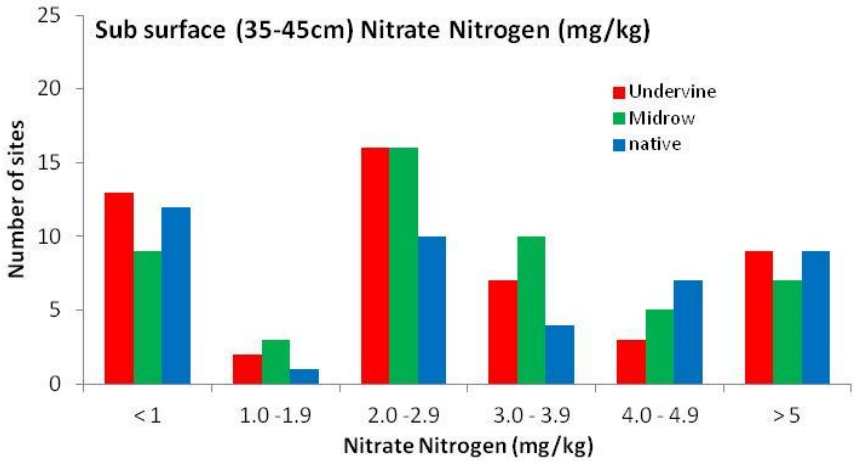
[B] EC = electrical conductivity; [C]ECEC = effective cation exchange capacity; [D]ESP = exchangeable sodium percentage; [E]MBC = microbial biomass carbon; [F]PMN = potentially mineralizable nitrogen; [G]ASWAT = a measure of dispersion

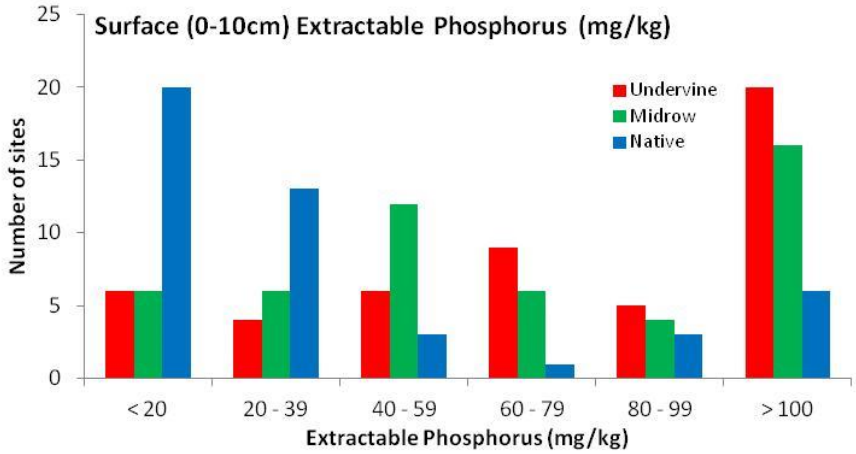
Figure 5.6 Distributions of surface (0-10 cm) and sub-surface (35-45 cm) soil properties in the McLaren Vale region in 2013 and 2014.

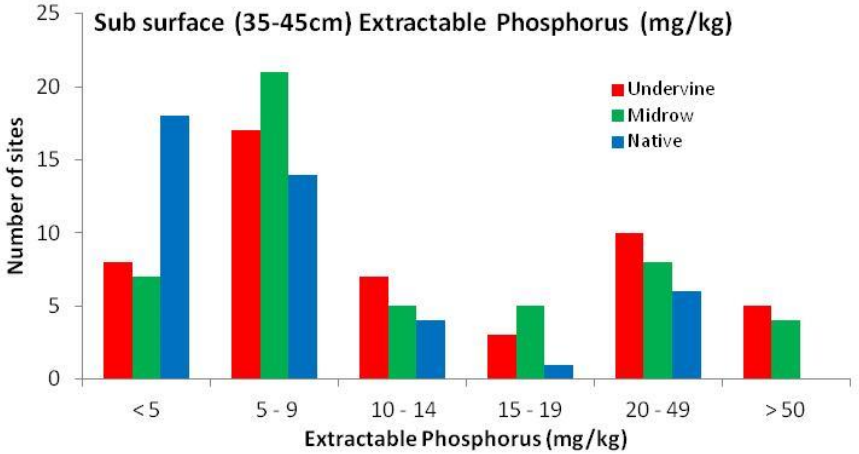


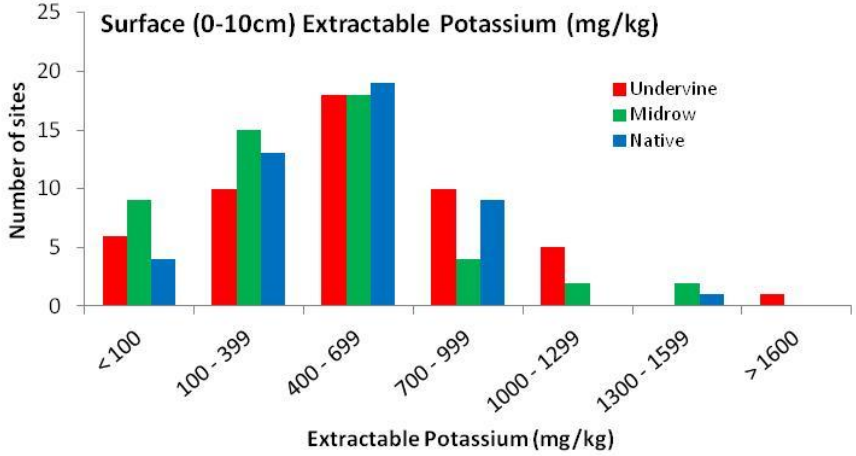


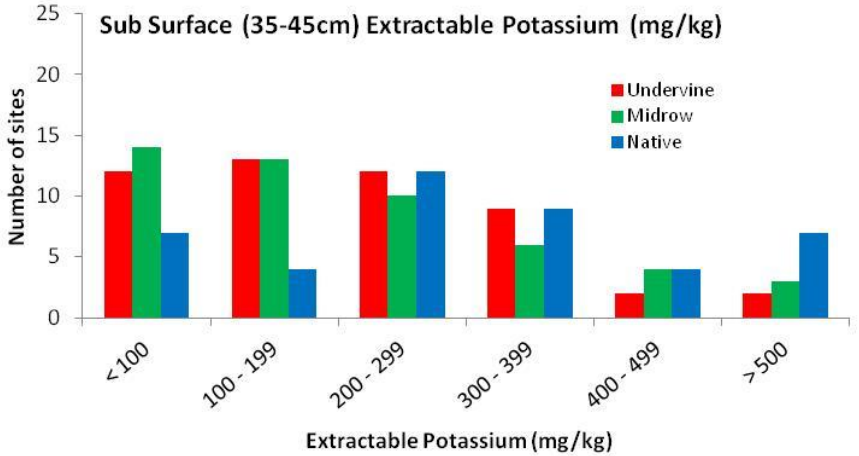


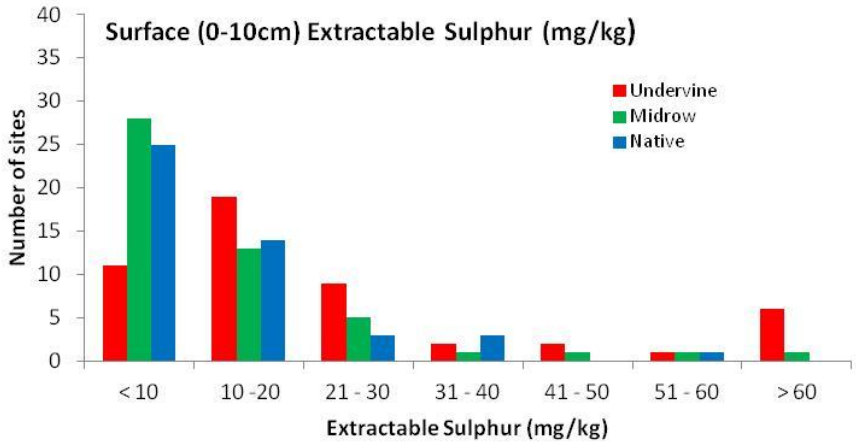


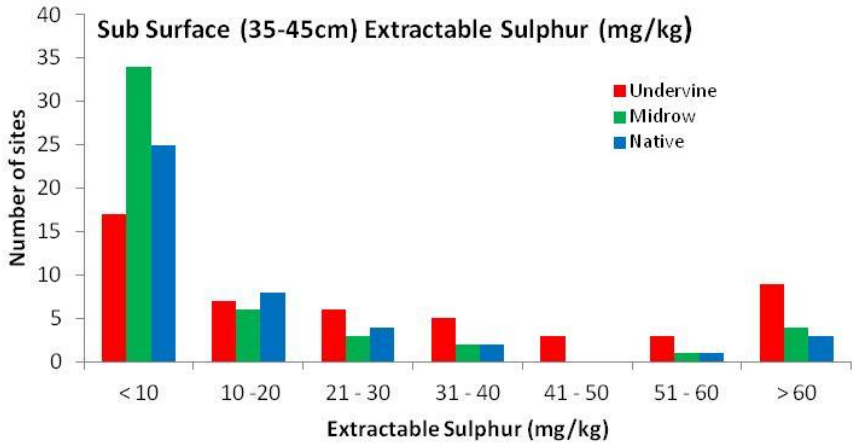

Surface (0-10cm) Extractable Phosphorus (mg/kg)
Number of sites
25
20
15
10
5
0
Undervine
Midrow
Native
< 20
20 - 39
40 - 59
60 - 79
80 - 99
> 100
Extractable Phosphorus (mg/kg)

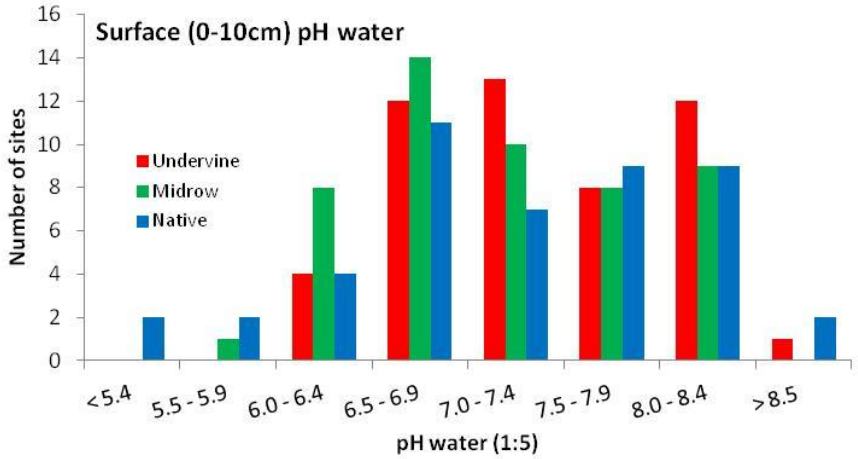

Sub surface (35-45cm) Extractable Phosphorus (mg/kg)
Number of sites
25
20
15
10
5
0
Undervine
Midrow
Native
< 5
5 - 9
10 - 14
15 - 19
20 - 49
> 50
Extractable Phosphorus (mg/kg)

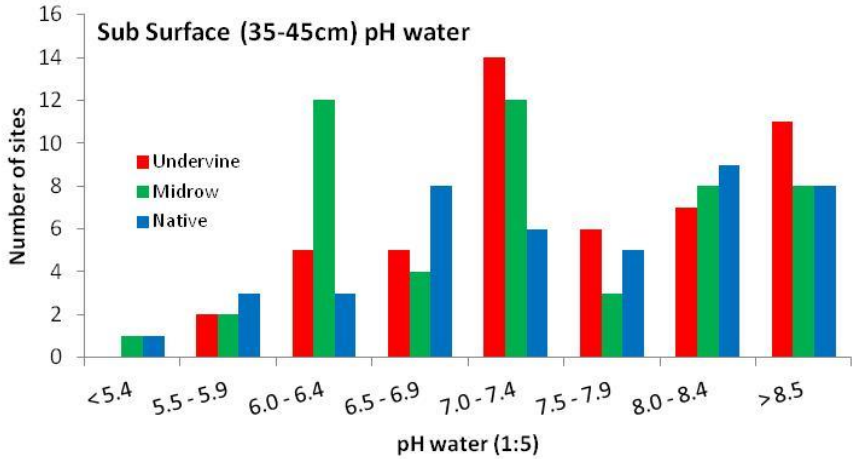

Surface (0-10cm) Extractable Potassium (mg/kg)
Number of sites
25
20
15
10
5
0
Undervine
Midrow
Native
<100
100 - 399
400 - 699
700 - 999
1000 - 1299
1300 - 1599
>1600
Extractable Potassium (mg/kg)

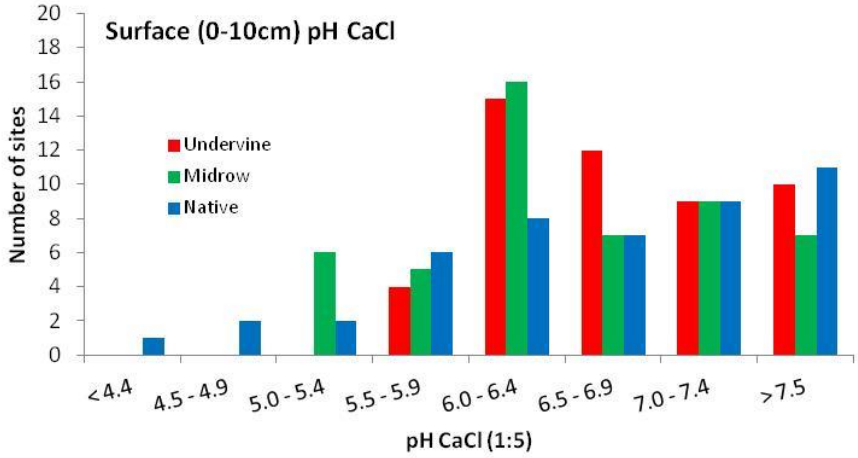

Sub Surface (35-45cm) Extractable Potassium (mg/kg)
Number of sites
25
20
15
10
5
0
Undervine
Midrow
Native
<100
100 - 199
200 - 299
300 - 399
400 - 499
>500
Extractable Potassium (mg/kg)

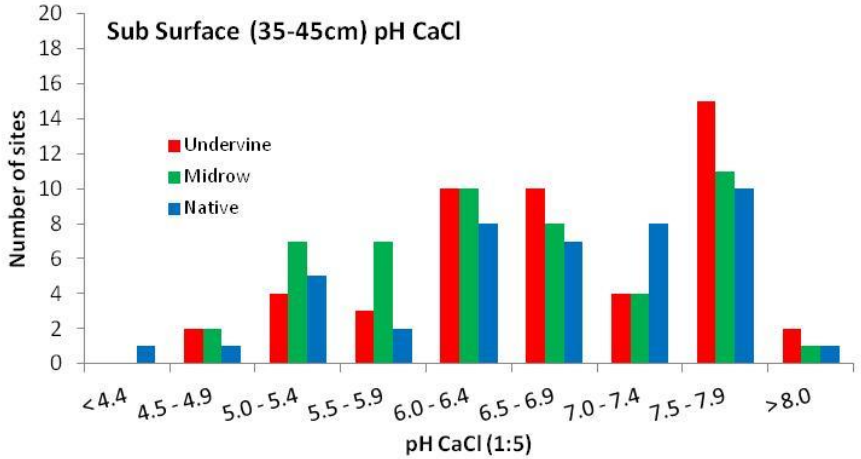

Surface (0-10cm) Extractable Sulphur (mg/kg)
Number of sites
40
35
30
25
20
15
10
5
0
Undervine
Midrow
Native
< 10
10 -20
21 - 30
31 - 40
41 - 50
51 - 60
> 60
Extractable Sulphur (mg/kg)

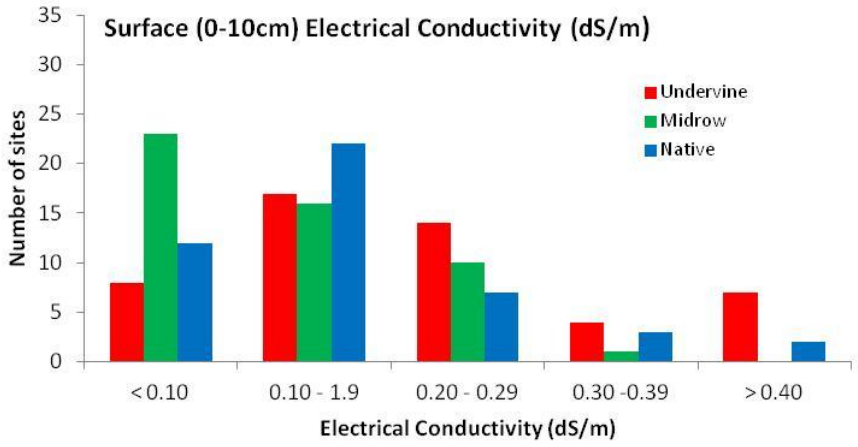

Sub Surface (35-45cm) Extractable Sulphur (mg/kg)
Number of sites
40
35
30
25
20
15
10
5
0
Undervine
Midrow
Native
< 10
10 -20
21 - 30
31 - 40
41 - 50
51 - 60
> 60
Extractable Sulphur (mg/kg)

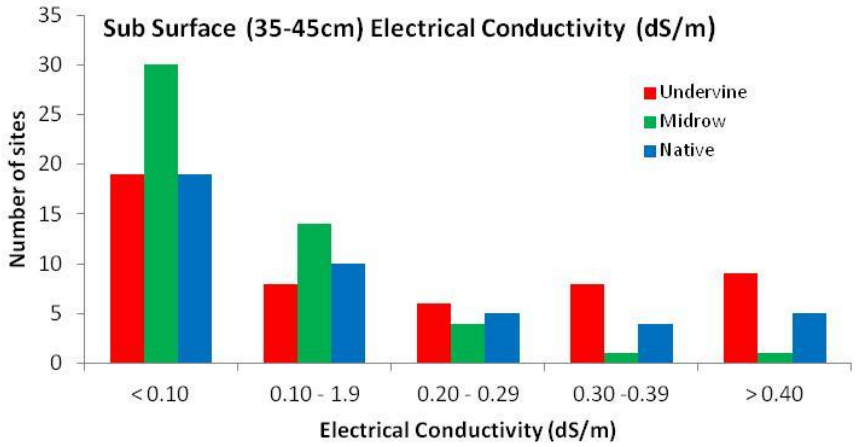

Surface (0-10cm) pH water
Number of sites
Undervine
Midrow
Native
<5.4
5.5 - 5.9
6.0 - 6.4
6.5 - 6.9
7.0 - 7.4
7.5 - 7.9
8.0 - 8.4
>8.5
pH water (1:5)

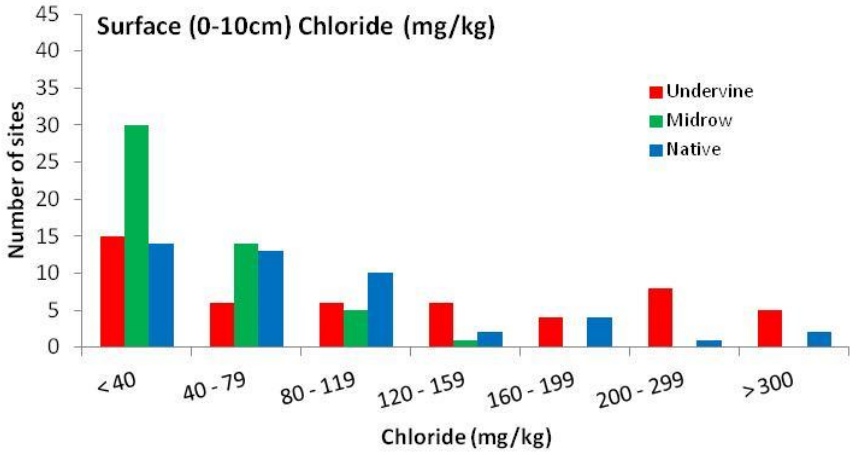

Sub Surface (35-45cm) pH water
Number of sites
Undervine
Midrow
Native
<5.4
5.5 - 5.9
6.0 - 6.4
6.5 - 6.9
7.0 - 7.4
7.5 - 7.9
8.0 - 8.4
>8.5
pH water (1:5)

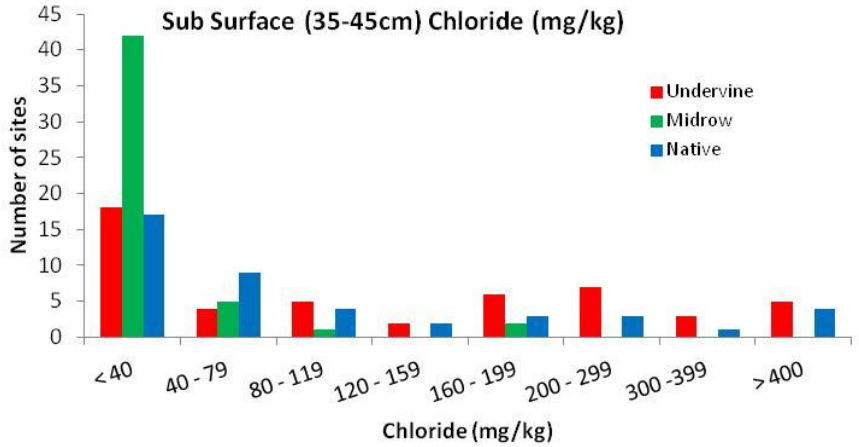

Surface (0-10cm) pH CaCl
Number of sites
Undervine
Midrow
Native
<4.4
4.5 - 4.9
5.0 - 5.4
5.5 - 5.9
6.0 - 6.4
6.5 - 6.9
7.0 - 7.4
>7.5
pH CaCl (1:5)

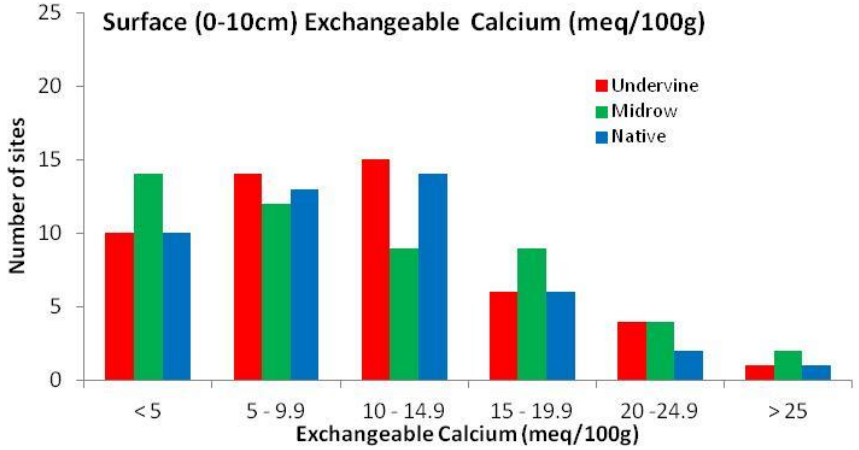

Sub Surface (35-45cm) pH CaCl
Number of sites
Undervine
Midrow
Native
<4.4
4.5 - 4.9
5.0 - 5.4
5.5 - 5.9
6.0 - 6.4
6.5 - 6.9
7.0 - 7.4
7.5 - 7.9
>8.0
pH CaCl (1:5)

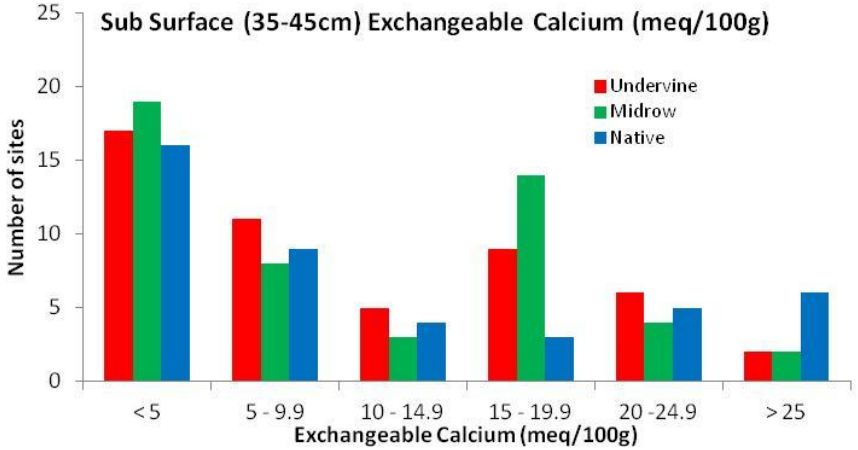

Surface (0-10cm) Electrical Conductivity (dS/m)
Number of sites
35
30
25
20
15
10
5
0
Undervine
Midrow
Native
< 0.10
0.10 - 1.9
0.20 - 0.29
0.30 -0.39
> 0.40
Electrical Conductivity (dS/m)

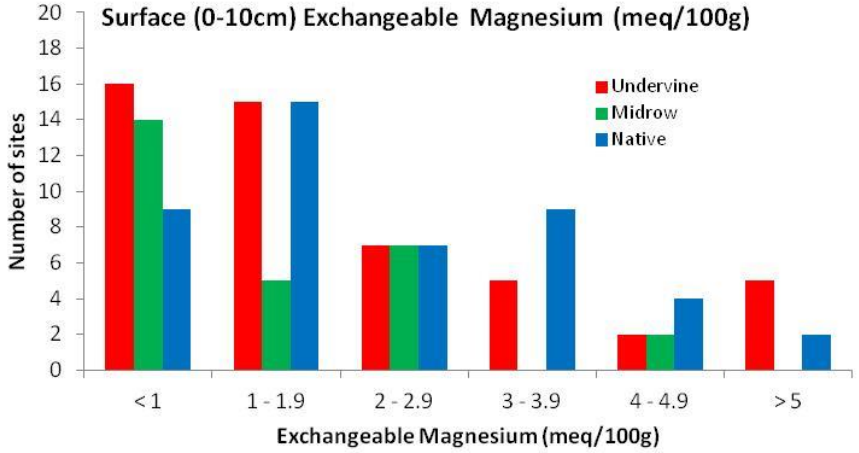

Sub Surface (35-45cm) Electrical Conductivity (dS/m)
Number of sites
35
30
25
20
15
10
5
0
Undervine
Midrow
Native
< 0.10
0.10 - 1.9
0.20 - 0.29
0.30 -0.39
> 0.40
Electrical Conductivity (dS/m)

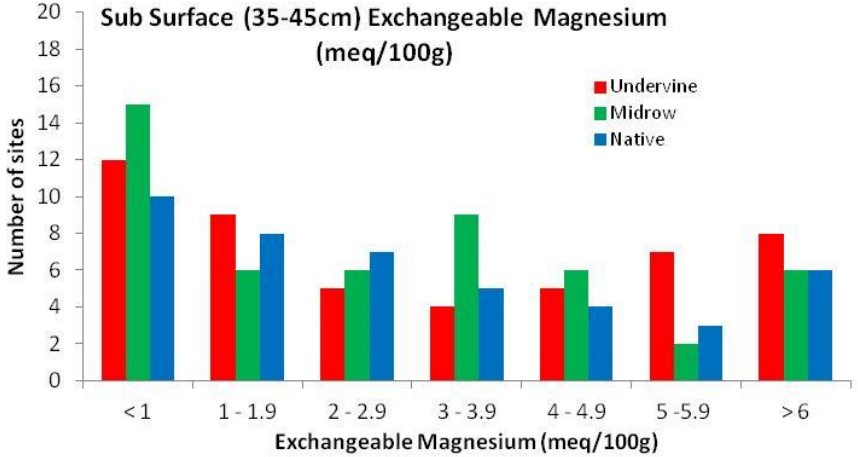

Surface (0-10cm) Chloride (mg/kg)
Number of sites
45
40
35
30
25
20
15
10
5
0
Undervine
Midrow
Native
< 40
40 - 79
80 - 119
120 - 159
160 - 199
200 - 299
> 300
Chloride (mg/kg)

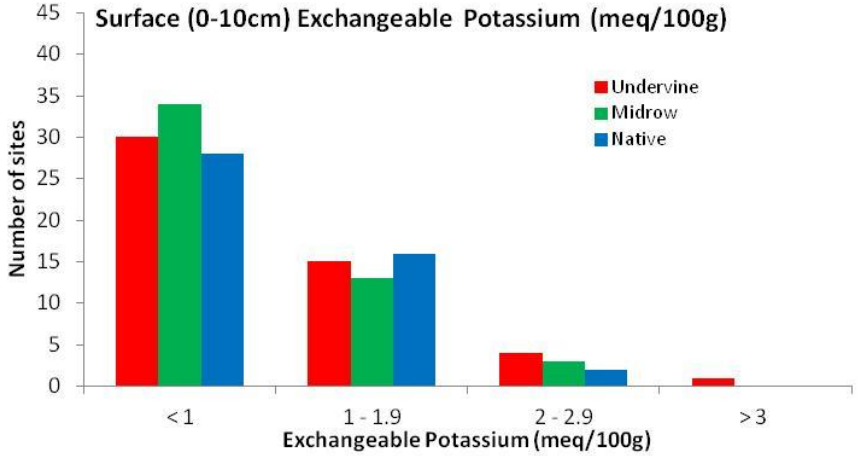

Sub Surface (35-45cm) Chloride (mg/kg)
Number of sites
45
40
35
30
25
20
15
10
5
0
Undervine
Midrow
Native
< 40
40 - 79
80 - 119
120 - 159
160 - 199
200 - 299
300 -399
> 400
Chloride (mg/kg)

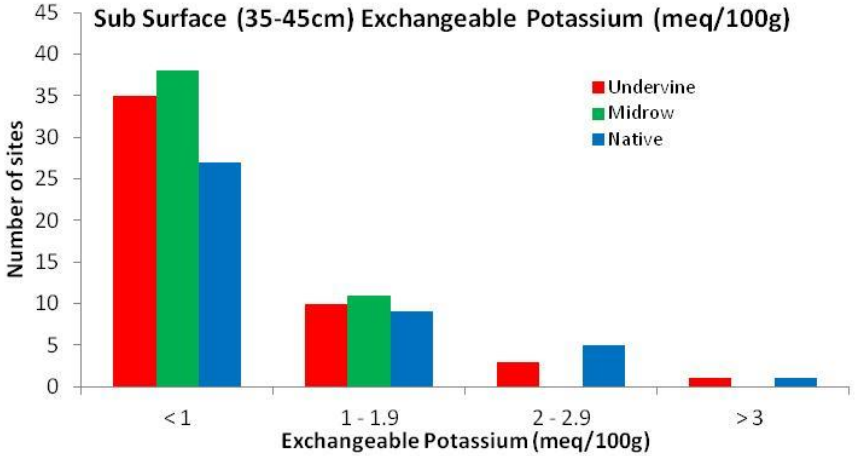

Surface (0-10cm) Exchangeable Calcium (meq/100g)
Undervine
Midrow
Native
Number of sites
0
5
10
15
20
25
< 5
5 - 9.9
10 - 14.9
15 - 19.9
20 -24.9
> 25
Exchangeable Calcium (meq/100g)

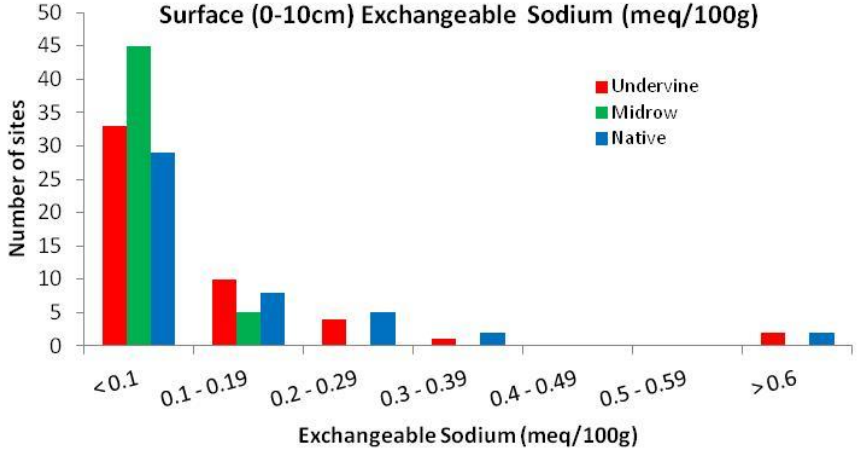

Sub Surface (35-45cm) Exchangeable Calcium (meq/100g)
Undervine
Midrow
Native
Number of sites
0
5
10
15
20
25
< 5
5 - 9.9
10 - 14.9
15 - 19.9
20 -24.9
> 25
Exchangeable Calcium (meq/100g)

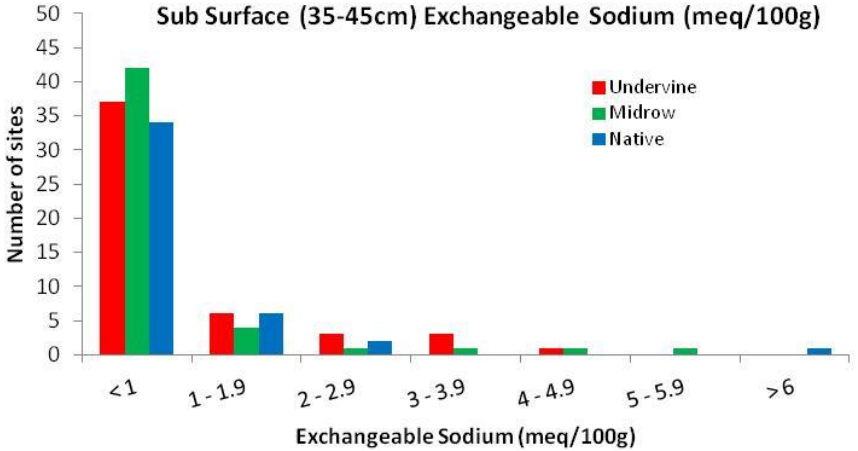

Surface (0-10cm) Exchangeable Magnesium (meq/100g)
Undervine
Midrow
Native
Number of sites
0
2
4
6
8
10
12
14
16
18
20
< 1
1 - 1.9
2 - 2.9
3 - 3.9
4 - 4.9
> 5
Exchangeable Magnesium (meq/100g)

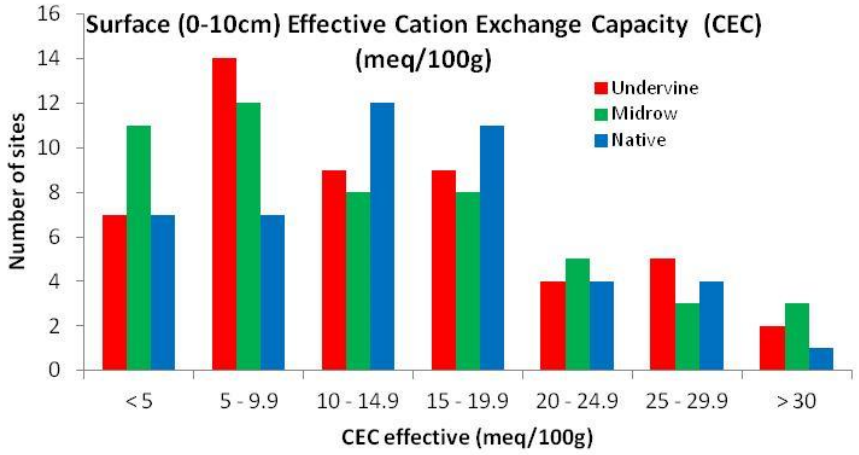

Sub Surface (35-45cm) Exchangeable Magnesium (meq/100g)
Undervine
Midrow
Native
Number of sites
0
2
4
6
8
10
12
14
16
18
20
< 1
1 - 1.9
2 - 2.9
3 - 3.9
4 - 4.9
5 -5.9
> 6
Exchangeable Magnesium (meq/100g)

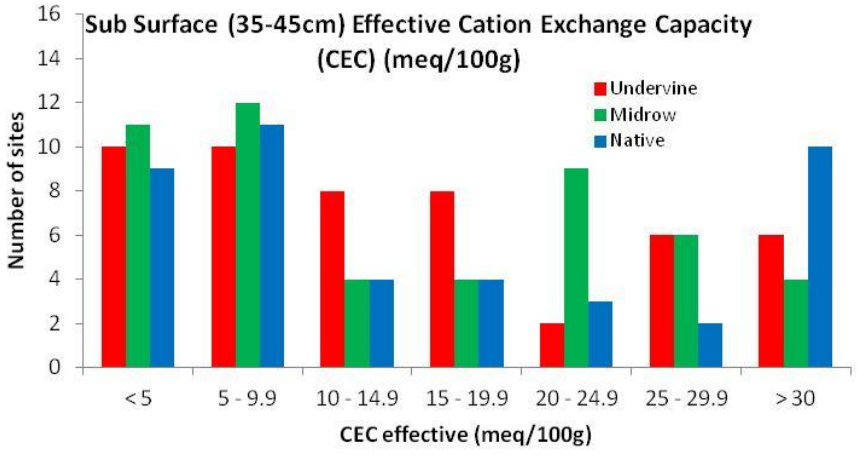

Surface (0-10cm) Exchangeable Potassium (meq/100g)
Number of sites
Undervine
Midrow
Native
< 1
1 - 1.9
2 - 2.9
> 3
Exchangeable Potassium (meq/100g)

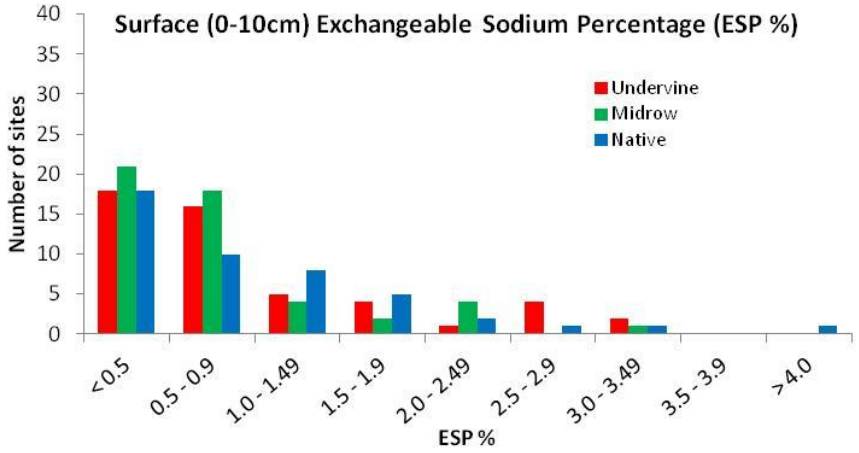

Sub Surface (35-45cm) Exchangeable Potassium (meq/100g)
Number of sites
Undervine
Midrow
Native
< 1
1 - 1.9
2 - 2.9
> 3
Exchangeable Potassium (meq/100g)

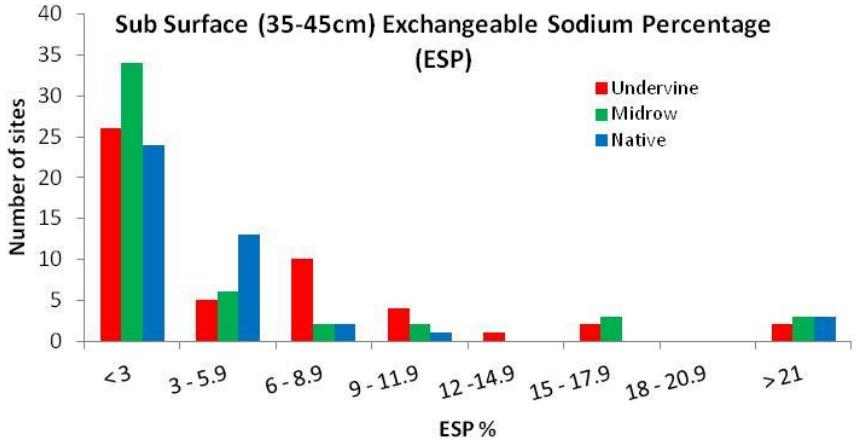

Surface (0-10cm) Exchangeable Sodium (meq/100g)
Number of sites
Undervine
Midrow
Native
<0.1
0.1 - 0.19
0.2 - 0.29
0.3 - 0.39
0.4 - 0.49
0.5 - 0.59
>0.6
Exchangeable Sodium (meq/100g)

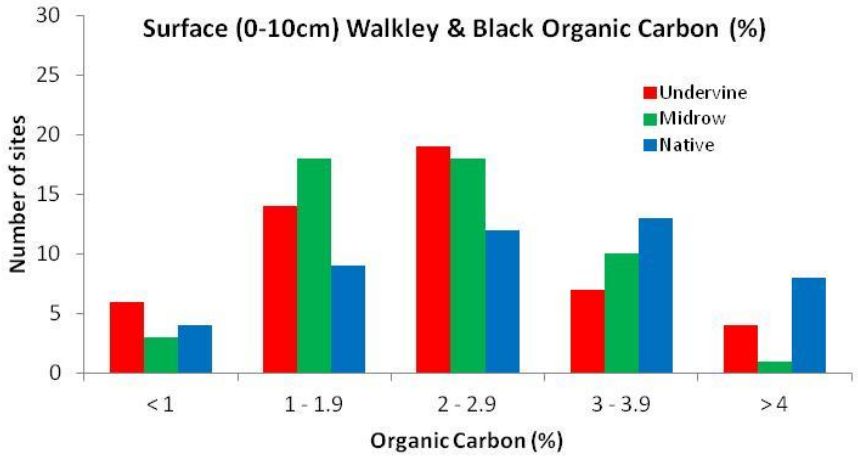

Sub Surface (35-45cm) Exchangeable Sodium (meq/100g)
Number of sites
Undervine
Midrow
Native
<1
1 - 1.9
2 - 2.9
3 - 3.9
4 - 4.9
5 - 5.9
>6
Exchangeable Sodium (meq/100g)

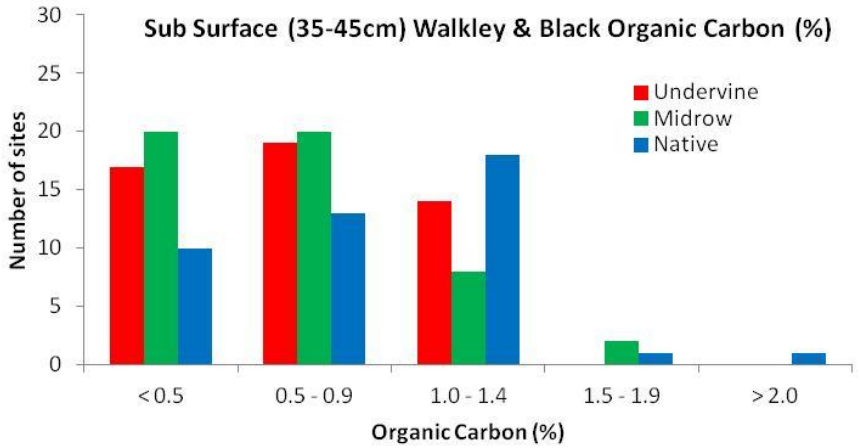

Surface (0-10cm) Effective Cation Exchange Capacity (CEC) (meq/100g)
Undervine
Midrow
Native
Number of sites
0
2
4
6
8
10
12
14
16
< 5
5 - 9.9
10 - 14.9
15 - 19.9
20 - 24.9
25 - 29.9
> 30
CEC effective (meq/100g)

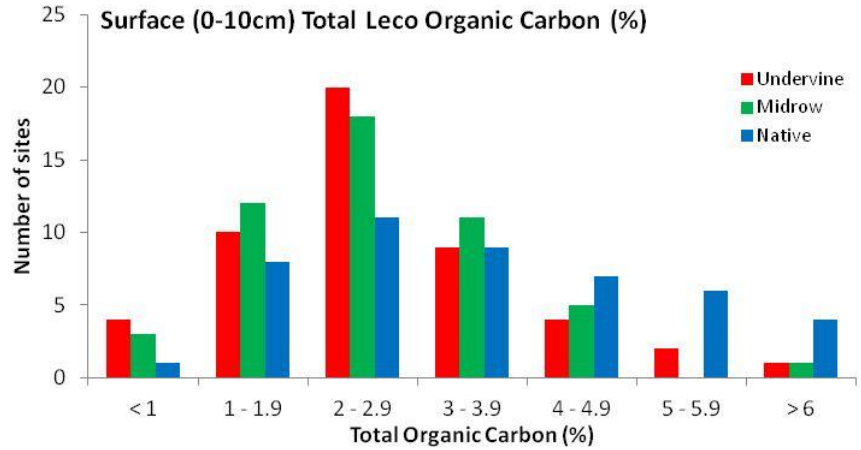

Sub Surface (35-45cm) Effective Cation Exchange Capacity (CEC) (meq/100g)
Undervine
Midrow
Native
Number of sites
0
2
4
6
8
10
12
14
16
< 5
5 - 9.9
10 - 14.9
15 - 19.9
20 - 24.9
25 - 29.9
> 30
CEC effective (meq/100g)

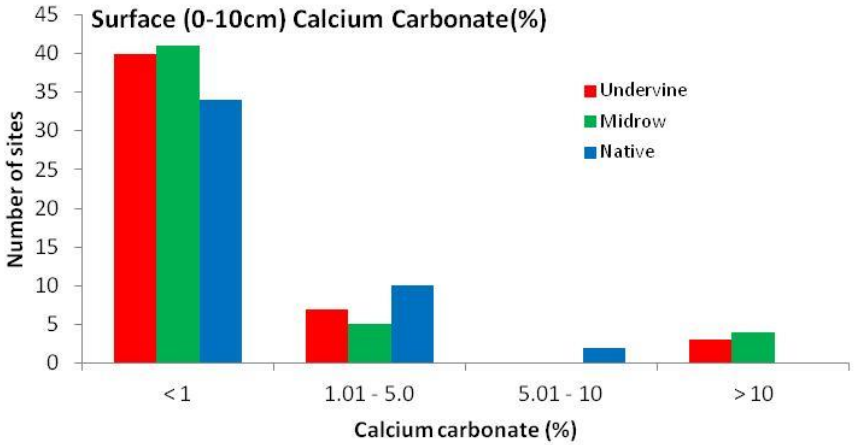

Surface (0-10cm) Exchangeable Sodium Percentage (ESP %)
Undervine
Midrow
Native
Number of sites
0
5
10
15
20
25
30
35
40
<0.5
0.5 - 0.9
1.0 - 1.49
1.5 - 1.9
2.0 - 2.49
2.5 - 2.9
3.0 - 3.49
3.5 - 3.9
>4.0
ESP %

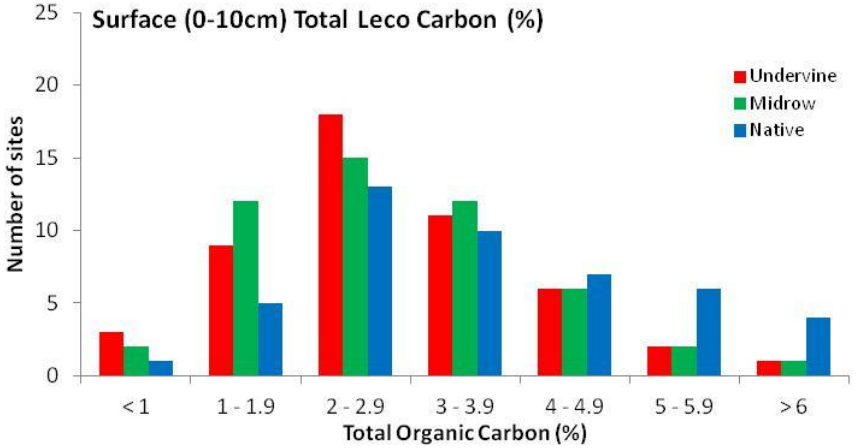

Sub Surface (35-45cm) Exchangeable Sodium Percentage (ESP)
Undervine
Midrow
Native
Number of sites
0
5
10
15
20
25
30
35
40
< 3
3 - 5.9
6 - 8.9
9 - 11.9
12 -14.9
15 - 17.9
18 - 20.9
> 21
ESP %

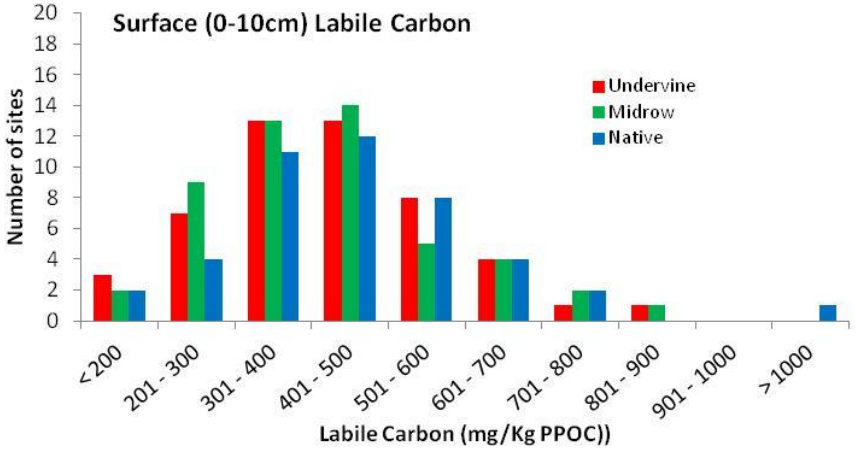

Surface (0-10cm) Walkley & Black Organic Carbon (%)
Number of sites
30
25
20
15
10
5
0
Undervine
Midrow
Native
< 1
1 - 1.9
2 - 2.9
3 - 3.9
> 4
Organic Carbon (%)

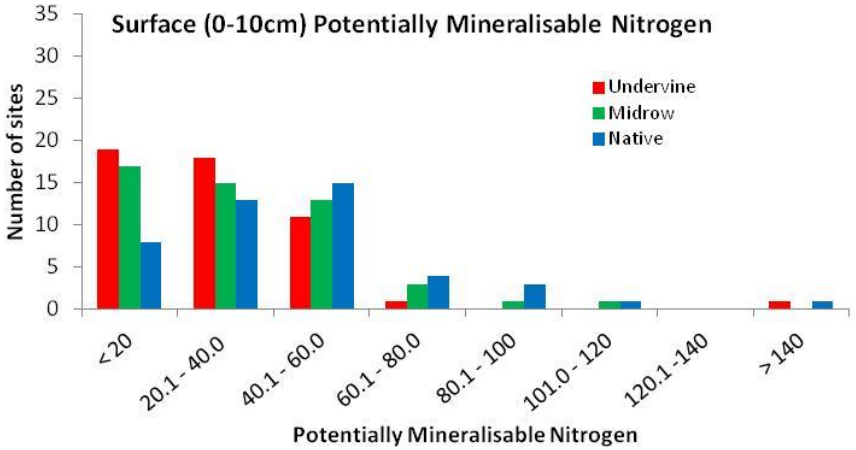

Sub Surface (35-45cm) Walkley & Black Organic Carbon (%)
Number of sites
30
25
20
15
10
5
0
Undervine
Midrow
Native
< 0.5
0.5 - 0.9
1.0 - 1.4
1.5 - 1.9
> 2.0
Organic Carbon (%)

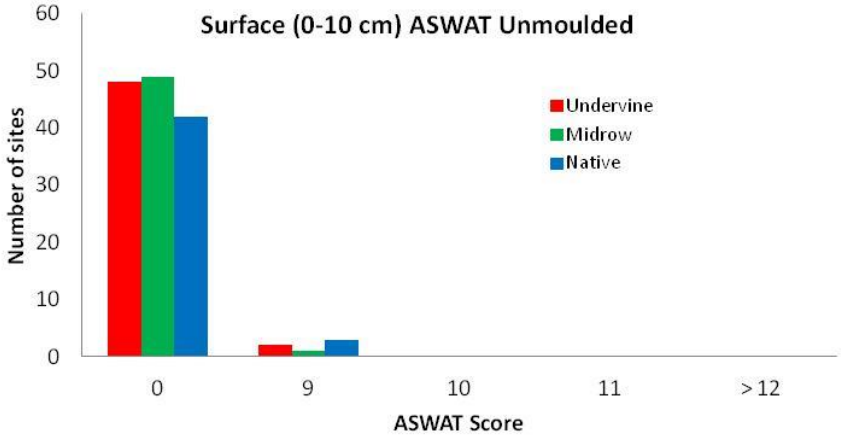

Surface (0-10cm) Total Leco Organic Carbon (%)
Number of sites
25
20
15
10
5
0
Undervine
Midrow
Native
< 1
1 - 1.9
2 - 2.9
3 - 3.9
4 - 4.9
5 - 5.9
> 6
Total Organic Carbon (%)

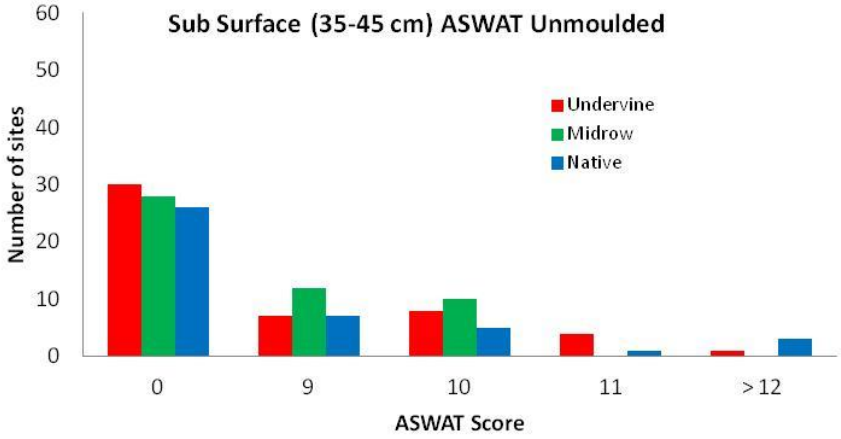

Surface (0-10cm) Calcium Carbonate(%)
Number of sites
45
40
35
30
25
20
15
10
5
0
Undervine
Midrow
Native
< 1
1.01 - 5.0
5.01 - 10
> 10
Calcium carbonate (%)

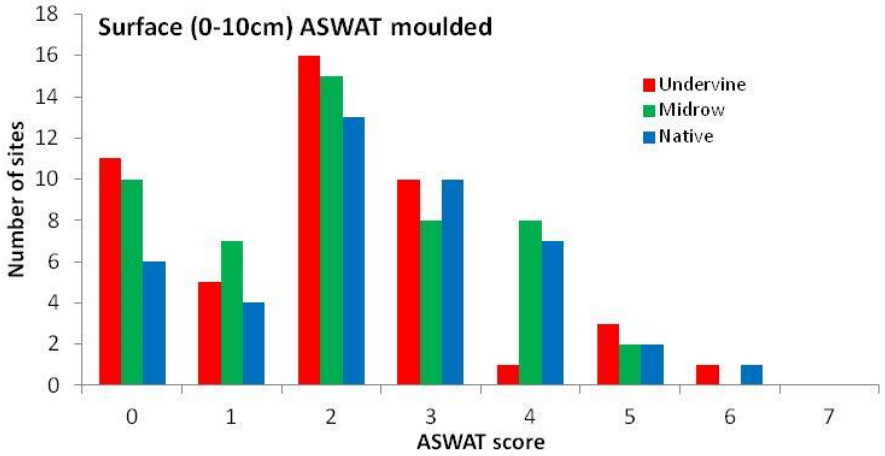

Surface (0-10cm) Total Leco Carbon (%)
Undervine
Midrow
Native
Number of sites
25
20
15
10
5
0
< 1
1 - 1.9
2 - 2.9
3 - 3.9
4 - 4.9
5 - 5.9
> 6
Total Organic Carbon (%)

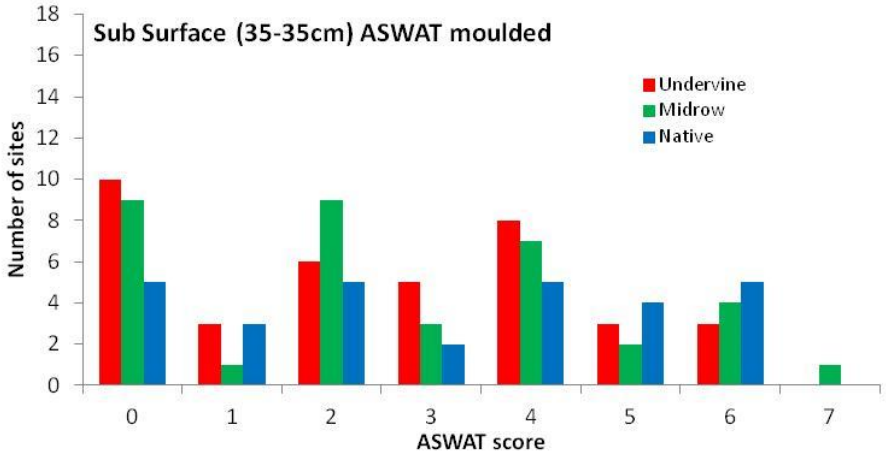

Surface (0-10cm) Labile Carbon
Undervine
Midrow
Native
Number of sites
20
18
16
14
12
10
8
6
4
2
0
<200
201 - 300
301 - 400
401 - 500
501 - 600
601 - 700
701 - 800
801 - 900
901 - 1000
>1000
Labile Carbon (mg/Kg PPOC))

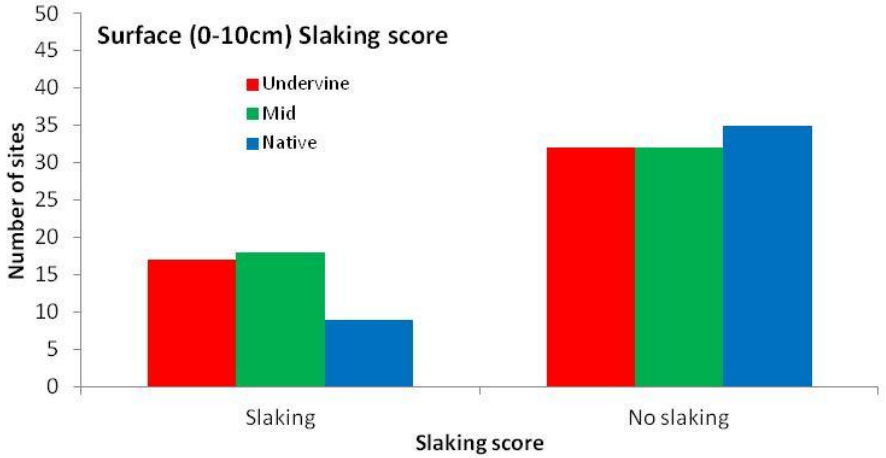

Surface (0-10cm) Potentially Mineralisable Nitrogen
Undervine
Midrow
Native
Number of sites
35
30
25
20
15
10
5
0
<20
20.1 - 40.0
40.1 - 60.0
60.1 - 80.0
80.1 - 100
101.0 - 120
120.1 -140
>140
Potentially Mineralisable Nitrogen

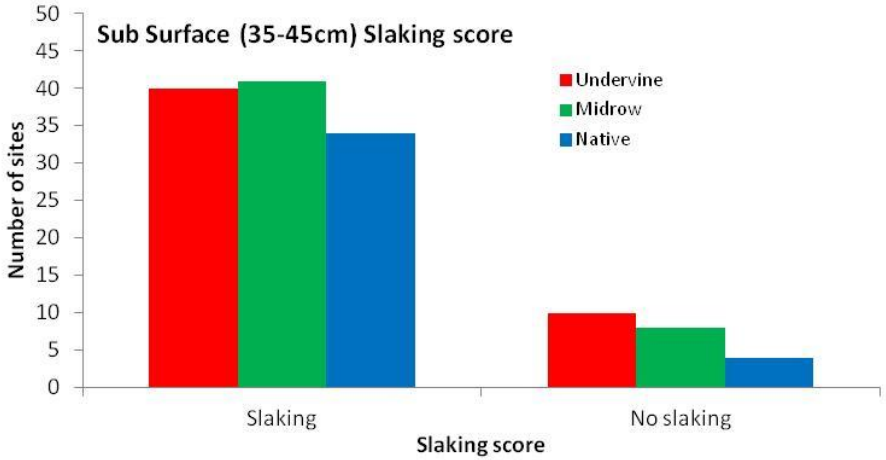

Surface (0-10 cm) ASWAT Unmoulded
Number of sites
60
50
40
30
20
10
0
Undervine
Midrow
Native
0
9
10
11
>12
ASWAT Score

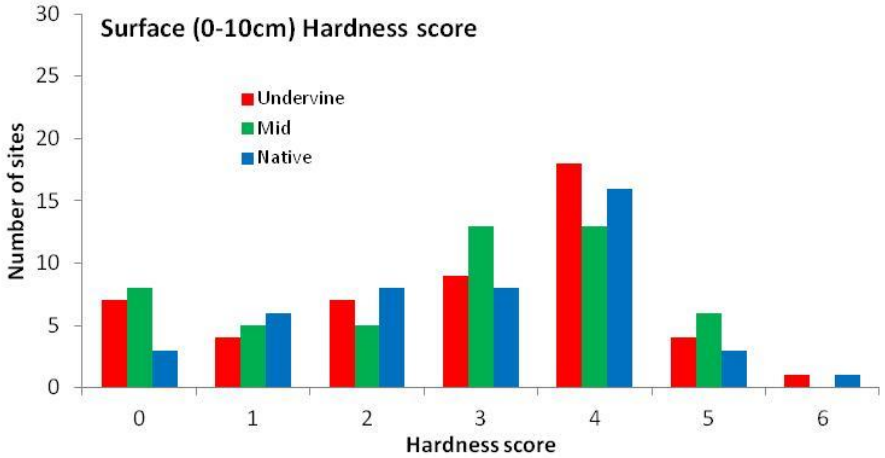

Sub Surface (35-45 cm) ASWAT Unmoulded
Number of sites
60
50
40
30
20
10
0
Undervine
Midrow
Native
0
9
10
11
>12
ASWAT Score


Surface (0-10cm) ASWAT moulded
Number of sites
18
16
14
12
10
8
6
4
2
0
Undervine
Midrow
Native
0
1
2
3
4
5
6
7
ASWAT score


Sub Surface (35-35cm) ASWAT moulded
Number of sites
18
16
14
12
10
8
6
4
2
0
Undervine
Midrow
Native
0
1
2
3
4
5
6
7
ASWAT score


Surface (0-10cm) Slaking score
Undervine
Mid
Native
Number of sites
Slaking
No slaking
Slaking score


Sub Surface (35-45cm) Slaking score
Undervine
Midrow
Native
Number of sites
Slaking
No slaking
Slaking score


Surface (0-10cm) Hardness score
Undervine
Mid
Native
Number of sites
Hardness score

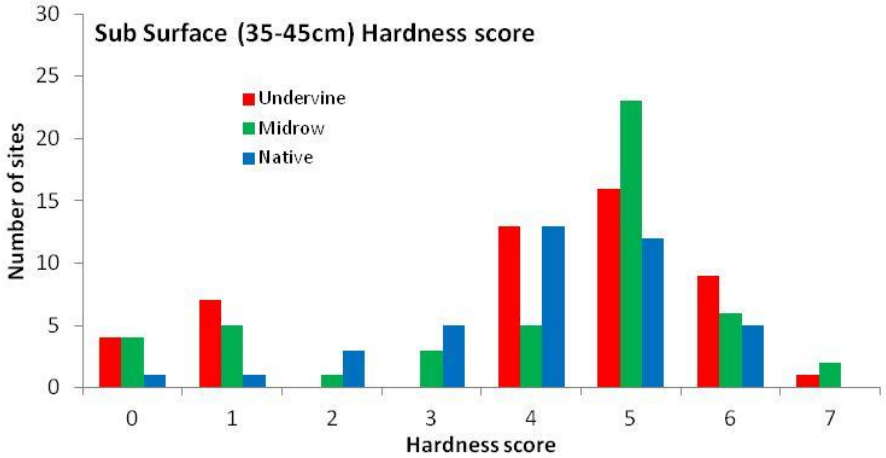

Sub Surface (35-45cm) Hardness score
Undervine
Midrow
Native
Number of sites
Hardness score

Table 5.8 Reproducibility of chemical and biological measurements made on the same soil sample in triplicate.

Laboratory variability for chemical and biological analyses was determined by submitting a subset (10%) of the soils for analyses in triplicate. The subset was chosen to represent a cross section of soil types and viticultural practices in McLaren Vale as well as sampling location (i.e. undervine, midrow or native). The results for these triplicate analyses of the same soil sample are given below. The results reported are for 2013 data only.

In each of the following tables, soil type is denoted by: Hard Red Brown, HRB; Sand over Clay, SoC; Deep uniform to gradational, DuG; Cracking clay, CC; Deep loamy texture contrast, DLTC; Calcareous, Cal.

Table 5.8a Average +/- standard deviation (std dev) for chemical properties measured in 9 surface (0-10cm) soils in triplicate by commercial laboratory.

Site	Soil Type	Sampling Location		Ammonium Nitrogen (mg/kg)	Nitrate Nitrogen (mg/kg)	Phosphorus Colwell (mg/kg)	Potassium Colwell (mg/kg)	Sulphur (mg/kg)	Organic Carbon (%)	Conductivity (dS/m)
2	HRB	Native	average	5.00	20.00	43.67	1309.00	22.43	3.85	0.23
			std dev	0.00	0.00	4.04	91.03	0.23	0.19	0.02
			%CV	0%	0%	9%	7%	1%	5%	7%
4	HRB	Undervine	average	5.33	8.00	107.67	1188.33	20.00	2.72	0.28
			std dev	0.58	0.00	6.66	81.99	1.50	0.19	0.01
			%CV	11%	0%	6%	7%	8%	7%	5%
5	Cal	Midrow	average	5.00	13.67	46.67	753.67	24.33	3.14	0.28
			std dev	0.00	1.15	4.51	20.55	0.80	0.17	0.01
			%CV	0%	8%	10%	3%	3%	6%	3%
8	HRB	Undervine	average	6.67	20.67	150.33	1265.33	16.97	2.85	0.22
			std dev	1.15	0.58	22.03	153.13	0.95	0.19	0.01
			%CV	17%	3%	15%	12%	6%	7%	6%
3	HRB	Undervine	average	2.33	12.00	55.67	171.67	49.13	0.84	0.17
			std dev	0.58	2.00	3.79	37.29	18.87	0.15	0.02
			%CV	25%	17%	7%	22%	38%	17%	10%
23	DLTC	Native	average	6.33	14.33	82.00	491.33	12.77	4.11	0.19
			std dev	4.93	4.51	24.56	169.90	4.12	2.23	0.10
			%CV	78%	31%	30%	35%	32%	54%	55%
26	HRB	Midrow	average	5.67	3.33	93.33	716.00	9.03	2.24	0.15
			std dev	0.58	1.15	2.31	46.77	1.85	0.10	0.03
			%CV	10%	35%	2%	7%	20%	5%	22%
27	HRB	Native	average	5.00	16.33	19.67	358.00	6.30	2.00	0.11
			std dev	1.00	1.53	4.04	46.52	0.96	0.27	0.01
			%CV	20%	9%	21%	13%	15%	13%	13%
27	HRB	Midrow	average	3.67	8.00	75.67	449.67	8.43	2.66	0.10
			std dev	0.58	1.73	12.34	48.69	0.64	0.23	0.00
			%CV	16%	22%	16%	11%	8%	9%	3%

Table 5.8a continued. Average +/- standard deviation (std dev) for chemical properties measured in 9 surface (0-10cm) soils in triplicate by commercial laboratory.

Site	Soil Type	Sampling Location		pH (CaCl2)	pH (H2O)	Chloride (mg/kg)	Total Nitrogen (%)	Total Carbon (%)	Calcium Carbonate (%)
2	HRB	Native	average	6.37	6.87	95.87	0.41	6.00	0.31
			std dev	0.06	0.06	13.03	0.01	0.11	0.01
			%CV	1%	1%	14%	1%	2%	3%
4	HRB	Undervine	average	7.23	7.77	137.43	0.20	2.95	0.48
			std dev	0.06	0.06	20.85	0.00	0.04	0.04
			%CV	1%	1%	15%	0%	1%	7%
5	Cal	Midrow	average	7.63	8.20	81.57	0.29	5.55	14.96
			std dev	0.06	0.00	2.54	0.01	0.05	1.56
			%CV	1%	0%	3%	2%	1%	10%
8	HRB	Undervine	average	7.20	7.80	55.00	0.23	3.37	0.53
			std dev	0.00	0.00	6.55	0.01	0.13	0.04
			%CV	0%	0%	12%	5%	4%	8%
3	HRB	Undervine	average	6.40	6.80	57.83	0.09	0.92	0.28
			std dev	0.10	0.00	6.99	0.01	0.03	0.01
			%CV	2%	0%	12%	11%	3%	4%
23	DLTC	Native	average	6.40	6.90	106.60	0.61	4.84	0.35
			std dev	0.35	0.35	58.92	0.15	2.88	0.09
			%CV	5%	5%	55%	25%	60%	25%
26	HRB	Midrow	average	6.77	7.27	34.83	0.46	2.68	0.29
			std dev	0.12	0.12	6.89	0.02	0.15	0.05
			%CV	2%	2%	20%	5%	6%	16%
27	HRB	Native	average	5.63	6.30	48.43	0.44	2.10	0.28
			std dev	0.40	0.26	1.66	0.03	0.07	0.01
			%CV	7%	4%	3%	6%	3%	2%
27	HRB	Midrow	average	6.20	6.87	27.40	0.24	2.78	0.27
			std dev	0.10	0.06	7.26	0.02	0.24	0.02
			%CV	2%	1%	26%	6%	9%	8%

Table 5.8a continued. Average +/- standard deviation (std dev) for chemical properties measured in 9 surface (0-10cm) soils in triplicate by commercial laboratory.

Site	Soil Type	Sampling Location		Prewash exch. Ca (meq/100g)	Prewash exch. K (meq/100g)	Prewash exch. Mg (meq/100g)	Prewash exch. Na (meq/100g)
2	HRB	Native	average	11.25	1.43	2.51	0.05
			std dev	0.19	0.03	0.07	0.00
			%CV	2%	2%	3%	0%
4	HRB	Undervine	average	13.90	1.60	3.33	0.08
			std dev	0.78	0.09	0.18	0.03
			%CV	6%	6%	5%	35%
5	Cal	Midrow	average	26.46	1.97	2.41	0.05
			std dev	0.61	0.11	0.07	0.00
			%CV	2%	5%	3%	0%
8	HRB	Undervine	average	13.70	1.74	2.05	0.05
			std dev	0.29	0.01	0.06	0.00
			%CV	2%	1%	3%	0%
3	HRB	Undervine	average	2.38	0.16	0.13	0.05
			std dev	0.19	0.06	0.02	0.00
			%CV	8%	41%	11%	0%
23	DLTC	Native	average	10.37	0.61	2.37	0.09
			std dev	5.37	0.36	2.65	0.07
			%CV	52%	60%	112%	77%
26	HRB	Midrow	average	14.41	1.67	2.10	0.05
			std dev	2.09	0.22	0.36	0.00
			%CV	14%	13%	17%	0%
27	HRB	Native	average	3.68	0.44	1.16	0.05
			std dev	0.42	0.04	0.06	0.00
			%CV	11%	9%	6%	0%
27	HRB	Midrow	average	5.57	0.58	0.81	0.05
			std dev	0.25	0.07	0.08	0.00
			%CV	4%	12%	9%	0%

Table 5.8b. Average +/- standard deviation (std dev) for chemical properties measured in 8 sub-surface (35-45 cm) soils in triplicate by commercial laboratory.

Site	Soil Type	Sampling Location		Ammonium Nitrogen (mg/kg)	Nitrate Nitrogen (mg/kg)	Phosphorus Colwell (mg/kg)	Potassium Colwell (mg/kg)	Sulphur (mg/kg)	Organic Carbon (%)	Conductivity (dS/m)
1	HRB	Native	average	1.33	4.67	6.00	286.67	6.33	1.26	0.10
			std dev	0.58	0.58	1.00	25.66	0.31	0.09	0.04
			%CV	43%	12%	17%	9%	5%	7%	40%
4	HRB	Midrow	average	0.67	2.33	5.67	131.33	9.03	1.04	0.35
			std dev	0.29	0.58	0.58	10.97	0.45	0.07	0.10
			%CV	43%	25%	10%	8%	5%	7%	30%
10	SoC	Midrow	average	0.50	0.67	5.67	15.17	3.60	0.22	0.02
			std dev	0.00	0.29	0.58	6.93	0.20	0.08	0.00
			%CV	0%	43%	10%	46%	6%	34%	2%
11		Undervine	average	0.50	0.50	3.67	23.33	1.80	0.18	0.01
			std dev	0.00	0.00	0.58	0.58	0.10	0.05	0.00
			%CV	0%	0%	16%	2%	6%	27%	40%
12	SoC	Midrow	average	0.50	1.00	4.67	58.33	10.63	0.32	0.05
			std dev	0.00	0.00	0.58	7.51	2.01	0.08	0.01
			%CV	0%	0%	12%	13%	19%	24%	18%
17	SoC	Undervine	average	0.50	0.50	22.00	30.00	2.77	0.32	0.03
			std dev	0.00	0.00	3.46	19.08	0.25	0.36	0.00
			%CV	0%	0%	16%	64%	9%	113%	16%
20	HRB	Native	average	0.50	2.00	3.33	307.33	3.50	0.50	0.05
			std dev	0.00	0.00	0.58	6.11	0.20	0.08	0.01
			%CV	0%	0%	17%	2%	6%	15%	20%
22	DLTC	Native	average	0.50	0.50	2.33	268.33	9.23	0.32	0.07
			std dev	0.00	0.00	0.58	8.50	0.12	0.02	0.00
			%CV	0%	0%	25%	3%	1%	6%	6%

Table 5.8b continued. Average +/- standard deviation (std dev) for chemical properties measured in 8 sub-surface (35-45 cm) soils in triplicate by commercial laboratory. (N=native, M=midrow, U= undervine)

Site	Soil Type	Sampling location		pH CaCl2	pH Level	Chloride (mg/kg)	exch. Ca (meq/100g)	exch. K (meq/100g)	exch. Mg (meq/100g)	exch. Na (meq/100g)
1	HRB	Native	average	6.83	7.67	6.80	9.16	0.60	1.97	8.96
			std dev	0.35	0.31	1.54	0.70	0.02	0.08	0.58
			%CV	5%	4%	23%	8%	3%	4%	6%
4	HRB	Midrow	average	7.70	8.70	188.80	21.75	0.44	3.66	0.66
			std dev	0.00	0.00	19.59	1.19	0.02	0.23	0.09
			%CV	0%	0%	10%	5%	5%	6%	14%
10	SoC	Midrow	average	5.93	6.70	8.73	3.89	6.93	0.51	0.85
			std dev	0.06	0.10	1.46	2.81	3.03	0.26	1.07
			%CV	1%	1%	17%	72%	44%	52%	126%
11	SoC	Undervine	average	5.47	6.33	4.20	2.30	0.06	0.20	0.09
			std dev	0.31	0.12	0.44	3.14	0.04	0.25	0.06
			%CV	6%	2%	10%	137%	67%	129%	73%
12	SoC		average	6.43	7.17	17.00	1.89	0.13	0.91	2.95
			std dev	0.12	0.15	3.04	0.34	0.01	0.18	4.90
			%CV	2%	2%	18%	18%	9%	20%	166%
17	SoC	Undervine	average	6.87	7.50	9.27	0.59	1.75	0.22	3.00
			std dev	0.15	0.20	1.35	0.47	1.48	0.07	4.16
			%CV	2%	3%	15%	80%	85%	30%	139%
20	HRB	Native	average	7.03	8.03	7.43	3.90	0.51	2.00	0.14
			std dev	0.06	0.06	1.72	0.17	0.02	0.07	0.01
			%CV	1%	1%	23%	4%	3%	4%	7%
22	DLTC	Native	average	5.07	6.07	58.10	1.50	0.36	1.12	0.13
			std dev	0.06	0.06	5.37	0.07	0.02	0.04	0.01
			%CV	1%	1%	9%	4%	5%	4%	9%

Table 5.8c. Average +/- standard deviation (std dev) for biological properties measured in 9 surface (0-10cm) soils in triplicate by commercial laboratory.

Site	Soil Type	Sampling Location		MBC (mg/kg dry soil)	PMN (mg NH4-N / kg dry soil)	Labile C (mg/kg)
2	HRB	Native	average	172.568	63.353	799.06
			std dev	31.545	1.792	32.15
			%CV	18%	3%	4%
4	HRB	Undervine	average	103.910	48.661	614.92
			std dev	11.863	3.175	70.93
			%CV	11%	7%	12%
5	Cal	Midrow	average	223.904	59.375	561.26
			std dev	34.958	3.559	148.50
			%CV	16%	6%	26%
8	HRB	Undervine	average	108.439	53.279	692.27
			std dev	60.204	4.934	76.71
			%CV	56%	9%	11%
3	HRB	Undervine	average	50.138	3.091	297.94
			std dev	10.957	1.221	47.70
			%CV	22%	39%	16%
23	DLTC	Native	average	488.952	64.603	775.23
			std dev	76.463	4.072	115.33
			%CV	16%	6%	15%
26	HRB	Midrow	average	296.401	39.942	574.24
			std dev	18.977	2.179	41.63
			%CV	6%	5%	7%
27	HRB	Native	average	330.457	55.426	684.95
			std dev	55.787	5.746	26.63
			%CV	17%	10%	4%
27	HRB	Midrow	average	193.242	47.158	450.51
			std dev	62.999	7.870	109.38
			%CV	33%	17%	24%

Chapter 6: Benchmarking indicators of soil quality at regional scale –Barossa

6.1 Introduction

The Barossa is one of the best known and revered wine making regions in the world, located 60 km northeast of Adelaide. With the oldest vines planted in 1843, the region contributes a significant proportion of Australian's premium grape and wine production. Barossa has accounted for between 18 and 20 percent of Australian exports greater than $7.50 per litre in volume at a value worth $77.6M.

The Barossa incorporates both Barossa Valley and Eden Valley. The Barossa is renowned for Shiraz and Eden Valley Riesling, with Cabernet Sauvignon, Grenache, Mataro (also known as Mourvedre), Grenache, Viognier, Semillon and Merlot contributing to varieties grown. There is a diversity of growing conditions and soil types across both valleys.

The region has a typical Mediterranean climate with dry summers and mild winters, making it one of the only areas in Australia to have neighbouring warm and cool climate growing conditions (Figure 6.1). Most rain falls between April and October with an average annual rainfall of 550 mm.

More recently, sub-regions (or parishes) have been designated within the Barossa, which denotes places that have reputations for consistently making a specific style of wine based on geographic location (Figure 6.2). The sub-regions do not have strict boundaries, rather describe the different grounds of the Barossa including microclimate, soil and aspect. The main sub-regions for the purpose of this study are: (1) Light Pass/Central/Nurioopta; (2) Gomersal; (3) Barossa Foothills/Bethany/Vine Vale; (4) Stonewell/Marananga, (5) Lyndoch/Williamstown; (6) Ebenezer/Kalimna/Koonunga (Northern); (7) Greenock/Seppeltsfield; (8) Rowland Flat and (9) Northern Eden/Central Eden/South Eden/High Eden (Eden).

This study aligned with the Barossa Grounds Project, initiated and funded by the Barossa Grape and Wine Association (BGWA). The project considers differences and similarities in the wine style of Shiraz due to 'terroir', or place of origin as opposed to the winemaker/winegrower. Shiraz wines from single vineyard sites are selected to compile a set of descriptors for the wines from the different sub-regions in the Barossa.

This chapter provides data from the soil analyses and outlines the distribution of data for each soil property measured for soils collected from the Barossa region, South Australia.

The objective here was to establish benchmarks as to typical regional and sub-regional values in Barossa and their distribution, so that through repeat measures in the future, assessment can be made of the effect of continued viticultural production on these soil properties.



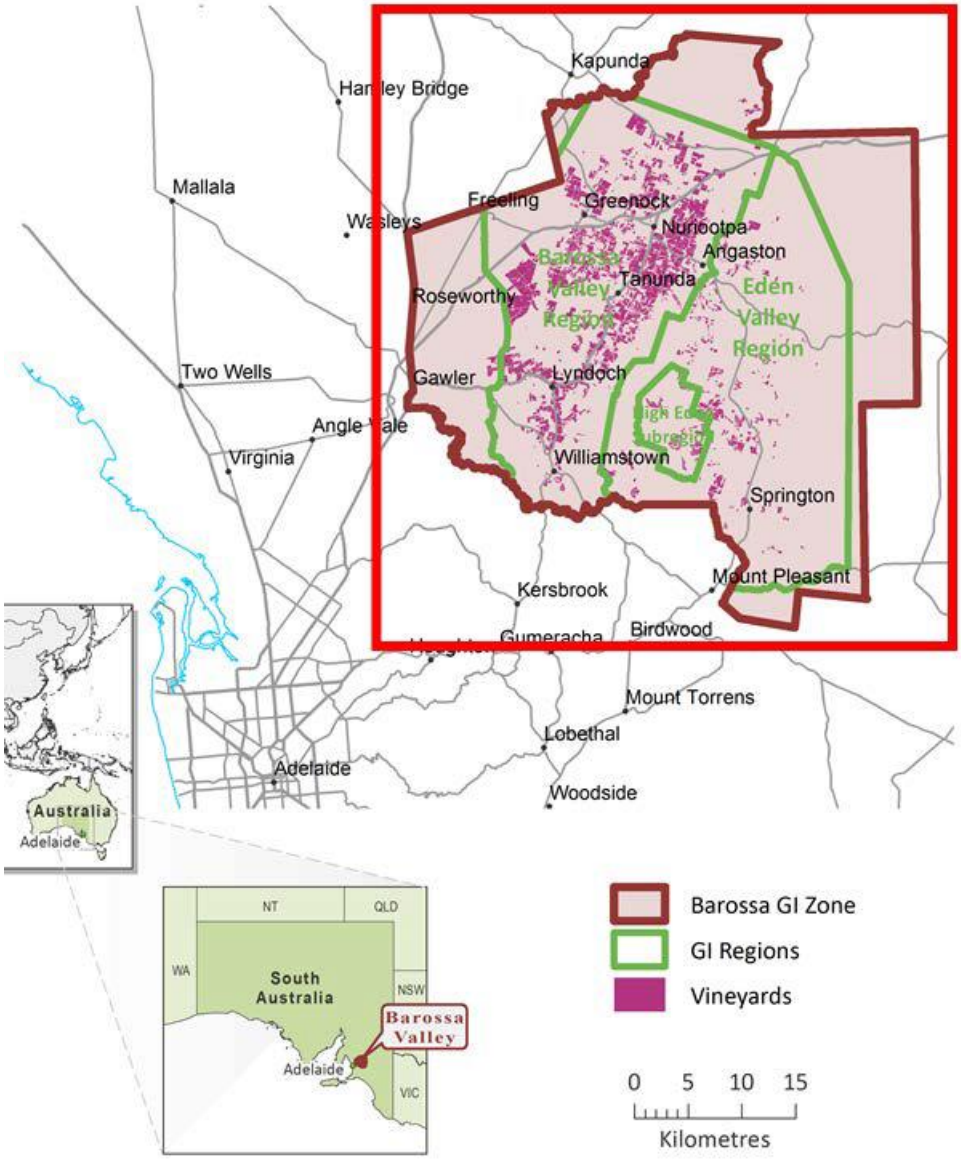


Figure 6.1. Map showing the location of the Barossa in South Australia, including the Barossa Valley and Eden Valley.

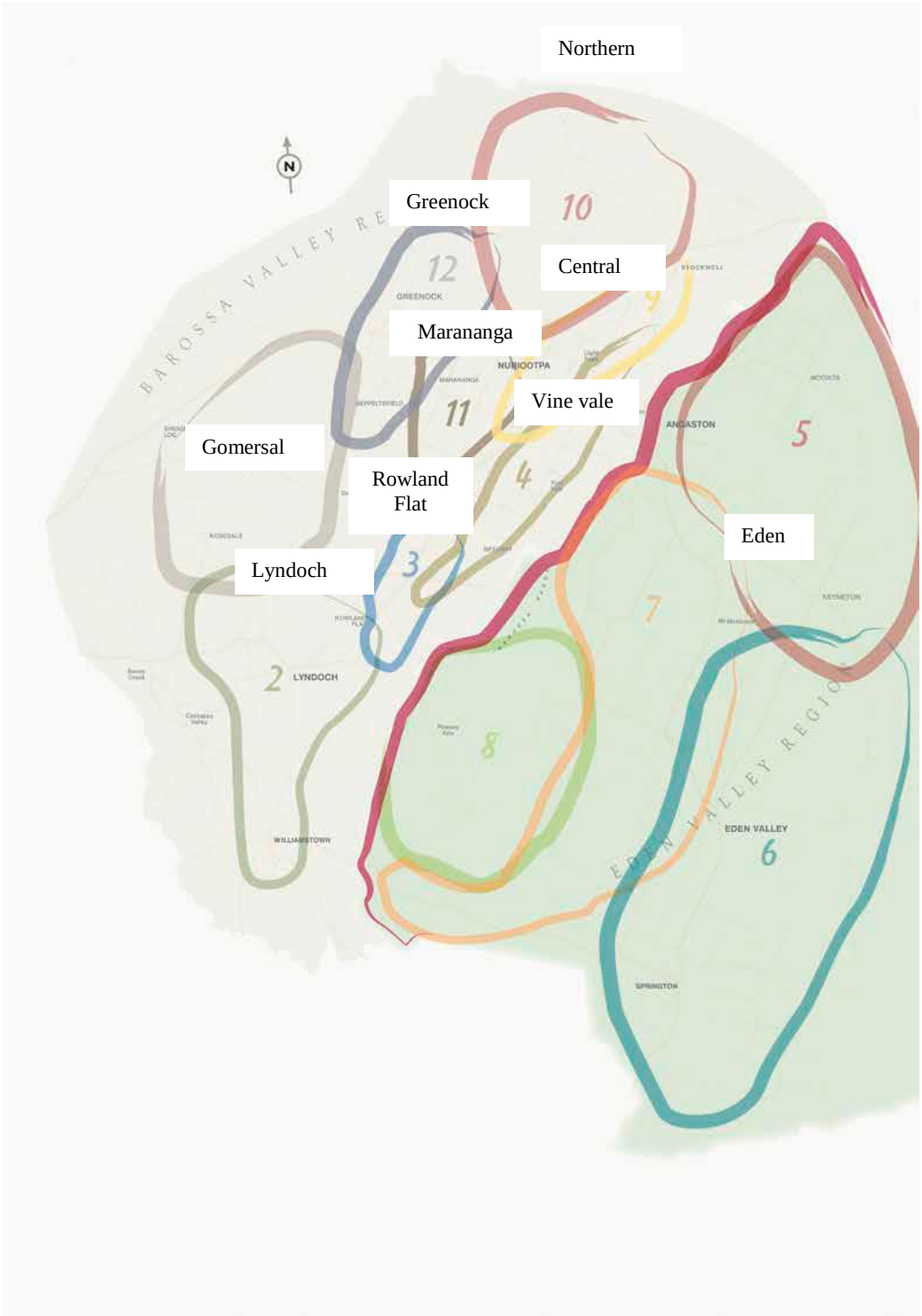


Figure 6.2. Sub-regions of the Barossa Valley and Eden Valley regions (courtesy Barossa Grape and Wine Association). 'Central' comprises Light Pass/Central/Nurioopta; 'Gomersal' comprises Gomersal/Rosedale; 'Vine Vale' comprises Barossa Foothills/Bethany/Vine Vale; 'Northern' comprises Ebenezer/Kalimna/Koonunga; 'Lyndoch' comprises Lyndoch/Williamstown; 'Eden' comprises Northern Eden, Central Eden, South Eden and High Eden; 'Marananga' comprises Stonewell/Marananga and 'Greenock' comprises Greenock/Seppeltsfield areas.

6.2 Method

6.2.1 Site Selection

Vineyard sites were identified through local knowledge and with the assistance of the Barossa Grape and Wine Association. Fifty vineyards were selected across the Barossa and Eden Valley regions for soil sampling a few weeks after harvest (late March – early April). In 2013, 30 vineyards were sampled. In 2014, sampling was repeated at 10 of these sites and another 20 new vineyards were sampled. In total, data was generated from 50 vineyards in the Barossa to represent both soil type and parish sub-region (Table 6.1).

The vineyards were chosen to cover the range of soil types in the region, initially identified by Northcote, Russell and Wells (1954). The location of the vineyards is shown on a map of the 15 generalised soil groups for the whole Barossa Valley region (Figure 6.3). The main soil types for viticultural sites were denoted as:

- red brown earth (loam over clay)
- black cracking clay
- sand over clay
- sandy loam over clay or rock

Soil maps were also available from Primary Industries and Regions, South Australia and some individual properties had detailed site specific maps to assist sampling location.

6.2.2 Soil sampling

Soil samples were collected from three locations at depths of 0-15 cm (surface) and 35-45 cm (sub-surface) as described previously (Figure 6.4). There were a few locations in 2013 where there was no nearby native site to a vineyard. In 2014, vineyard sites were specifically selected near a native vegetation. Typically native sites comprised endemic species such as Eucalyptus. Details for each site are given in Table 6.1.

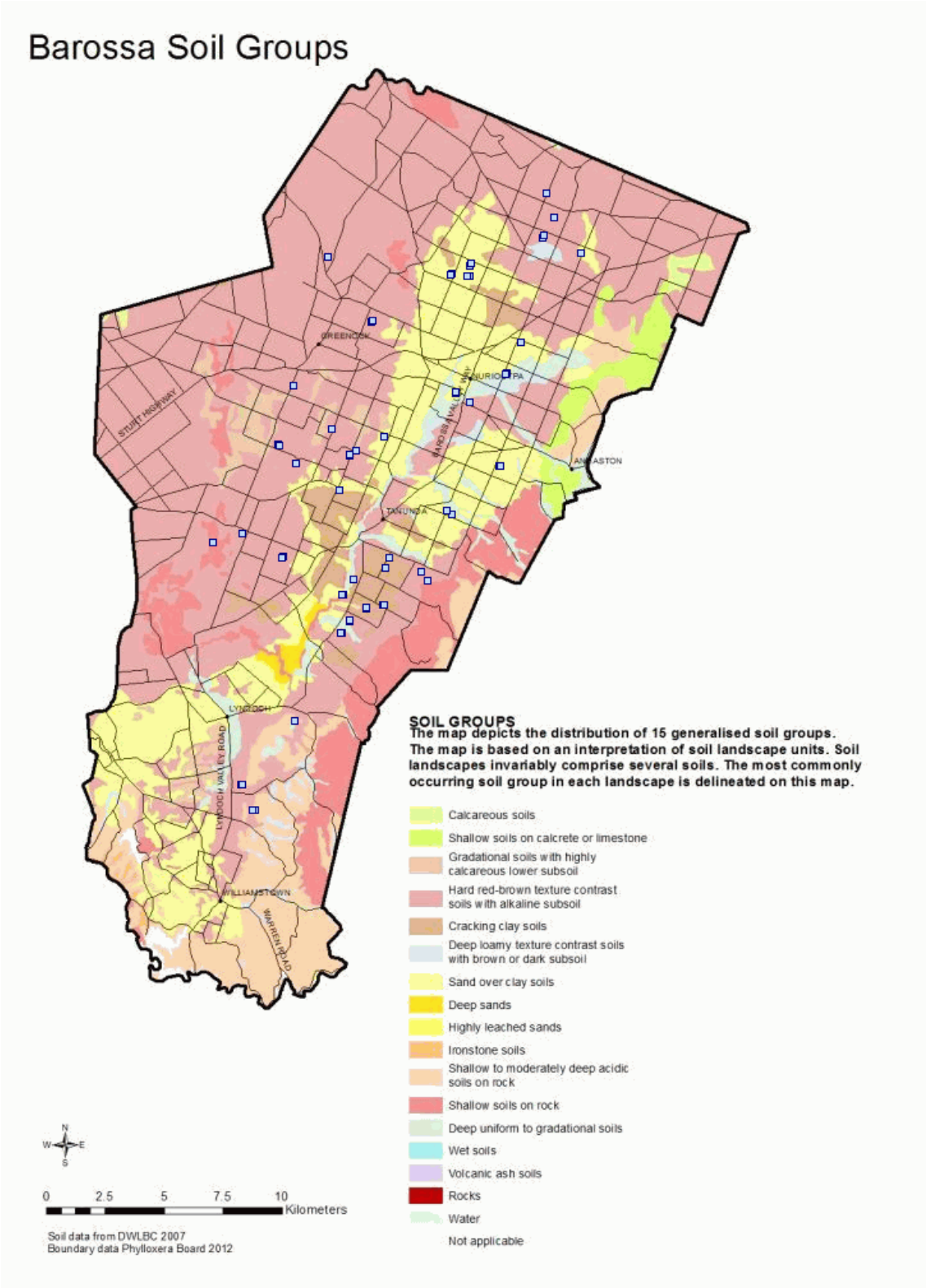


Figure 6.3. Sampling locations (□) across the 15 generalised soil groups throughout the Barossa sub-regions, excluding Eden Valley (Hall *et al*. 2009).

Table 6.1. Fifty Shiraz vineyards sampled in the Barossa sub-regions and corresponding textural soil type and altitude within the vineyard, 2013 and 2014.

Name	Sub-region	Soil type	Altitude (above sea level)	Sample year
BV1	Northern	red brown earth	301 m	2013, 2014
BV2	Northern	red brown earth	299 m	2013
BV3	Northern	sandy loam over clay	275 m	2013, 2014
BV4	Greenock	red brown earth	312 m	2013
BV5	Greenock	red brown earth	257 m	2013
BV6	Gomersal	deep loam	226 m	2013, 2014
BV7	Gomersal	deep loam	228 m	2013
BV8	Gomersal	red brown earth	198 m	2013, 2014
BV9	Lyndoch	grey clay	206 m	2013, 2014
BV10	Rowland Flat	black cracking clay	276 m	2013
BV11	Rowland Flat	black cracking clay	272 m	2013
BV12	Vine Vale	red brown earth	295 m	2013
BV13	Vine Vale	red brown earth	277 m	2013
BV14	Vine Vale	black cracking clay	275 m	2013
BV15	Vine Vale	deep sand over clay	289 m	2013
BV16	Vine Vale	deep sand over clay	285 m	2013
BV17	Lyndoch	dark grey loam over clay	292 m	2013, 2014
BV18	Rowland Flat	deep texture loam/clay	255 m	2013
BV19	Gomersal	Red brown earth	205 m	2013
BV20	Foot/Beth/VineVale	black cracking clay	267 m	2013
BV21	Foot/Beth/VineVale	Sand over clay	289 m	2013
BV22	Eden	sandy loam over rock	512 m	2013, 2014
BV23	Eden	red brown earth	401 m	2013
BV24	Eden	loam	460 m	2013, 2014
BV25	Central	Red brown earth	281 m	2013
BV26	Central	sandy loam	277 m	2013, 2014
BV27	Lyndoch	grey light clay	235 m	2013
BV28	Rowland Flat	sandy loam over clay	235 m	2013
BV29	Rowland Flat	loam over rock	232 m	2013, 2014
BV30	Marananga	sand over clay	270 m	2013
BV31	Vine Vale	sand	315 m	2014
BV32	Northern	loam	307 m	2014
BV33	Northern	red brown earth	308 m	2014
BV34	Northern	sandy loam over clay	290 m	2014
BV35	Northern	sand over clay	284 m	2014
BV36	Northern	red brown earth	362 m	2014
BV37	Marananga	grey loam over clay	260 m	2014
BV38	Marananga	loam over clay with rock	258 m	2014
BV39	Marananga	loam	233 m	2014
BV40	Marananga	loam over clay with rock	240 m	2014
BV41	Marananga	loam over clay with rock	250 m	2014
BV42	Marananga	loam over clay	291 m	2014

Name	Sub-region	Soil type	Altitude (above sea level)	Sample year
BV43	Marananga	red brown earth	238 m	2014
BV44	Rowland Flat	sandy loam with gravel	239 m	2014
BV45	Rowland Flat	sandy loam	252 m	2014
BV46	Central	sandy loam over clay	291 m	2014
BV47	Central	loam	283 m	2014
BV48	Gomersal	red brown earth	218 m	2014
BV49	Greenock	loam over rock	322 m	2014
BV50	Eden	sandy loam	455 m	2014

’Central’ comprises Light Pass/Central/Nurioopta;
‘Gomersal;’ comprises Gomersal/Rosedale;
‘Vine Vale’ comprises Barossa Foothills/Bethany/Vine Vale;
‘Northern’ comprises Ebenezer/Kalimna/Koonunga;
‘Lyndoch’ comprises Lyndoch/Williamstown;
‘Eden’ ‘comprises Northern Eden, Central Eden, South Eden and High Eden;
‘Marananga’ comprises Stonewell/Marananga
‘Greenock’ comprises Greenock/Seppeltsfield
‘Rowland Flat’ is a single sub-region.



Figure 6.4. Soil collection from (a) undervine, (b) mid-row and (c) native locations, Barossa Valley, SA

6.3 Results and Discussion

6.3.1 Benchmarking soil analysis

To gain an understanding of the health of soils in the Barossa, soil properties from the minimum data set (MDS) were analysed (as described in Chapters 1 and 5). The results were used to assess how individual vineyard soil properties were in accordance to the distribution of the region.

The distribution of data was evaluated for each soil property tested by allocating categories aligned to each soil property (see Figure 6.11 at end of chapter). Typically, the pattern of distribution showed a peak at the median value and frequency of observations in each category. For example, the distribution of soil organic carbon data showed a peak at many vineyard sites having 1-2% soil organic carbon (Figure 6.5). As a region, the mean soil organic carbon was 1.86% for undervine soil and 1.83% for the midrow in 2013.

However, the soil data also highlighted there was an obvious difference between soils collected from the undervine, midrow and native locations. Compared to soils collected within the vineyard, native soils had a significantly higher soil organic carbon mean of 3.25% (see Table 6.7 at end of chapter). This is observed in graphical distribution of the data, where native soils had a higher percentage of samples above 4% soil organic carbon (Figure 6.5). This reflects high organic matter content in soil under a native environment but also shows the change imposed by soil management and land use to soil in its natural state.

Analyses and distribution of data was used to support the selection of minimum data set soil properties. For instance, soil organic carbon is widely reported to decrease with depth (Baldock, and Skjemstad, 1999; Esteban *et al.,* 2000) and location of roots which is highly influenced by irrigation in a vineyard system (Rawnsley, 2008). Franzluebbers (2010) also showed relative distribution of soil organic carbon had a strong association with vegetation, yet at depth is influenced by clay content. For these reasons, soil organic carbon is typically measured in surface soils.

The majority of surface vineyard soils in the Barossa had between 1-3% total organic carbon (Figure 6.5a) compared to subsurface soils which had <1% total organic carbon (Figure 6.5b). The distribution of soil organic carbon is normally distributed for vineyard (undervine and midrow) surface soils (0-15 cm) compared to a skewed distribution for subsurface soils. It is more relevant to monitor soil parameters that are indicative of changes in soil management. The data supports the assumptions that soil organic matter is measured for surface soils only.

The distribution of data is important to consider when benchmarking values for a region. Low frequency data (e.g. the collection of data on an annual basis) is more comprehensive and accurate than high frequency data (e.g. collected monthly). The minimum data set provides a good set of indicators which allow changes in soil management to be monitored against regional data regardless of the individual values.

We can further see this in measurement of pH_{CaCl2}. In comparison to measurement of soil organic carbon, there is less variability across the range of pH levels when sampling at depth (Figure 6.6). The distribution of data is more evenly distributed across the category range. Native soils tended to be more acidic than vineyard soils. On a regional basis, the mean average was pH 6.87 and pH 6.51 for undervine and midrow surface soils, respectively. In comparison, pH was slightly lower for native soils (pH 6.43).

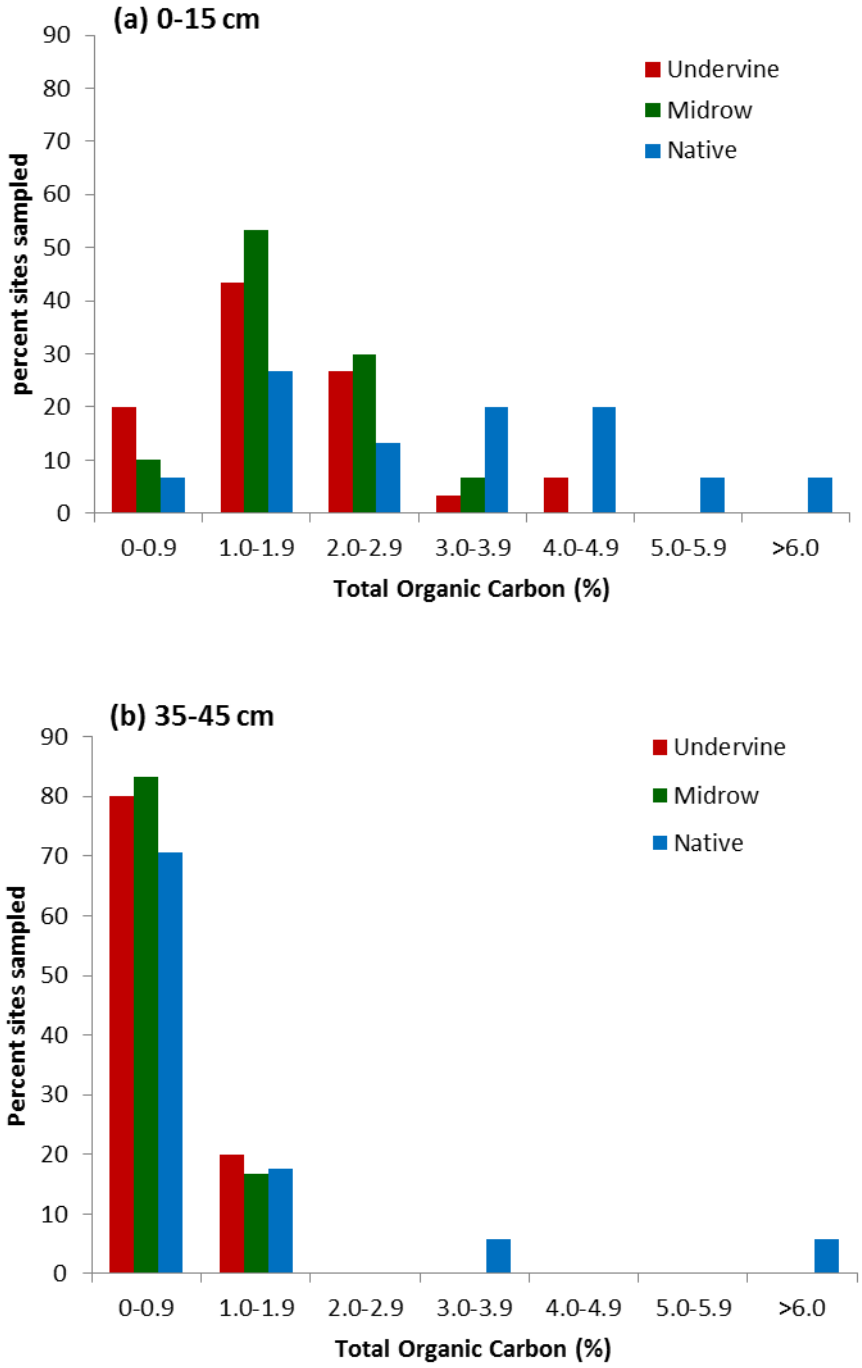


Figure 6.5. Distribution of total organic carbon (%) in (a) surface soils (0-15 cm) and (b) sub-surface soils (35-45cm) from 30 Barossa sites sampled in 2013.

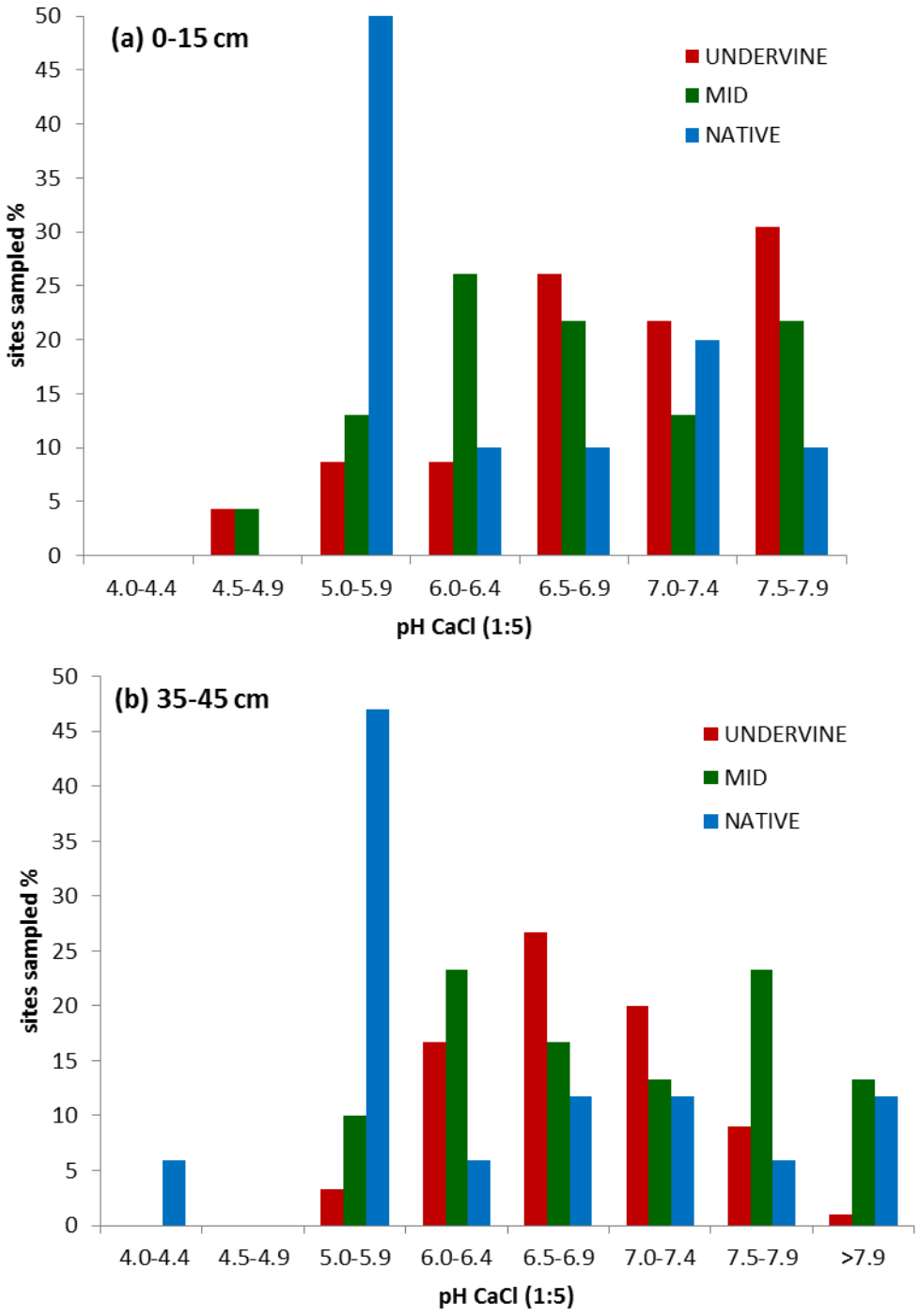


Figure 6.6. Distribution of pH $_{CaCl2}$ levels in (a) surface soils (0-15 cm) and (b) sub-surface soils (35-45cm) from 30 Barossa sites sampled in 2013.

6.3.2 Sampling location

Statistical analyses showed the most significant difference between soil properties were observed between location of soils collected in the vineyard (undervine, midrow and native). Analysis of variance showed a number of chemical soil properties were significantly different between locations (Table 6.2 and Table 6.3).

In 2013 and 2014, the content of soil organic carbon was highest in native soils compared to undervine and midrow soils. Similarly, analysis of total carbon and total nitrogen was higher in native soils. Both soil carbon and nitrogen form part of the soil organic matter pool which is derived from plant (including leaf litter and roots), animal and microbial residues. In most instances, soils from the native location had substantially more leaf litter and decomposed material than that found in vineyard soils. It has been reported that almost 95% of soil total nitrogen is closely associated with the amount of soil organic matter (Schulten and Schnitzer 1998). There was a correlation between soil organic carbon, total carbon and total nitrogen in surface soils, but there was no significance observed at depth when assessed in 2013. Total nitrogen and total carbon were not considered essential soil properties in the minimum data set.

There was a significant difference in the concentration of chloride between locations in both years. In 2013, undervine soils had a higher concentration (126 mg/kg) compared to midrow and native soils (28 and 71 mg/kg respectively). Soil depth also influences the accumulation of chloride salts, where there was a build-up in native sub-surface soils. In 2014, chloride concentration was lower than in 2013 for all soils although native soils had significantly higher chloride than vineyard soils. It is most likely these seasonal differences are associated with irrigation requirements and rainfall events. All vineyard sites were drip-irrigated which greatly influences the accumulation and movement of salts in the soil profile.

Conductivity is a measure of salt content in soils (ds/m). In 2013, there was a significant difference observed with greater conductivity in undervine soils than other surface soils. However the units expressed were not a concern for vine growth. This highlights the need to measure both conductivity and chloride to monitor changes in irrigation and salt accumulation.

Of the chemical properties analysed in 2013, organic carbon, conductivity, chloride, total nitrogen, total carbon and prewash exchangeable magnesium were significantly different between location (Table 6.2). In 2014 however, greater variability was observed in more soil properties between locations which further included potassium, pH levels, calcium carbonate and prewash exchangeable cations (Table 6.3).

Analysis of biological soil properties showed significant differences between locations. In 2013, the trend was similar for measurements of potentially mineralisable nitrogen, microbial biomass and labile carbon, where there was greater biological activity in native soils compared to undervine and midrow soils. There was no significant difference between undervine and midrow soils. There was a trend observed that increased labile carbon was correlated to increased microbial biomass (Figure 6.7).

Soil biological properties are intrinsically linked to soil chemical and physical properties. Soil properties such as pH, the availability of organic carbon and clay content all influence the size of the soil microbial population. It is useful to compare soil biological properties of vineyard soils to native soils as microbial biomass responds to disturbance and change in soil management. As no difference was observed between locations within the vineyard, sampling native soils showed possible soil biological properties of same soil type in a natural environment.

Table 6.2. Comparison of soil properties based on the location and depth of sampling in 2013. Samples were collected from the undervine (UV), midrow (MR) or native area adjacent to the vineyard (within 50 m).

2013

Soil property	Unit	Surface soils (0-15 cm) UV	MR	Native	Significance	Sub surface soils (35-45 cm) UV	MR	Native	Significance
Ammonium Nitrogen	mg/Kg	4.11	4.14	19.85	NS	6.15	1.96	5.40	NS
Nitrate Nitrogen	mg/Kg	25.27	16.03	11.64	NS	5.73	5.14	4.36	NS
Phosphorus Colwell	mg/Kg	73.07	79.57	65.27	NS	34.76	41.30	27.36	NS
Potassium Colwell	mg/Kg	473.80	369.13	457.93	NS	238.87	235.00	386.53	NS
Sulphur	mg/Kg	29.80	32.09	13.29	NS	13.54	54.43	14.77	NS
Organic Carbon	%	1.85b	1.83b	3.24a	*	0.72b	0.75b	1.41a	**
Conductivity	dS/m	0.25a	0.13ab	0.15b	*	0.13	0.15	0.17	NS
pH Level (CaCl2)	pH	6.87	6.51	6.43	NS	7.03a	6.99a	6.27b	*
pH Level (H2O)	pH	7.52	7.24	7.17	NS	7.84a	7.75ab	7.14b	**
Chloride	mg/Kg	126.16a	28.56ab	71.3b	*	53.67ab	18.73b	114.92a	***
Total Nitrogen	%	0.169b	0.15b	0.31a	*	0.09	0.08	0.11	NS
Total Carbon	%	2.24b	2.06b	4.72a	*	1.30	1.38	1.96	NS
Calcium Carbonate	%	1.10	1.08	0.71	NS	3.99	4.92	0.93	NS
Prewash exch. Ca	meq/100g	8.78	8.42	8.92	NS	9.12	9.70	5.64	NS
Prewash exch. K	meq/100g	0.82	0.89	0.69	NS	0.55	0.52	0.56	NS
Prewash exch. Mg	meq/100g	1.91	1.22	2.38	**	3.21	3.41	2.23	NS
Prewash exch. Na	meq/100g	3.34	3.63	2.80	NS	1.22	1.59	2.70	NS
Moisture	%	5.72	4.55	6.08	NS	7.62	7.57	3.40	NS
Potentially Mineralisable Nitrogen	mg NH4-N/kg	26.24b	33.57b	50.79a	***	-	-	-	-
Microbial Biomass C	mg/Kg	331.92b	311.69b	569.46a	***	-	-	-	-
Labile C	%	154.41b	120.91b	455.94a	***	-	-	-	-

Significance is denoted by NS, not significant, *P<0.05, **P<0.01, ***P<0.005 based on comparisons for all pairs using the Turkey-Kramer HSD test. Significant properties are highlighted in yellow.

Table 6.3. Comparison of soil properties based on the location and depth of sampling in 2014. Samples were collected from the undervine (UV), midrow (MR) or native area adjacent to the vineyard (within 50 m).

2014

		Surface soils (0-15 cm)				Sub surface soils (35-45 cm)			
Soil property	**Unit**	**UV**	**MR**	**Native**	**Significance**	**UV**	**MR**	**Native**	**Significance**
Ammonium Nitrogen	mg/Kg	1.61	1.71	8.54	NS	4.17	1.92	2.13	NS
Nitrate Nitrogen	mg/Kg	8.77	11.47	19.20	NS	4.38	4.19	8.11	NS
Phosphorus Colwell	mg/Kg	57.23	63.27	42.00	NS	19.37	21.29	13.48	NS
Potassium Colwell	mg/Kg	382.13b	348.70b	501.37a	***	242.23ab	200.58b	320.14a	**
Sulphur	mg/Kg	14.55	105.90	8.38	NS	16.49	48.79	8.71	NS
Organic Carbon	%	1.29b	1.33b	2.62a	***	0.70b	0.57b	0.99a	**
Conductivity	dS/m	0.11	0.11	0.14	NS	0.12	0.10	0.13	NS
pH Level (CaCl2)	pH	6.57a	5.95b	6.26ab	***	6.71	6.41	6.36	NS
pH Level (H2O)	pH	7.27a	6.67b	6.97ab	**	7.45	7.09	7.11	NS
Chloride	mg/Kg	33.39b	13.36c	49.23a	***	49.54a	14.19b	80.73a	***
Total Nitrogen	%	0.15b	0.14b	0.28a	***	-	-	-	-
Total Carbon	%	1.75b	1.64b	3.778a	***	-	-	-	-
Calcium Carbonate	%	0.59b	0.44b	1.001a	**	-	-	-	-
Prewash exch. Ca	meq/100g	6.55b	6.10b	9.11a	**	6.24	6.25	5.36	NS
Prewash exch. K	meq/100g	0.64	0.53	0.76	*	0.47	0.40	0.54	NS
Prewash exch. Mg	meq/100g	1.98a	0.89b	2.00a	**	2.84	2.58	1.71	NS
Prewash exch. Na	meq/100g	0.28	< 0.10	0.24	NS	0.66	0.51	0.64	NS
Moisture	%	6.93	5.14	6.33	NS	11.70a	10.02ab	7.54b	*
Labile Carbon	mg/kg	188.26b	199.35b	321.56a	***	-	-	-	-
Potentially Mineralisable Nitrogen	mg/kg	19.18b	21.35b	57.88a	***	-	-	-	-

Significance is denoted by NS, not significant, *P<0.05, **P<0.01, ***P<0.005 based on comparisons for all pairs using the Turkey-Kramer HSd test. Significant properties are highlighted in yellow.

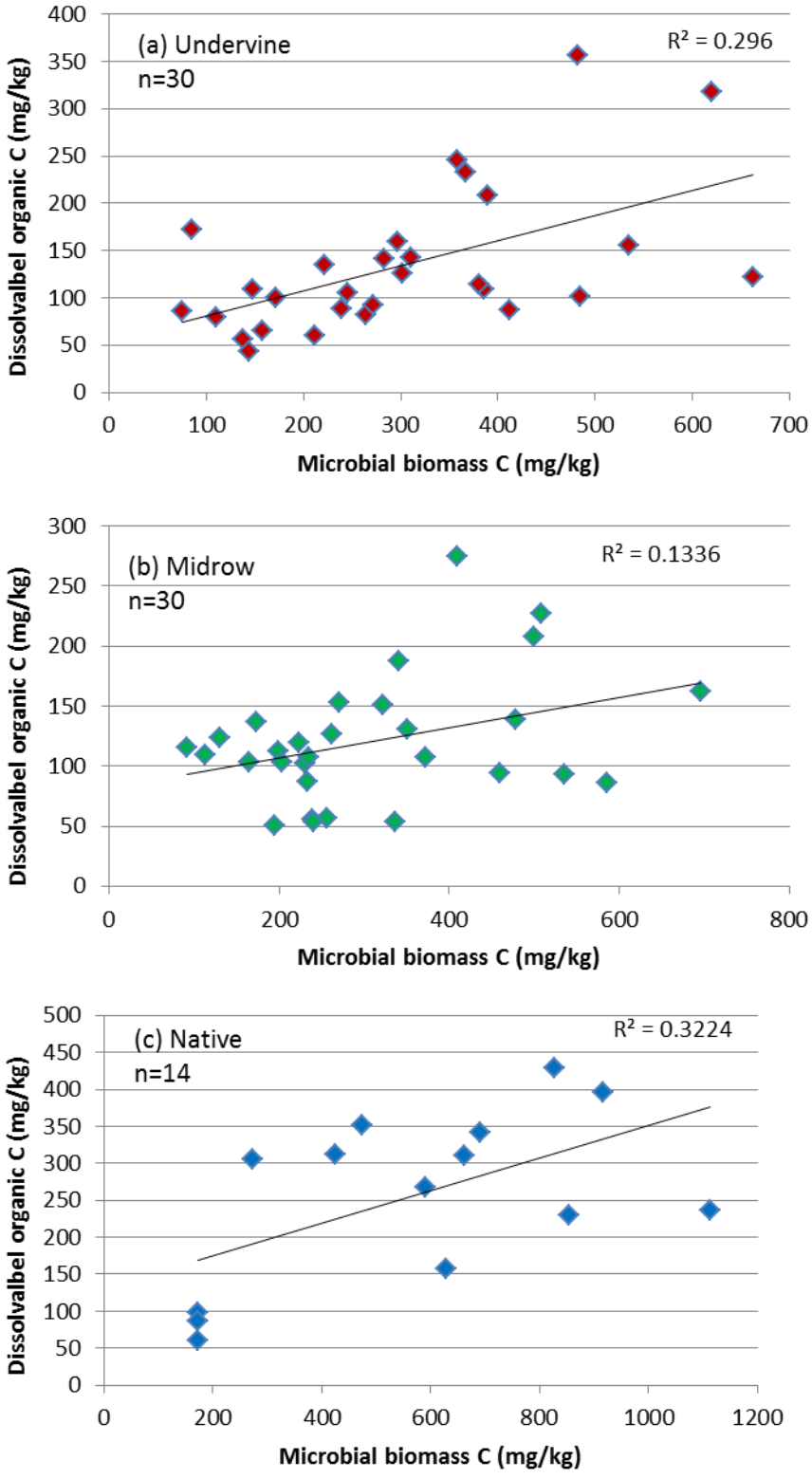


Figure 6.7. Relationship between microbial biomass (mg/kg soil) and labile carbon (dissolvable organic carbon) (mg/kg soil) for surface (0-15 cm) soils from (a) undervine (b) midrow (c) native locations, Barossa 2013.

The results highlight the importance of sampling technique and interpretation of corresponding soil data. Sampling undervine and midrow soils showed there can be strong variation in some chemical properties yet no difference in others. Most routine tests for chemical analysis are conducted on soils collected from a depth of 0-10 cm but it has been reported that a high proportion of vine active roots are located to 30 cm (Rawnsley, 2008). For this reason, sampling to 0-15 cm in a vineyard system provides accuracy across a range of soil properties. The results also highlighted the importance of providing a baseline of soil properties by assessing undisturbed soil in close proximity to the cropping soil. Using native soils shows desirable soil properties relevant to corresponding vineyard soils. Typically general commercial desirable levels do not take into consideration soil type and geography.

6.3.3 Analysis between seasons

The selection of a minimum data set to assess soil quality over time is validated by repeated sampling at 10 vineyards across the two years. Vineyards were selected to represent the different soil types and sub-regions in the Barossa, with each site having undervine, midrow and native soils analysed.

Analysis of the entire suite of surface (0-15 cm) soil properties showed only a few soil properties were significantly different between the sampling years (Table 6.4). Chloride concentration significantly declined in the vineyard soils from one year to the next. However the reduction detected in native soils was not significant. Ammonium nitrate significantly declined for midrow soils, as did prewash exchangeable magnesium. All other soil properties did not significantly alter between seasons.

Comparison of potentially mineralizable nitrogen showed a similar trend between both seasons with no significance between years (Figure 6.8a). A significant difference was observed between native soil and soils sampled in the vineyard (undervine and midrow). This correlates well with analysis of soil organic carbon, whereby no significance was observed between the years and no difference was observed between undervine and midrow soils (Figure 6.8b).

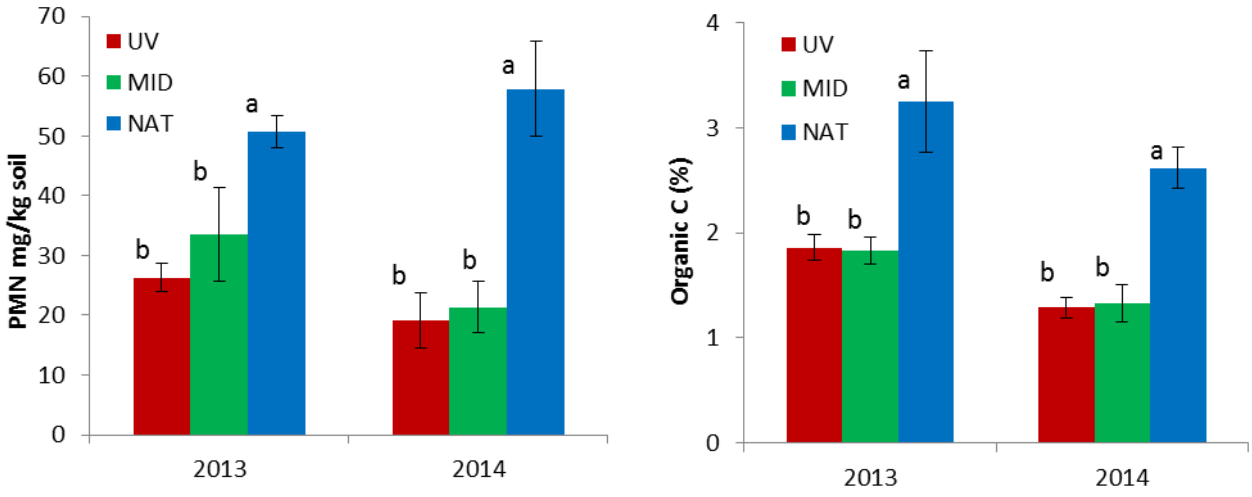


Figure 6.8. Comparison of regional average for (a) potentially mineralizable nitrogen (PMN) and (b) soil organic carbon at three sampling locations (undervine, midrow and native) across two years. Different letters denote significant difference between the locations within the one year using Tukeys HSD test.

Table 6.4. Mean values for surface (0-15 cm) soil properties measured at 10 Barossa sites in 2013 and 2014 showing significance of between year difference.

Location	2013	2014	P value	Significance
Ammonium Nitrogen mg/kg				
Undervine	2.60	1.70	0.2168	NS
Midrow	2.70	1.30	0.0026	***
Native	27.88	3.67	0.2486	NS
Nitrate Nitrogen mg/kg				
Undervine	24.50	9.10	0.1526	NS
Midrow	12.80	9.70	0.3824	NS
Native	13.70	14.20	0.924	NS
Phosphorus Colwell mg/kg				
Undervine	83.80	63.70	0.4667	NS
Midrow	83.20	65.30	0.5517	NS
Native	77.80	43.70	0.4166	NS
Potassium Colwell mg/kg				
Undervine	520.50	447.60	0.5734	NS
Midrow	345.50	361.10	0.8058	NS
Native	488.50	556.30	0.6661	NS
Sulphur mg/kg				
Undervine	21.49	29.89	0.6717	NS
Midrow	29.14	309.55	0.3288	NS
Native	15.78	5.75	0.2389	NS
Organic Carbon %				
Undervine	1.91	1.42	0.2565	NS
Midrow	1.77	1.34	0.1698	NS
Native	3.38	2.34	0.1811	NS
Conductivity dS/m				
Undervine	0.21	0.13	0.2052	NS
Midrow	0.11	0.20	0.495	NS
Native	0.16	0.13	0.4999	NS
pH Level (CaCl2)				
Undervine	6.75	6.84	0.7783	NS
Midrow	6.30	6.32	0.9542	NS
Native	6.18	6.30	0.7597	NS
pH Level (H2O)				
Undervine	7.45	7.48	0.9207	NS
Midrow	7.02	6.98	0.913	NS
Native	6.92	7.08	0.6909	NS
Chloride mg/kg				
Undervine	76.32	33.41	0.0787	*
Midrow	22.64	11.91	0.043	**
Native	71.71	41.59	0.120	NS
Total Nitrogen %				
Undervine	0.22	0.18	0.7025	NS
Midrow	0.16	0.15	0.8153	NS
Native	0.35	0.24	0.3364	NS
Total Carbon %				
Undervine	2.77	2.24	0.6624	NS
Midrow	2.00	1.73	0.4556	NS
Native	4.82	3.35	0.394	NS

Location	2013	2014	P value	Significance
	Calcium Carbonate %			
Undervine	1.31	1.09	0.8222	NS
Midrow	1.34	0.84	0.6464	NS
Native	0.42	2.33	0.1465	NS
	Prewash exch. Ca meq/100 g			
Undervine	7.53	8.08	0.8199	NS
Midrow	5.91	7.98	0.33	NS
Native	7.76	9.15	0.5579	NS
	Prewash exch. K meq/100 g			
Undervine	0.80	0.70	0.7154	NS
Midrow	1.26	0.53	0.3329	NS
Native	0.73	0.77	0.8734	NS
	Prewash exch. Mg meq/100 g			
Undervine	1.77	2.22	0.5709	NS
Midrow	0.97	1.08	0.8059	NS
Native	2.66	2.20	0.6038	NS
	Prewash exch. Na meq/100 g			
Undervine	2.23	0.15	0.424	NS
Midrow	1.593a	< 0.10b	0.0017	***
Native	3.94	0.24	0.3384	NS
	Moisture %			
Undervine	4.74	7.63	0.1025	NS
Midrow	4.91	6.02	0.450	NS
Native	6.32	6.89	0.736	NS

Significant properties are highlighted in yellow.

6.3.4 Barossa sub-region soils

The Barossa Grounds project (Barossa Grape and Wine Association) aims to portray sub-regional differences in wine style based on a range of climatic and geographical characteristics, including soil. A Shiraz symposium was held on 29th and 30th May, 2013 to taste wines from the different sub-regions which coincided with initial benchmarking analysis of soils from 30 vineyards within this project. A further tasting of wines was held on 2 July 2014. An example of wine style from each Barossa sub-region is shown in Table 6.5.

Mean averages were calculated for each sub-region and compared to the mean average of the total Barossa region (see Table 6.7). Segregation of individual vineyard sites was based on sub-region location and soil type. Mean averages were used to compare neighbouring grower properties in each sub-region.

Statistical analysis of chemical and physical data showed some significance difference between soil properties and sub-regions but the majority of soil properties were not influenced by sub-region. For example, comparison of labile organic carbon showed a similar trend in each sub-region, where variability is predominantly between location in the vineyard rather than between sub-region (Figure 6.9).

In the minimum data set, soil organic carbon and potassium were affected by sub-region. For undervine soils, sub-region had a significant (P<0.0098) influence on soil organic carbon where soils in Eden had higher soil organic carbon than Vine Vale, Northern, Gomersal and Central. Compost was used in most vineyards in Eden (Figure 6.10). In 2014, potassium was highest in vineyards in the Gomersal and Marananga vineyards than in Eden, Rowland flat, Vine vale and Greenock. This is likely however a reflection of soil management practices in these areas.

Table 6.5. Barossa sub-region and selected wine characteristics.

Sub-region	***Aroma***	***Flavour***	***Body***
Light Pass/Central/ Nurioopta	Tar, iodine, peat	Lolly shop, floral top notes	Soft tannins, dense structure
Gomersal/Rosedale	Morello jubes, forest fruit, black fruit, floral	Raspberry-blackberry	Supple tannins, medium body
Lyndoch/Williamstown	Aromatic, brambles, perfumes, fragrant	sage, mint, spice	medium body
Barossa Foothills/Bethany/ Vine Vale	Red fruit, mulberry, blueberry, herbs	Ferrous, mineral, earthy	Powdery tannins, light body
Ebenezer/Kalimna/ Koonunga	Plums, anise, nettles	Prunes, olives, chocolate	Velvet tannins, hearty body
Eden	Carbon, sage, menthol, white pepper	Spicy, cranberry, cherry	Savoury, elegant body
Rowland Flat	Chocolate	violet, peppermint	Soft tannins, solid body
Stonewell/Marananga	Red currants, brambles	Fennel, aniseed, spices	Pronounced tannins, sinewy structure
Greenock/Seppeltsfield	Milk chocolate, fruitcake, mixed spice	Mulberry, blackberry, dark cherry	Robust tannins, ferrous structure

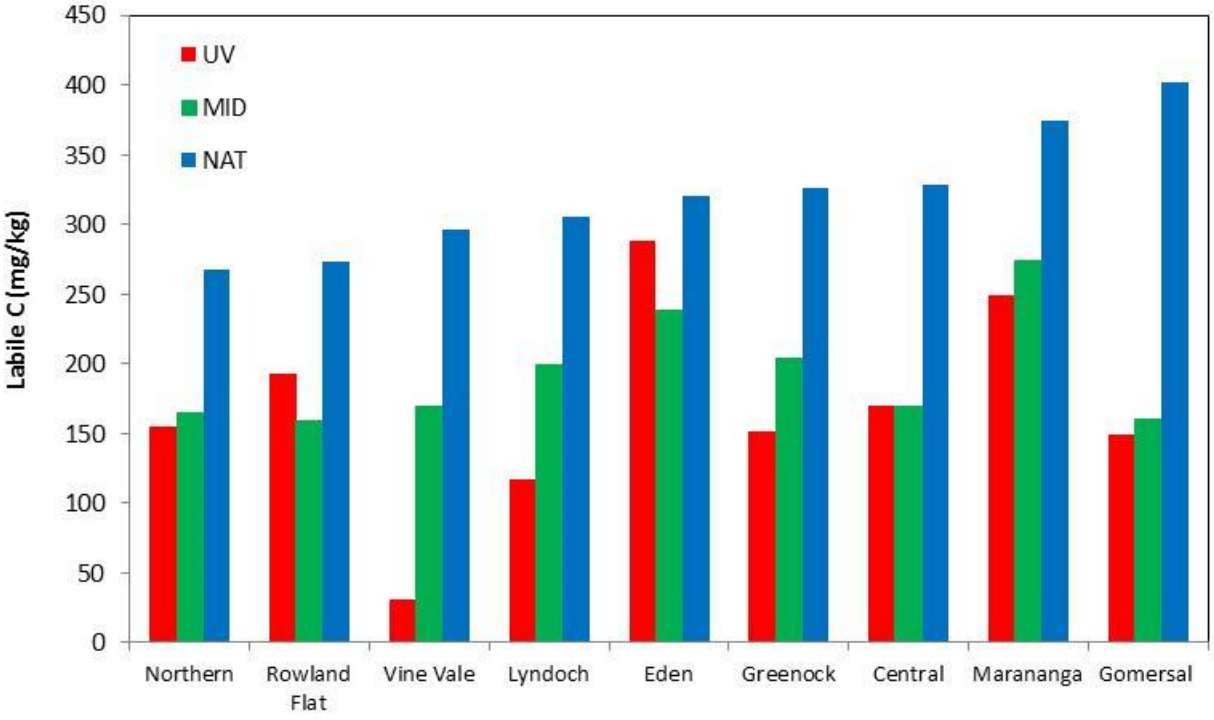


Figure 6.9. Mean Labile Carbon values in surface soils (0-15cm) measured at 30 Barossa sub-region sites, 2014.

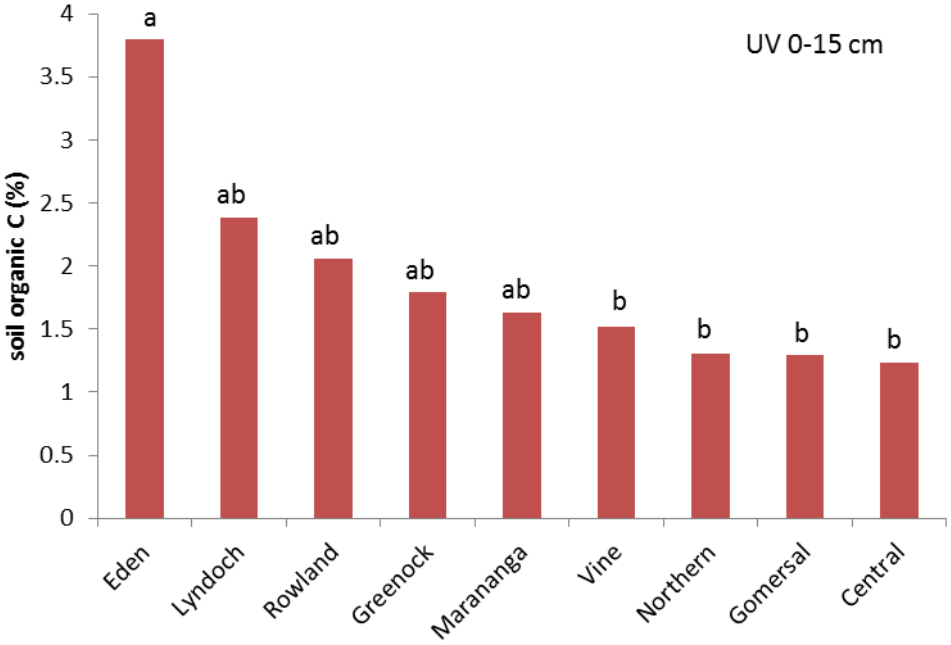


Figure 6.10. Comparison of regional average for soil organic carbon in undervine surface soils (0-15 cm) at sub-regions in Barossa, 2014. Different letters denote significant difference between the subregion using Tukeys HSD test.

6.3.5 Physical analyses

Physical analysis was conducted on all soils sampled from the Barossa as described in Chapter 1. While texture is defined by the mineral component of a soil and is an innate property of the soil that does not change, three soil physical properties were included in the minimum data set that could reflect change imposed by soil management. Dispersion, slaking and consistency of soils was assessed from the 50 sites and the mean average calculated for each property (Table 6.6).

Table 6.6. Median regional average of soil physical properties (dispersion, slaking and consistency) of 50 vineyard sites in regard to location of sampling (undervine, midrow and native), Barossa, SA.

		Dispersion (ASWAT score)	*Slaking*	*Consistency*
0-15	Undervine	3	3	3
	Midrow	3	3	3
	Native	2	3	2
35-45	Undervine	5	2	4
	Midrow	5	2	4
	Native	4	3	3

ASWAT dispersion rating score 0-1=negligible; 2-6=moderate and 7-16=serious dispersion.
Slaking rating score 0=no slaking, 1=minimal slaking, 2=moderate slaking, 3=rapid slaking.
Consistency rating score 0=loose, 1=very weak, 2=weak, 3= firm, 4= very firm, 5=strong, 6=very strong, 7=rigid.

Dispersion results in the separation of soils into single particles, leading to soil degradation and restricts air, water and root movement. Dispersion was rated following moulding of most dried soils that did not disperse after 2 hours. A highly dispersive soil was rated 7-16 and it was observed with the most dispersive soils (score >10) were at 35-45 cm depth. Statistical analysis showed there was a significant (P<0.000) interaction between dispersion and soil depth. Surface soils (0-15 cm) were significantly less dispersive than sub-surface soils (35-45 cm). The level of dispersion is correlated to organic matter and clay content of the soil by influencing the negative charge of the soil. In many soils in the Barossa, sub-surface soils contain high clay content. An example of dispersion is shown in Figure 6.11.

Dispersion was also significantly different at vineyard sites (P<0.001), but not at location within the vineyard. This highlights dispersion as being a useful indicator of benchmarking soil quality within a region.

Slaking is the breakdown of aggregates into smaller fragments and relates to the organic matter content of the soil. Slaking was significantly affected by soil depth, location of sampling (undervine, midrow and native) and site (P<0.000). More slaking was evident in surface soils and in native soils. Undervine and midrow soils showed no significant difference in slaking.

Soil consistency was significantly affected by site (P<0.000), depth (P<0.000) and location (P<0.003). Native soils were more friable. At depth, soils were stronger and aggregates harder to break with force. There was a statistically significant different between sub-regions in relation to soil type, where sandy soils were obviously less stable than soils containing a high clay content.

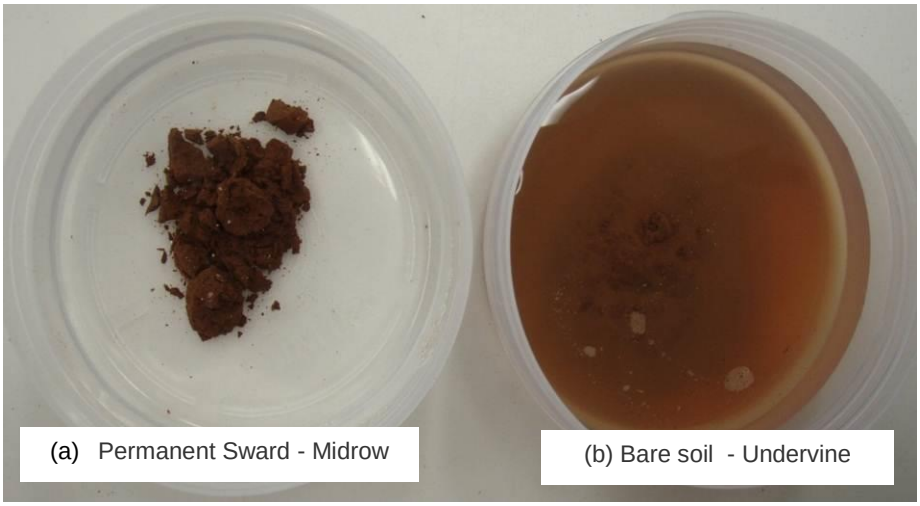


Figure 6.11. Dispersion of soil in water as rated by ASWAT scores whereby (a) no dispersion (ASWAT score=0) and (b) complete dispersion of the soil aggregate (ASWAT score=12) of soil taken from the same site, but different location within the vineyard.

Table 6.7 Mean properties of soil collected from 0-15 cm (surface soil) and 35-45cm (sub-surface soils) at undervine, mid-row and native locations in Barossa Valley sub-regions, 2013 and 2014.

2013	Ammonium Nitrogen	Nitrate Nitrogen	Phosphorus Colwell	Potassium Colwell	Sulphur	Organic Carbon	Conductivity	pH Level (CaCl2)	pH Level (H2O)	Chloride	Total Nitrogen	Total Carbon	Calcium Carbonate	Prewash exch. Ca	Prewash exch. K	Prewash exch. Mg	Prewash exch. Na	Moisture	Active Labile Carbon
UNDERVINE 0-15 cm	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg	%	dS/m	pH	pH	mg/Kg	%	%	%	meq/100g	meq/100g	meq/100g	meq/100g	%	mg/kg
Total Barossa Region	**4.11**	**25.27**	**73.07**	**473.80**	**29.80**	**1.86**	**0.25**	**6.87**	**7.52**	**126.16**	**0.17**	**2.24**	**1.10**	**8.78**	**0.82**	**1.91**	**3.34**	**5.72**	**628.67**
Central	4.00	62.50	84.00	470.00	13.50	1.24	0.23	6.85	7.50	85.95	0.11	1.37	0.27	5.47	0.61	1.06	2.62	3.60	461.00
Eden	9.33	26.67	128.33	687.33	16.97	3.80	0.22	6.67	7.47	28.23	0.49	6.27	1.06	10.37	1.06	2.51	2.33	6.41	809.33
Gomersal	2.25	14.00	60.50	556.50	11.08	1.29	0.20	7.10	7.78	118.03	0.12	1.50	0.74	8.46	1.02	2.40	2.39	5.48	*
Greenock	7.00	21.00	51.00	604.00	39.10	1.79	0.28	6.90	7.40	131.70	0.16	1.84	0.37	6.02	1.02	1.18	3.95	3.44	*
Lyndoch	2.50	14.33	54.00	435.33	11.70	2.38	0.15	6.87	7.57	82.77	0.16	2.43	0.31	7.67	0.51	1.22	1.84	4.26	768.00
Marananga	2.00	37.00	73.00	359.00	21.20	1.63	0.23	7.10	7.70	94.40	0.15	1.77	0.87	6.82	0.47	0.93	2.46	3.54	497.00
Northern	2.00	9.25	31.50	317.50	31.43	1.31	0.17	6.83	7.48	60.95	0.11	1.51	2.35	6.87	0.61	1.16	8.47	6.38	*
Rowland Flat	2.25	27.00	86.60	554.80	28.56	2.06	0.35	7.00	7.70	240.50	0.16	2.22	1.41	11.36	1.18	2.81	3.00	9.66	521.50
VineVale	5.57	32.00	78.86	381.86	58.29	1.52	0.32	6.73	7.26	162.21	0.13	1.66	1.12	9.64	0.68	1.92	3.45	4.26	*

	Ammonium Nitrogen	Nitrate Nitrogen	Phosphorus Colwell	Potassium Colwell	Sulphur	Organic Carbon	Conductivity	pH Level (CaCl2)	pH Level (H2O)	Chloride	Total Nitrogen	Total Carbon	Calcium Carbonate	Prewash exch. Ca	Prewash exch. K	Prewash exch. Mg	Prewash exch. Na	Moisture	Active Labile Carbon
UNDERVINE 35-45 cm	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg	%	dS/m	pH	pH	mg/Kg	%	%	%	meq/100g	meq/100g	meq/100g	meq/100g	%	mg/kg
Total Barossa Region	**6.15**	**5.73**	**34.76**	**238.87**	**13.54**	**0.72**	**0.13**	**7.04**	**7.85**	**53.67**	**0.09**	**1.30**	**3.99**	**9.12**	**0.55**	**3.21**	**1.22**	**7.62**	*
Central	2.00	7.00	19.00	207.50	6.50	0.43	0.08	7.10	7.90	27.80	0.10	0.58	0.24	5.35	0.40	2.24	0.90	9.33	*
Eden	2.00	5.67	27.67	201.33	5.77	1.04	0.07	6.50	7.13	13.83	0.11	1.14	0.25	3.52	0.31	0.66	2.30	6.14	*
Gomersal	1.75	3.50	119.50	336.50	6.98	0.72	0.17	7.28	8.15	70.03	0.09	1.39	5.36	12.65	0.97	6.50	0.71	*	*
Greenock	< 1	1.00	4.00	307.00	4.00	0.56	0.04	6.60	7.80	11.00	0.07	0.68	0.28	5.96	0.74	2.58	0.36	*	*
Lyndoch	2.00	3.50	8.00	375.33	15.20	1.03	0.14	7.20	7.97	55.20	0.10	1.22	0.58	9.44	0.87	3.60	2.29	8.91	*
Marananga	< 1	9.00	45.00	230.00	9.10	0.69	0.11	7.20	7.80	28.90	0.09	0.75	0.40	3.58	0.27	0.71	3.44	2.84	*
Northern	2.33	3.75	9.75	217.25	37.55	0.61	0.15	6.75	7.48	59.65	0.08	1.28	4.30	7.98	0.57	4.04	0.80	*	*
Rowland Flat	29.67	3.20	29.50	229.40	15.14	0.74	0.17	7.32	8.20	102.82	0.08	2.65	13.09	14.11	0.56	3.14	1.12	9.87	*
VineVale	2.00	10.50	25.57	160.29	9.07	0.60	0.11	7.04	7.89	39.26	0.07	0.77	1.70	8.77	0.31	2.56	0.43	*	*

2013	Ammonium Nitrogen	Nitrate Nitrogen	Phosphorus Colwell	Potassium Colwell	Sulphur	Organic Carbon	Conductivity	pH Level (CaCl2)	pH Level (H2O)	Chloride	Total Nitrogen	Total Carbon	Calcium Carbonate	Prewash exch. Ca	Prewash exch. K	Prewash exch. Mg	Prewash exch. Na	Moisture	Active Labile Carbon
MIDROW 0-15 cm	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg	%	dS/m	pH	pH	mg/Kg	%	%	%	meq/100g	meq/100g	meq/100g	meq/100g	%	mg/kg
Total Barossa Region	**4.14**	**16.03**	**79.57**	**369.13**	**32.09**	**1.83**	**0.14**	**6.51**	**7.24**	**28.56**	**0.16**	**2.07**	**1.08**	**8.42**	**0.89**	**1.22**	**3.63**	**4.55**	**535.44**
Central	2.50	15.00	133.50	312.50	6.45	1.29	0.09	6.10	6.90	33.90	0.13	1.39	0.22	4.96	0.45	0.81	1.06	4.02	460.00
Eden	2.33	18.67	60.67	376.67	7.50	2.72	0.11	6.23	7.13	35.57	0.30	3.13	0.29	7.22	0.50	0.79	3.27	8.65	694.00
Gomersal	2.25	9.25	44.50	513.25	7.95	1.93	0.10	6.58	7.38	16.63	0.14	2.01	0.53	7.29	0.89	1.84	2.07	4.33	*
Greenock	4.00	10.00	55.00	539.00	17.90	1.78	0.10	6.90	7.60	14.70	0.14	1.87	0.35	6.12	0.85	0.98	4.07	1.92	*
Lyndoch	2.33	13.00	55.33	314.67	6.67	2.15	0.08	6.30	7.10	19.93	0.15	2.36	0.25	6.67	0.36	0.79	2.91	4.07	663.00
Marananga	< 1	7.00	52.00	277.00	4.10	1.14	0.07	7.10	8.10	20.20	0.05	1.16	0.41	4.86	0.36	0.45	1.44	3.58	464.00
Northern	2.25	4.50	42.50	255.25	115.53	1.39	0.17	6.70	7.25	11.95	0.11	1.68	2.71	6.98	2.38	0.77	3.50	3.66	*
Rowland Flat	2.80	12.80	95.60	352.20	20.60	1.76	0.16	6.46	7.24	48.62	0.15	2.16	1.00	11.96	0.73	1.45	4.21	5.60	345.00
VineVale	9.29	31.43	119.86	389.14	41.21	1.82	0.20	6.57	7.19	32.90	0.16	2.04	1.64	10.46	0.75	1.58	5.29	3.53	

	Ammonium Nitrogen	Nitrate Nitrogen	Phosphorus Colwell	Potassium Colwell	Sulphur	Organic Carbon	Conductivity	pH Level (CaCl2)	pH Level (H2O)	Chloride	Total Nitrogen	Total Carbon	Calcium Carbonate	Prewash exch. Ca	Prewash exch. K	Prewash exch. Mg	Prewash exch. Na	Moisture	Active Labile Carbon
MIDROW 35-45 cm	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg	%	dS/m	pH	pH	mg/Kg	%	%	%	meq/100g	meq/100g	meq/100g	meq/100g	%	mg/kg
Total Barossa Region	**1.96**	**5.14**	**41.30**	**235.00**	**54.43**	**0.75**	**0.15**	**6.99**	**7.76**	**18.73**	**0.08**	**1.38**	**4.92**	**9.70**	**0.52**	**3.41**	**1.59**	**7.57**	*
Central	4.00	2.50	61.00	183.00	3.70	0.39	0.07	6.95	7.70	6.30	0.08	0.56	0.23	5.93	0.39	1.97	0.74	7.06	*
Eden	1.00	4.67	108.33	177.00	4.20	1.01	0.04	5.93	6.73	4.97	0.12	1.19	0.21	3.22	0.26	0.39	4.35	6.14	*
Gomersal	2.25	2.67	7.00	316.25	10.50	0.63	0.14	7.38	8.33	22.63	0.08	0.98	2.94	11.07	0.84	6.65	0.91	*	*
Greenock	2.00	2.00	6.00	354.00	18.60	0.94	0.07	6.30	7.60	16.90	0.10	0.77	0.30	5.34	0.83	3.78	0.78	*	*
Lyndoch	1.50	3.00	20.33	252.67	3.60	1.33	0.05	6.43	7.10	6.50	0.13	1.52	0.30	7.16	0.48	1.80	0.10	7.79	*
Marananga	< 1	4.00	25.00	146.00	2.90	0.64	0.05	7.20	7.80	2.10	0.06	0.66	0.32	3.12	0.21	0.44	3.39	8.25	*
Northern	1.50	1.75	20.33	250.75	84.80	0.67	0.24	7.18	7.95	33.75	0.08	1.51	7.22	10.58	0.63	5.14	0.65	*	*
Rowland Flat	1.60	2.60	30.00	210.80	172.26	0.82	0.27	7.28	8.00	31.38	0.08	2.07	10.34	15.68	0.52	4.09	2.18	9.76	*
VineVale	2.40	13.67	50.14	224.71	48.31	0.55	0.16	7.24	7.90	16.23	0.05	1.50	7.53	10.64	0.45	2.85	0.42	*	*

2013 NATIVE 0-15 cm	Ammonium Nitrogen mg/Kg	Nitrate Nitrogen mg/Kg	Phosphorus Colwell mg/Kg	Potassium Colwell mg/Kg	Sulphur mg/Kg	Organic Carbon %	Conductivity dS/m	pH Level (CaCl2) pH	pH Level (H2O) pH	Chloride mg/Kg	Total Nitrogen %	Total Carbon %	Calcium Carbonate %	Prewash exch. Ca meq/100g	Prewash exch. K meq/100g	Prewash exch. Mg meq/100g	Prewash exch. Na meq/100g	Moisture %	Active Labile Carbon mg/kg
Total Barossa Region	19.85	11.64	65.27	457.93	13.29	3.25	0.16	6.43	7.17	71.30	0.32	4.72	0.71	8.92	0.69	2.38	2.80	6.08	758.86
Central	8.00	3.00	20.00	182.00	4.00	3.87	0.08	5.50	6.50	37.50	0.23	4.26	0.22	5.01	0.25	2.02	#DIV/0!	7.94	836.00
Eden	5.67	12.00	24.67	295.33	7.73	3.64	0.13	6.17	6.90	70.83	0.26	3.89	0.43	6.72	0.38	1.74	4.09	6.65	842.00
Foothill/VineVale	12.00	5.50	24.50	470.00	9.40	3.75	0.15	6.60	7.25	25.45	0.37	6.80	0.36	14.52	0.82	2.50	1.32	4.38	*
Lyndoch	90.00	20.50	267.00	859.00	49.65	5.38	0.31	6.20	6.75	119.50	0.78	11.49	0.50	13.24	1.13	4.58	0.35	6.87	*
Marananga	3.00	1.00	27.00	176.00	4.20	1.52	0.07	7.50	8.50	24.40	0.09	2.03	4.10	7.45	0.16	0.65	1.44	2.62	428.00
Northern	12.50	20.50	39.00	387.00	12.00	3.90	0.11	5.40	6.15	36.50	0.35	4.53	0.28	4.53	0.56	1.13	4.85	1.93	*
Rowland Flat	4.00	15.00	68.00	490.50	7.85	1.97	0.16	6.40	7.20	110.40	0.15	2.55	0.54	7.98	0.79	1.47	0.10	8.30	659.50

NATIVE 35-45 cm	Ammonium Nitrogen mg/Kg	Nitrate Nitrogen mg/Kg	Phosphorus Colwell mg/Kg	Potassium Colwell mg/Kg	Sulphur mg/Kg	Organic Carbon %	Conductivity dS/m	pH Level (CaCl2) pH	pH Level (H2O) pH	Chloride mg/Kg	Total Nitrogen %	Total Carbon %	Calcium Carbonate %	Prewash exch. Ca meq/100g	Prewash exch. K meq/100g	Prewash exch. Mg meq/100g	Prewash exch. Na meq/100g	Moisture %	Active Labile Carbon mg/kg
Total Barossa Region	**5.40**	**4.36**	**27.36**	**386.53**	**14.77**	**1.42**	**0.17**	**6.27**	**7.15**	**114.93**	**0.11**	**1.96**	**0.93**	**5.64**	**0.56**	**2.23**	**2.70**	**3.40**	*
Central	< 1	< 1	22.00	315.00	23.80	0.60	0.33	8.00	8.70	276.10	0.11	0.79	0.35	5.50	0.42	1.51	0.13	4.88	*
Eden	2.00	3.00	6.00	134.00	5.87	0.84	0.05	5.00	5.93	34.23	0.09	0.82	0.22	1.43	0.16	0.57	4.65	3.86	*
Foothill/VineVale	1.50	< 1	3.00	170.00	2.65	0.78	0.07	7.10	8.15	14.35	0.05	0.87	0.43	11.85	0.44	3.78	0.45	*	*
Lyndoch	19.50	8.00	92.50	1270.00	32.95	5.23	0.34	6.25	6.90	309.95	0.31	8.14	0.52	10.83	1.38	4.33	1.22	*	*
Marananga	< 1	< 1	6.00	98.00	3.60	0.44	0.09	7.40	8.10	39.40	0.03	0.46	0.37	2.24	0.13	0.79	< 0.10	2.00	*
Northern	2.50	13.00	20.00	351.50	6.20	0.95	0.06	5.65	6.55	19.70	0.07	0.99	0.29	2.12	0.65	0.93	< 0.10	*	*
Rowland Flat	< 1	< 1	5.00	207.50	2.35	0.82	0.03	6.05	6.95	6.40	0.07	1.00	0.22	3.12	0.32	0.46	6.06	2.68	*

2014	Ammonium Nitrogen	Nitrate Nitrogen	Phosphorus Colwell	Potassium Colwell	Sulphur	Organic Carbon	Conductivity	pH Level (CaCl2)	pH Level (H2O)	Chloride	Total Nitrogen	Total Carbon	Calcium Carbonate	Prewash exch. Ca	Prewash exch. K	Prewash exch. Mg	Prewash exch. Na	Moisture %	Active Labile Carbon	Potentially Mineralisable Nitrogen
UNDERVINE 0-15 cm	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg	%	dS/m	pH	pH	mg/Kg	%	%	%	meq/100 g	meq/100 g	meq/100 g	meq/100g	%	mg/kg	mg/kg
Total Barossa Region	**1.61**	**8.77**	**57.23**	**382.13**	**14.55**	**1.29**	**0.11**	**6.57**	**7.27**	**33.39**	**0.15**	**1.76**	**0.59**	**6.55**	**0.64**	**1.98**	**0.28**	**6.93**	**188.26**	**19.18**
Central	1.00	2.67	51.00	271.00	6.70	1.10	0.10	7.17	7.90	48.73	0.11	1.42	0.83	5.72	0.37	1.74	< 0.10	5.00	170.33	18.05
Eden	3.00	11.33	57.67	329.33	9.60	1.87	0.09	6.10	6.83	19.17	0.31	3.55	0.79	7.26	0.43	1.45	< 0.10	7.49	287.83	39.13
Gomersal	1.33	5.33	74.33	620.33	22.43	0.94	0.12	6.83	7.50	20.97	0.11	1.22	0.44	8.68	1.24	3.31	0.25	0.25	10.08	148.67
Greenock	1.00	3.00	54.00	189.00	12.20	1.47	0.09	6.80	7.60	29.30	0.17	2.15	0.30	4.66	0.25	1.43	< 0.10	5.78	151.00	17.00
Lyndoch	1.50	8.00	24.00	345.50	7.85	1.32	0.11	7.05	7.85	60.90	0.14	1.67	0.27	5.15	0.42	2.96	0.15	6.14	116.80	1.80
Marananga	1.80	9.00	67.29	461.14	7.84	1.63	0.10	6.73	7.41	31.31	0.18	2.04	0.28	8.70	0.88	2.53	0.25	9.37	248.86	15.62
Northern	1.50	8.29	56.29	380.71	31.60	1.16	0.14	6.57	7.23	40.24	0.12	1.50	1.13	6.31	0.66	1.83	0.58	6.21	155.83	27.34
Rowland Flat	1.00	12.33	52.33	268.00	4.77	0.97	0.07	5.30	6.10	25.10	0.11	1.15	0.22	3.08	0.37	0.56	< 0.10	3.40	193.13	2.10
Vine Vale	< 1	28.00	44.00	225.00	2.10	0.32	0.08	6.80	7.30	7.90	0.03	0.36	0.20	2.28	0.24	0.49	< 0.10	2.88	30.40	2.20
UNDERVINE 35-45 cm	Ammonium Nitrogen	Nitrate Nitrogen	Phosphorus Colwell	Potassium Colwell	Sulphur	Organic Carbon	Conductivity	pH Level (CaCl2)	pH Level (H2O)	Chloride	Total Nitrogen	Total Carbon	Calcium Carbonate	Prewash exch. Ca	Prewash exch. K	Prewash exch. Mg	Prewash exch. Na	Moisture %	Active Labile Carbon	Potentially Mineralisable Nitrogen
Total Barossa Region	**4.17**	**4.38**	**19.37**	**242.23**	**16.49**	**0.71**	**0.12**	**6.71**	**7.45**	**49.54**	*	*	*	**6.24**	**0.47**	**2.84**	**0.66**	**11.70**	*	*
Central	1.00	3.33	11.00	218.67	10.93	0.56	0.15	7.17	7.93	100.70	*	*	*	5.79	0.36	2.38	0.26	11.78	*	*
Eden	2.33	9.67	45.33	252.00	8.83	1.61	0.08	6.30	7.07	16.57	*	*	*	5.32	0.34	1.09	< 0.10	7.24	*	*
Gomersal	3.50	3.50	19.67	305.67	35.73	0.56	0.13	7.03	7.73	52.73	*	*	*	8.67	0.71	5.82	0.47	12.38	*	*
Greenock	2.00	2.00	6.00	86.00	20.30	0.55	0.07	5.90	6.50	63.90	*	*	*	4.19	0.17	1.86	0.24	12.86	*	*
Lyndoch	8.00	3.50	11.00	413.00	13.95	0.90	0.12	7.30	8.00	91.90	*	*	*	6.67	0.89	4.86	0.28	0.28	*	*
Marananga	3.00	3.86	18.71	313.00	20.44	0.75	0.20	6.97	7.80	57.23	*	*	*	7.43	0.64	3.93	0.98	13.69	*	*
Northern	8.17	3.00	13.71	169.29	17.84	0.54	0.11	6.43	7.19	35.47	*	*	*	6.74	0.36	2.14	0.89	11.35	*	*
Rowland Flat	2.00	4.00	25.00	163.33	3.50	0.48	0.05	6.13	6.83	23.90	*	*	*	3.07	0.26	0.93	0.32	10.46	*	*
Vine Vale	< 1	12.00	23.00	160.00	1.60	0.19	0.05	7.10	7.40	7.90	*	*	*	2.02	0.18	0.40	< 0.10	2.94	*	*

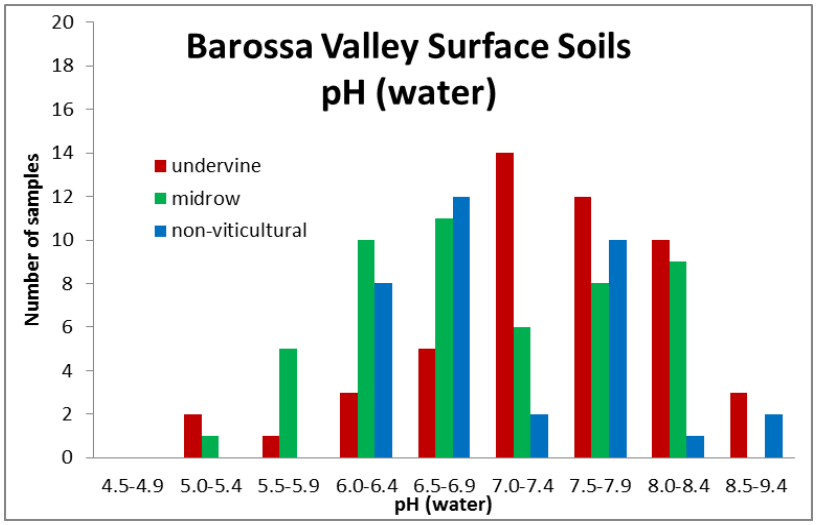
MIDROW 0-15 cm	Ammonium Nitrogen	Nitrate Nitrogen	Phosphorus Colwell	Potassium Colwell	Sulphur	Organic Carbon	Conductivity	pH Level (CaCl2)	pH Level (H2O)	Chloride	Total Nitrogen	Total Carbon	Calcium Carbonate	Prewash exch. Ca	Prewash exch. K	Prewash exch. Mg	Prewash exch. Na	Moisture %	Active Labile Carbon mg/Kg Soil	Potentially Mineralisable Nitrogen
Total Barossa Region	**1.71**	**11.47**	**63.27**	**348.70**	**6.64**	**1.33**	**0.11**	**5.95**	**6.67**	**13.36**	**0.14**	**1.64**	**0.44**	**6.11**	**0.53**	**0.90**	**< 0.10**	**5.14**	**199.4**	**21.4**
Central	1.00	7.67	56.00	283.33	3.13	0.95	0.05	6.40	7.17	8.17	0.10	1.17	0.23	5.14	0.33	0.53	< 0.10	3.44	169.0	6.2
Eden	1.67	5.33	43.67	275.67	2.97	1.65	0.04	5.90	6.60	9.67	0.19	2.07	0.61	5.19	0.34	0.55	< 0.10	6.16	237.8	23.9
Gomersal	1.67	10.33	59.67	448.33	25.90	1.08	0.08	6.43	7.20	10.23	0.12	1.44	0.40	7.24	0.85	2.46	< 0.10	7.63	160.0	18.8
Greenock	2.00	1.00	21.00	170.00	2.60	1.39	0.03	5.20	6.10	10.40	0.14	1.95	0.22	2.71	0.22	0.32	< 0.10	3.47	204.00	3.20
Lyndoch	1.50	7.50	36.00	365.00	3.55	1.49	0.04	5.90	6.70	17.65	0.16	1.78	0.21	5.04	0.37	0.83	< 0.10	4.12	199.00	21.50
Marananga	2.20	16.57	79.71	376.14	5.69	1.82	0.08	5.90	6.61	15.63	0.18	2.20	0.24	7.81	0.64	1.15	< 0.10	5.99	274.0	32.8
Northern	1.50	14.29	51.71	428.43	6.04	1.06	0.08	5.89	6.57	14.40	0.11	1.30	0.85	5.29	0.69	0.54	< 0.10	4.98	158.9	17.2
Rowland Flat	1.67	13.00	110.33	190.00	2.30	1.17	0.45	5.37	5.93	9.40	0.13	1.41	0.26	7.54	0.26	0.70	< 0.10	3.18	159.5	27.7
Vine Vale	< 1	3	76	337	4.5	0.89	0.071	6.8	7.6	32.6	0.09	0.97	0.26	3.48	0.41	0.27	< 0.10	4.32	169.0	11.0

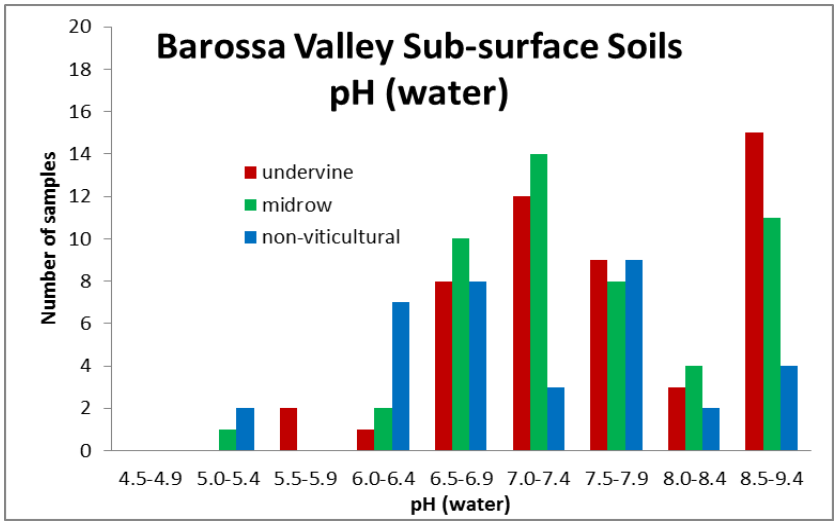
MIDROW 35-45 cm	Ammonium Nitrogen	Nitrate Nitrogen	Phosphorus Colwell	Potassium Colwell	Sulphur	Organic Carbon	Conductivity	pH Level (CaCl2)	pH Level (H2O)	Chloride	Total Nitrogen	Total Carbon	Calcium Carbonate	Prewash exch. Ca	Prewash exch. K	Prewash exch. Mg	Prewash exch. Na	Moisture %	Active Labile Carbon	Potentially Mineralisable Nitrogen
Total Barossa Region	**1.92**	**4.19**	**21.29**	**200.59**	**16.02**	**0.58**	**0.10**	**6.41**	**7.09**	**14.19**	*	*	*	**6.25**	**0.40**	**2.58**	**0.51**	**10.02**	*	*
Central	2.00	2.00	25.00	163.33	1.50	0.54	0.04	6.43	7.03	7.33	*	*	*	4.71	0.37	3.06	1.48	7.14	*	*
Eden	1.33	5.00	25.67	230.33	3.60	0.65	0.09	6.17	6.93	9.67	*	*	*	2.81	0.20	0.51	< 0.10	8.73	*	*
Gomersal	1.67	4.33	10.67	218.00	20.83	0.44	0.12	6.90	7.60	11.63	*	*	*	10.04	0.77	6.74	0.36	10.28	*	*
Greenock	2	2	6	86	20.3	0.55	0.074	5.9	6.5	63.9	*	*	*	4.19	0.17	1.86	0.24	12.86	*	*
Lyndoch	1.50	5.00	9.50	291.50	3.90	0.80	0.05	6.20	7.00	14.75	*	*	*	10.55	0.84	4.87	0.34	21.50	*	*
Marananga	1.57	3.43	13.43	246.86	36.80	0.73	0.11	6.80	7.59	18.11	*	*	*	9.04	0.43	3.02	0.61	12.45	*	*
Northern	3.20	4.83	35.50	140.29	13.11	0.43	0.15	5.86	6.39	15.87	*	*	*	4.10	0.26	1.41	0.18	7.15	*	*
Rowland Flat	2.00	5.50	23.00	154.00	9.13	0.40	0.08	6.57	7.27	16.37	*	*	*	3.48	0.23	0.38	< 0.10	8.76	*	*
Vine Vale	< 1	12	23	160	1.6	0.19	0.05	7.1	7.4	7.9	*	*	*	2.02	0.18	0.40	< 0.10	2.94	*	*

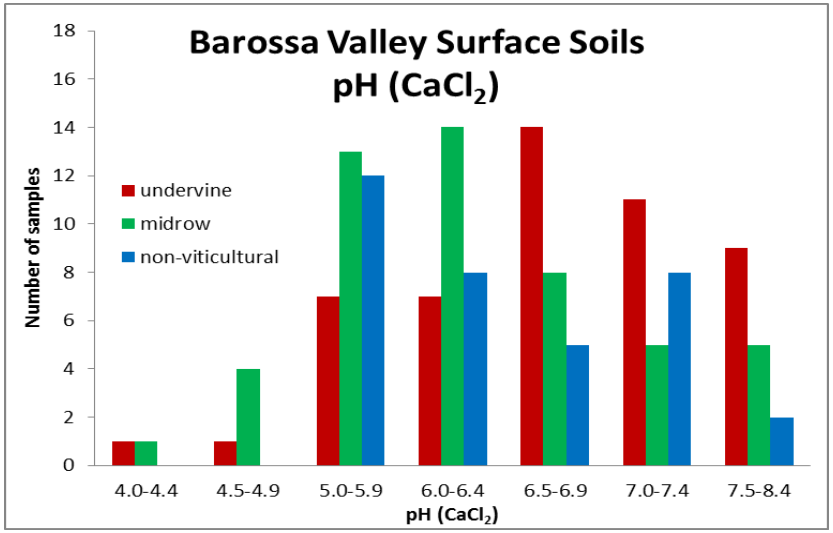
NATIVE 0-15cm	Ammonium Nitrogen	Nitrate Nitrogen	Phosphorus Colwell	Potassium Colwell	Sulphur	Organic Carbon	Conductivity	pH Level (CaCl2)	pH Level (H2O)	Chloride	Total Nitrogen	Total Carbon	Calcium Carbonate	Prewash exch. Ca	Prewash exch. K	Prewash exch. Mg	Prewash exch. Na	Moisture %	Active Labile Carbon mg/Kg Soil	Potentially Mineralisable Nitrogen
Total Barossa Region	**8.54**	**19.20**	**42.00**	**501.37**	**8.38**	**2.63**	**0.14**	**6.26**	**6.97**	**49.23**	**0.28**	**3.78**	**1.01**	**9.11**	**0.76**	**2.00**	**0.24**	**6.33**	**321.57**	**57.88**
Central	8.00	30.67	58.00	532.67	8.73	2.44	0.22	7.17	7.97	50.60	0.26	3.43	1.23	11.40	0.74	2.01	< 0.10	7.42	328.67	63.23
Eden	2.50	2.33	12.33	246.67	2.67	1.91	0.05	5.70	6.43	20.83	0.18	2.28	0.23	4.43	0.30	1.11	< 0.10	4.79	320.67	75.33
Gomersal	3.00	18.33	51.67	946.67	4.97	3.11	0.18	6.63	7.37	48.47	0.34	4.48	3.26	13.20	1.55	4.02	< 0.10	9.32	402.33	54.43
Greenock	5.00	8.00	23.00	240.00	3.50	5.38	0.14	5.60	6.20	83.20	0.78	11.65	0.24	14.90	0.32	3.65	0.14	7.25	326.00	78.00
Lyndoch	2.50	12.00	58.50	652.00	6.90	2.27	0.13	6.45	7.25	65.30	0.24	2.89	0.24	8.36	0.81	2.48	0.24	7.58	305.50	22.50
Marananga	19.14	29.29	54.57	719.71	11.84	3.22	0.17	6.23	6.96	48.44	0.34	4.69	0.35	10.82	1.19	2.14	0.32	7.10	374.86	77.03
Northern	6.86	15.86	44.71	340.00	12.11	2.37	0.15	5.84	6.50	69.31	0.24	3.11	0.26	6.67	0.51	1.67	0.31	4.74	259.29	50.14
Rowland Flat	3.00	19.00	17.33	264.67	4.23	1.84	0.10	6.43	7.17	22.17	0.19	2.88	3.60	8.31	0.30	1.00	< 0.10	4.95	273.33	25.77
Vine Vale	< 1	17.00	7.00	107.00	4.70	1.81	0.07	7.00	7.50	12.60	0.18	2.14	0.30	7.19	0.11	0.38	< 0.10	5.13	296.00	67.00

NATIVE 35-45 cm	Ammonium Nitrogen	Nitrate Nitrogen	Phosphorus Colwell	Potassium Colwell	Sulphur	Organic Carbon	Conductivity	pH Level (CaCl2)	pH Level (H2O)	Chloride	Total Nitrogen	Total Carbon	Calcium Carbonate	Prewash exch. Ca	Prewash exch. K	Prewash exch. Mg	Prewash exch. Na	Moisture %	Active Labile Carbon	Potentially Mineralisable Nitrogen
Total Barossa Region	**2.13**	**8.11**	**13.48**	**320.14**	**8.71**	**0.99**	**0.13**	**6.36**	**7.11**	**80.73**	*	*	*	**5.36**	**0.54**	**1.71**	**0.64**	**7.54**	*	*
Central	< 1	7.50	11.00	276.67	6.47	0.60	0.11	6.83	7.80	64.53	*	*	*	3.30	0.43	0.95	0.17	7.12	*	*
Eden	1.67	2.00	7.67	245.33	2.43	0.77	0.06	5.63	6.47	28.87	*	*	*	3.84	0.38	1.50	< 0.10	5.72	*	*
Gomersal	2.67	7.50	4.33	425.67	10.17	1.06	0.21	6.33	7.10	149.03	*	*	*	9.49	1.14	4.71	0.74	16.48	*	*
Greenock	2.00	2.00	6.00	86.00	20.30	0.55	0.07	5.90	6.50	63.90	*	*	*	4.19	0.17	1.86	0.24	12.86	*	*
Lyndoch	3.50	4.00	8.00	237.50	3.40	0.88	0.06	6.05	6.85	20.50	*	*	*	3.39	0.29	0.94	< 0.10	3.53	*	*
Marananga	2.57	12.57	14.57	333.57	10.39	1.17	0.13	6.26	7.03	64.44	*	*	*	6.96	0.56	1.57	0.48	7.56	*	*
Northern	1.33	8.57	19.57	285.14	8.60	0.74	0.13	6.41	7.06	71.36	*	*	*	2.88	0.43	1.04	0.49	4.99	*	*
Rowland Flat	1.00	6.33	6.33	195.67	2.57	0.71	0.07	6.93	7.53	9.80	*	*	*	5.45	0.18	0.53	< 0.10	4.67	*	*
Vine Vale	< 1	12.00	23.00	160.00	1.60	0.19	0.05	7.10	7.40	7.90	*	*	*	2.02	0.18	0.40	< 0.10	2.94	*	*

Figure 6.11 Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Barossa Valley region in 2013 and 2014.







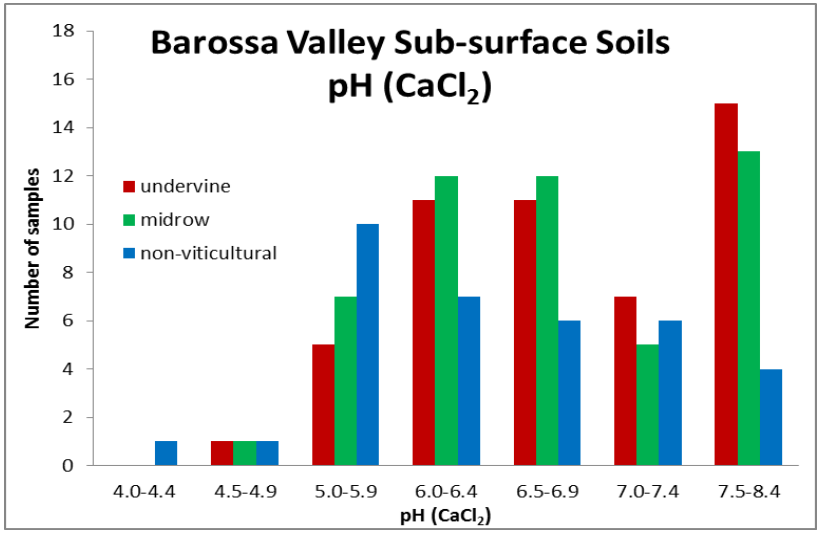
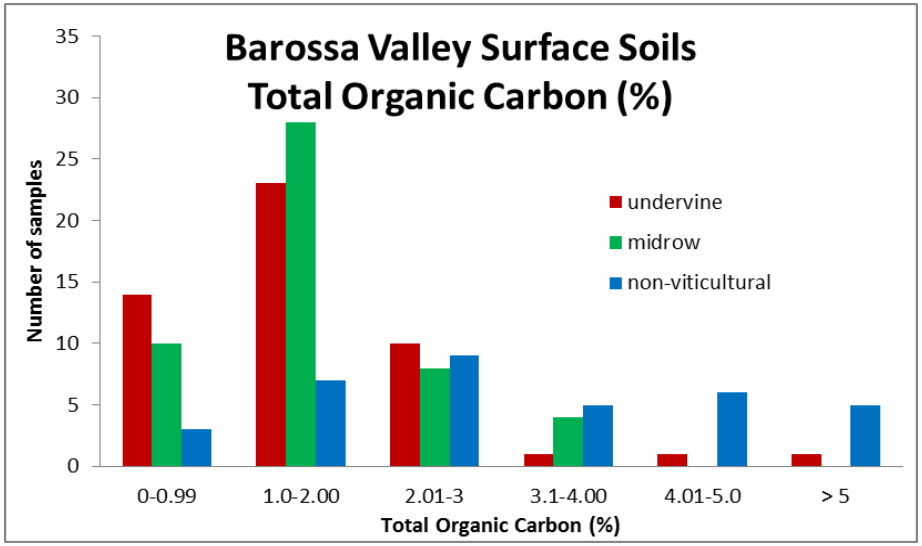
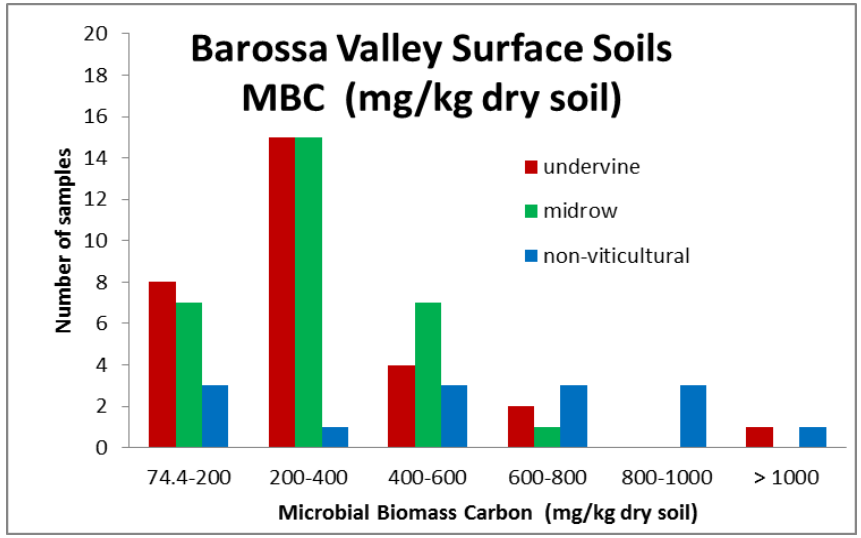
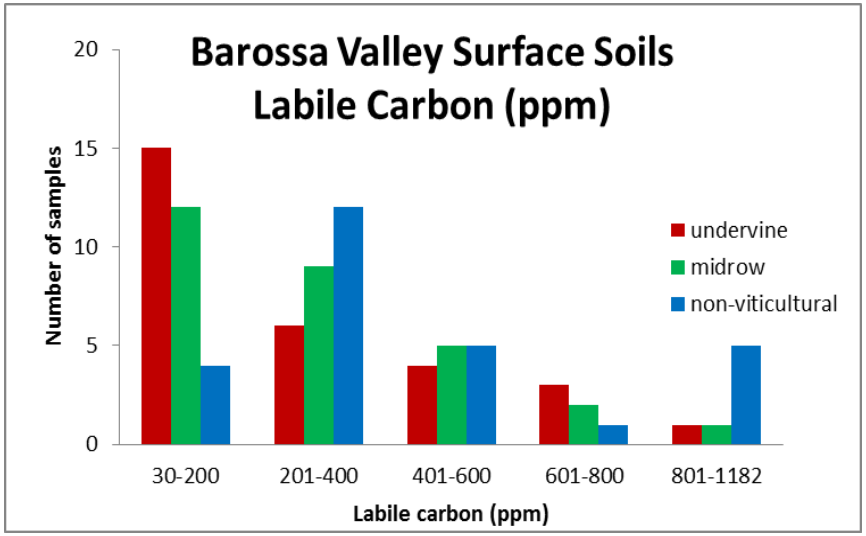


Figure 6.11 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Barossa Valley region in 2013 and 2014.







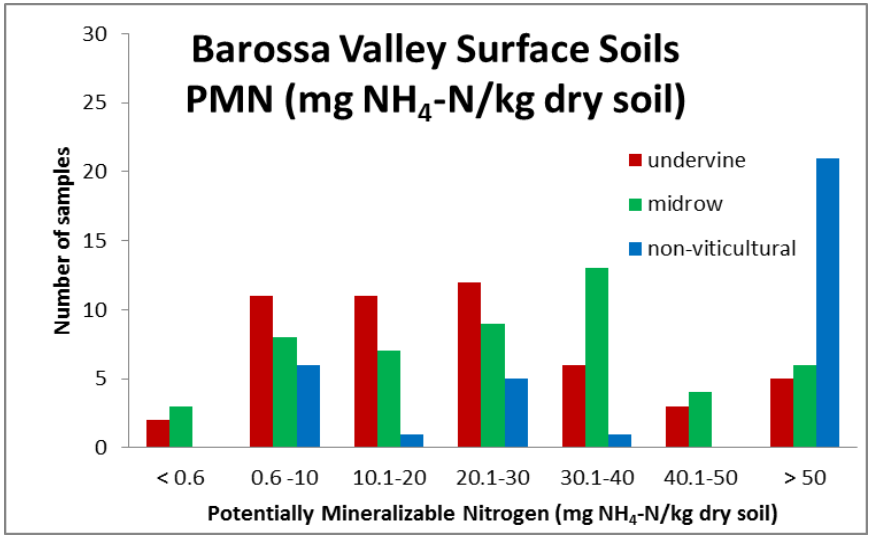
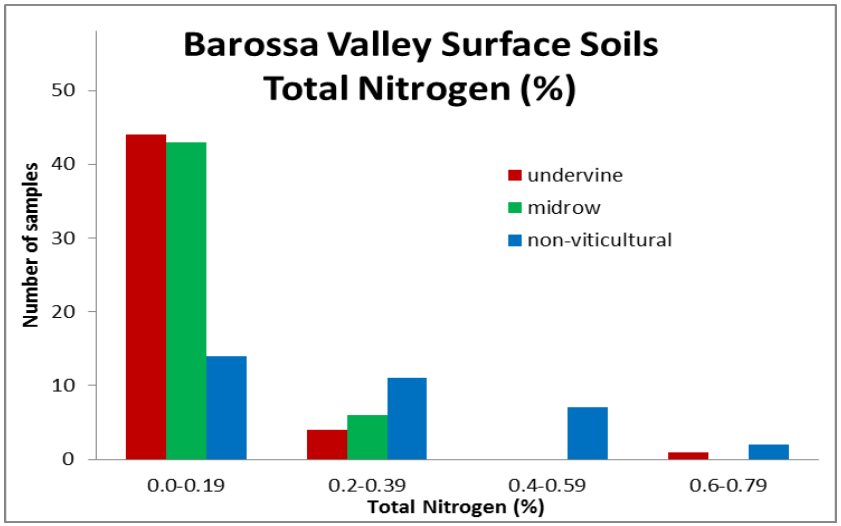
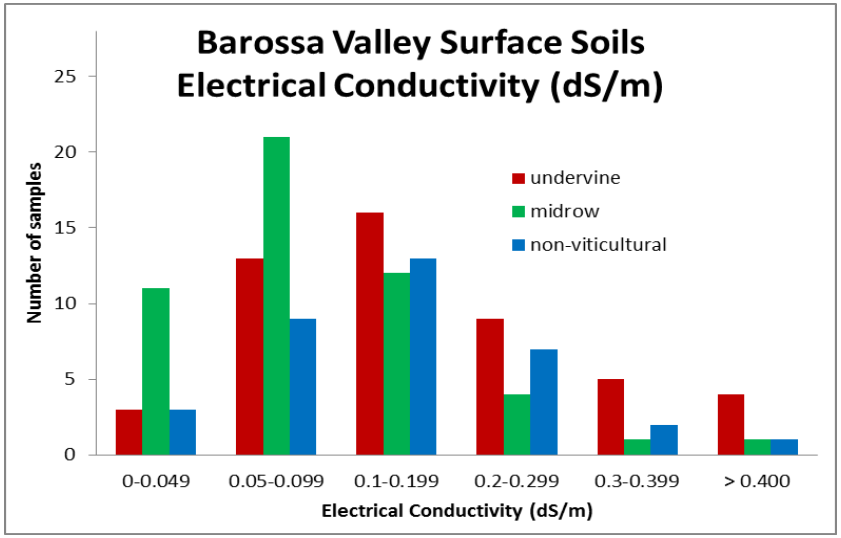


Figure 6.11 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Barossa Valley region in 2013 and 2014.





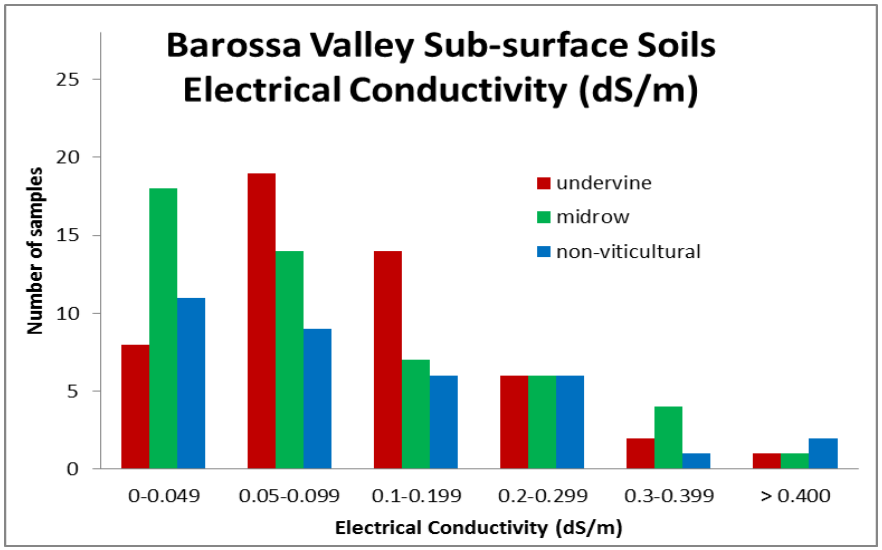
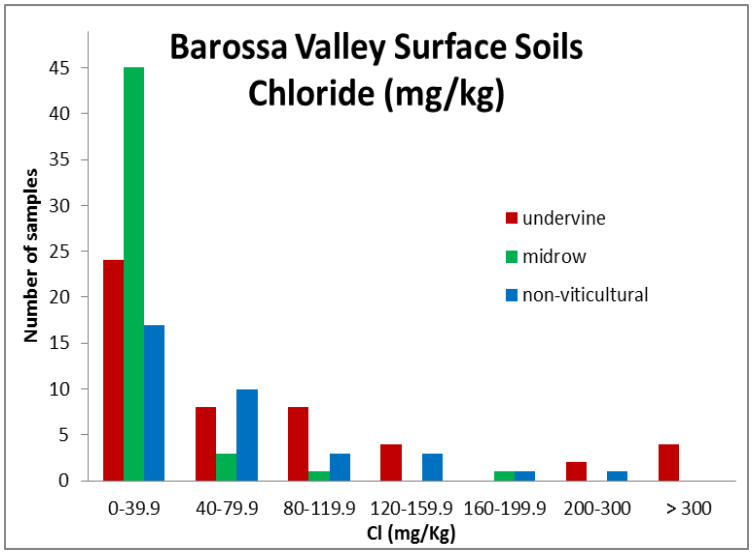
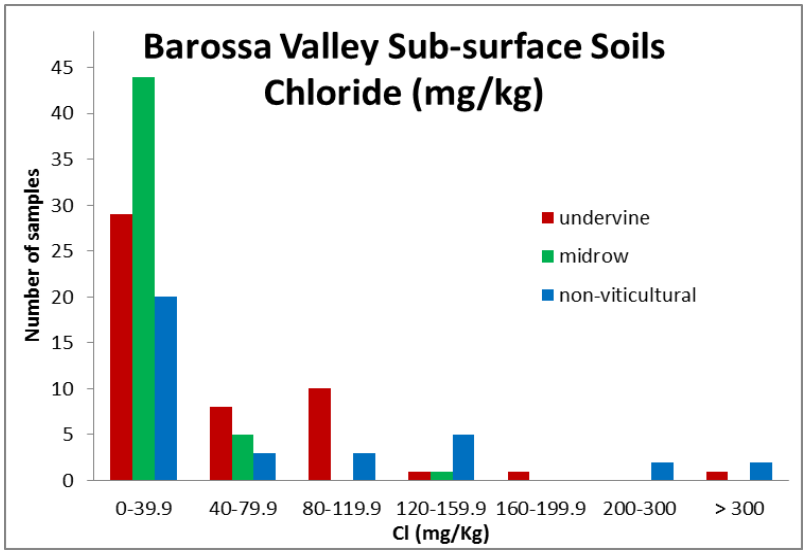
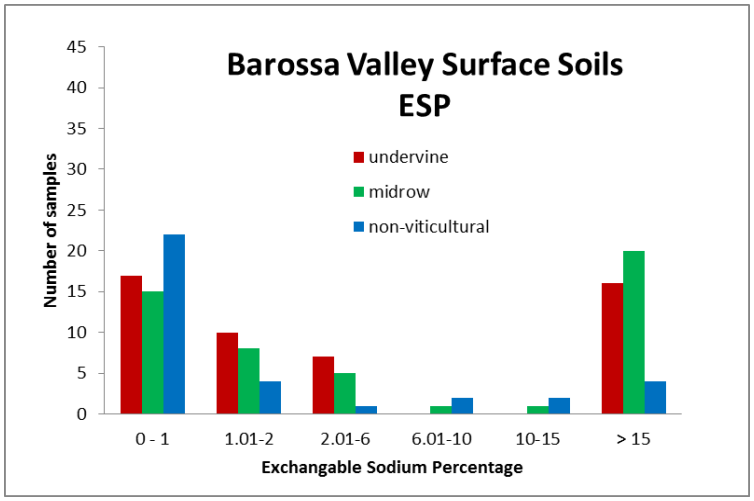


Figure 6.11 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Barossa Valley region in 2013 and 2014.







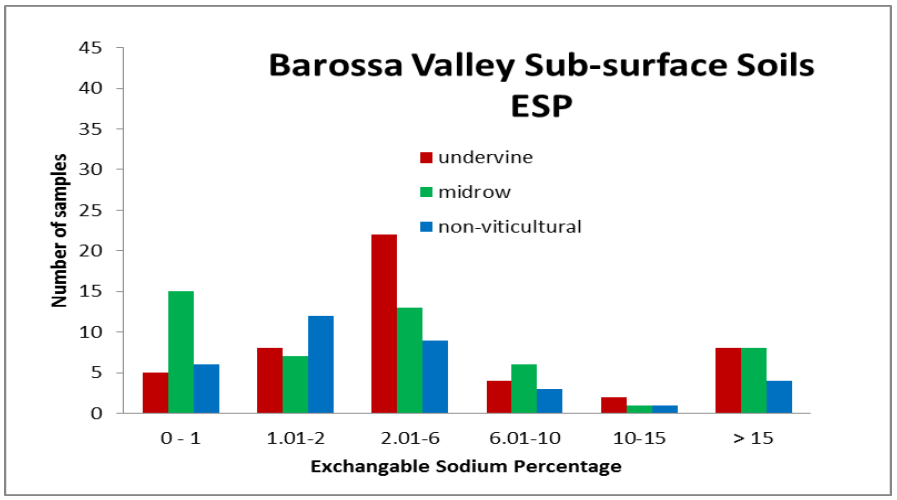
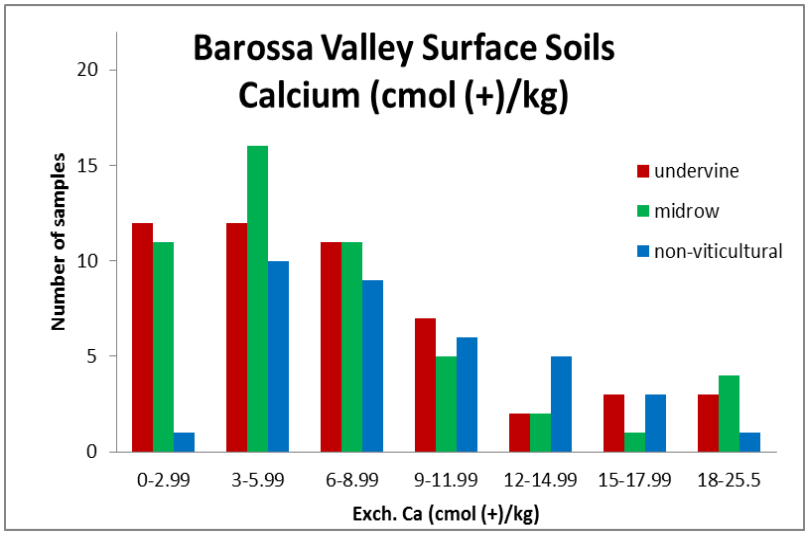
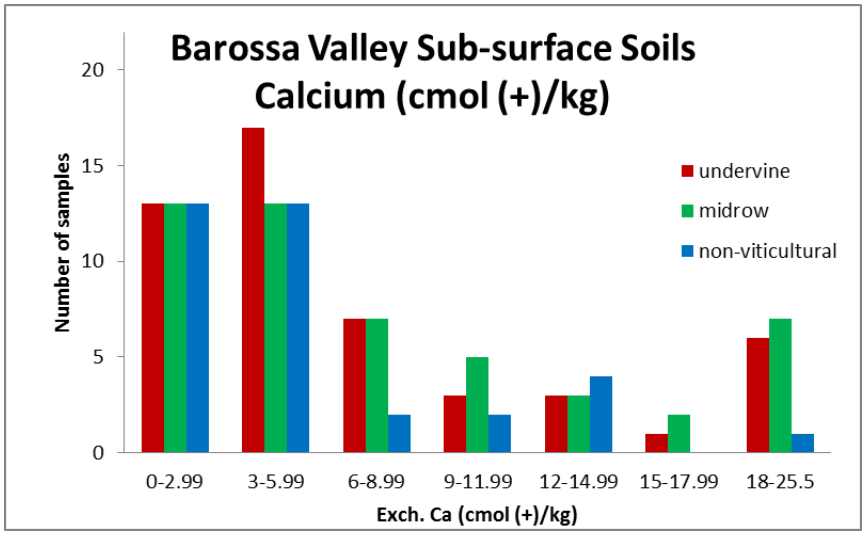
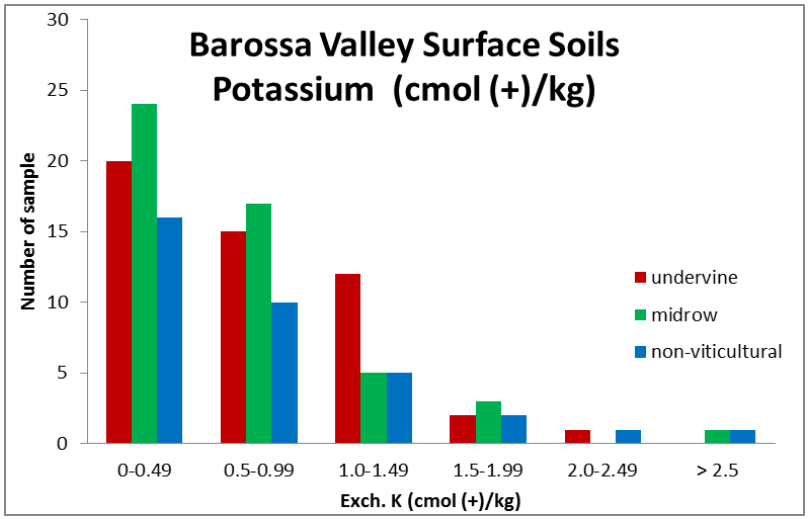


Figure 6.11 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Barossa Valley region in 2013 and 2014.







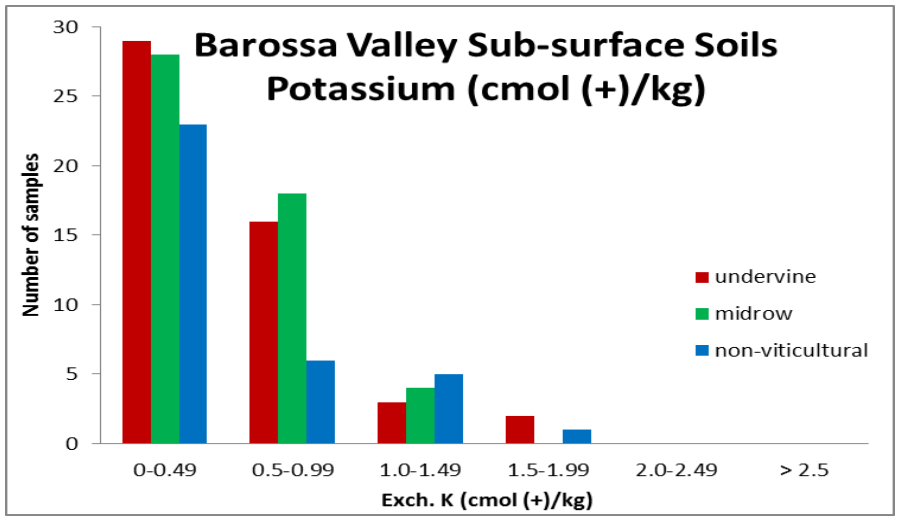
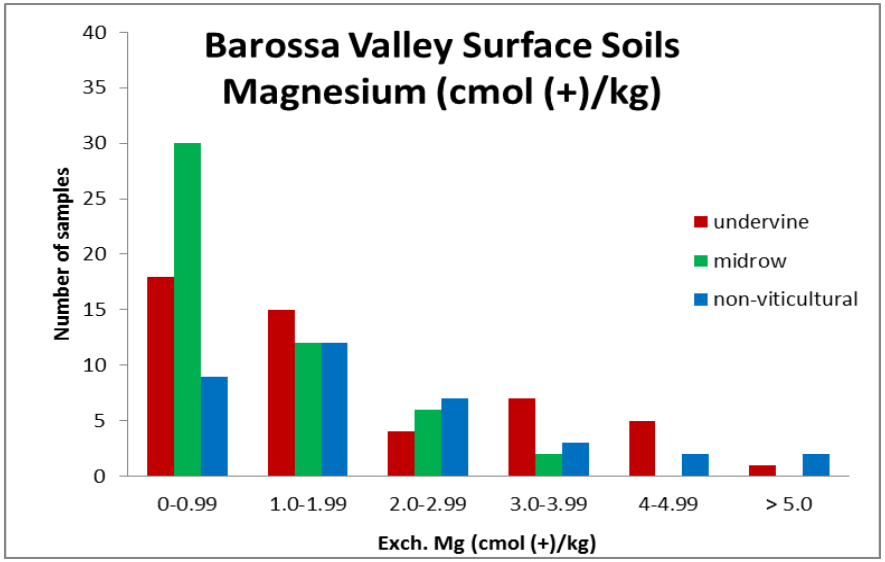
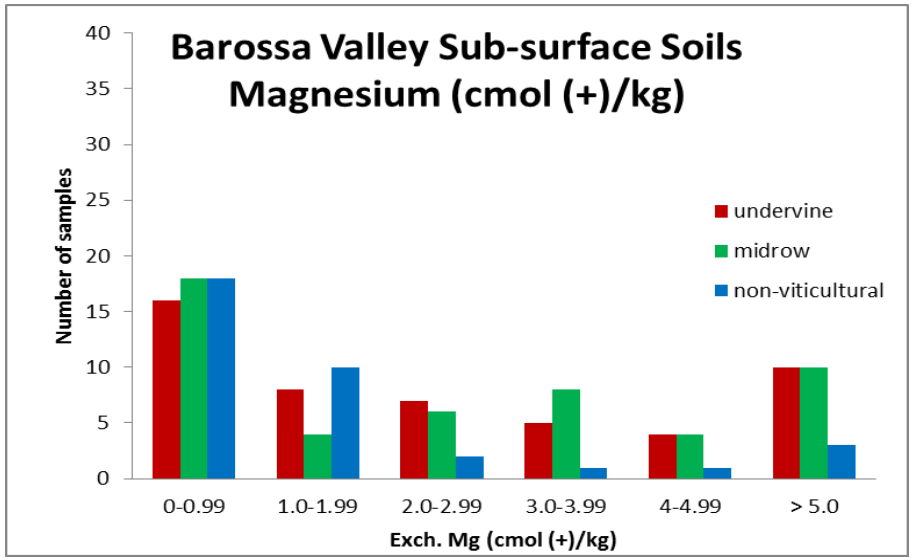
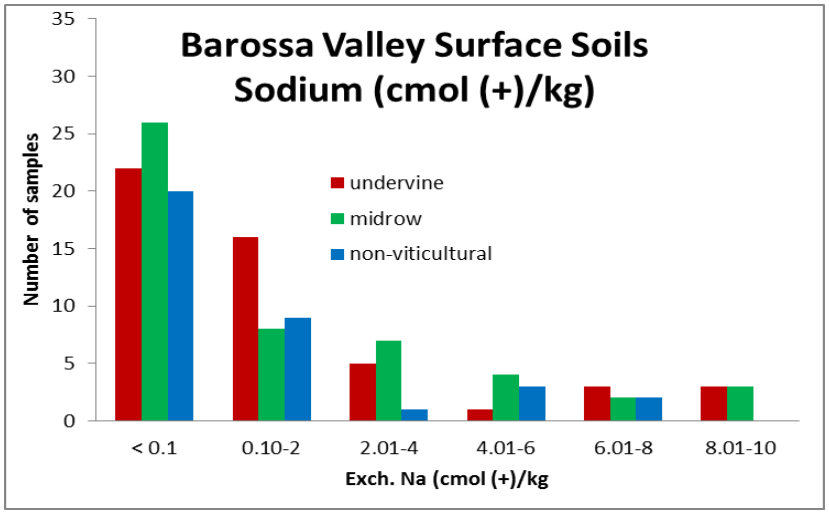


Figure 6.11 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Barossa Valley region in 2013 and 2014.







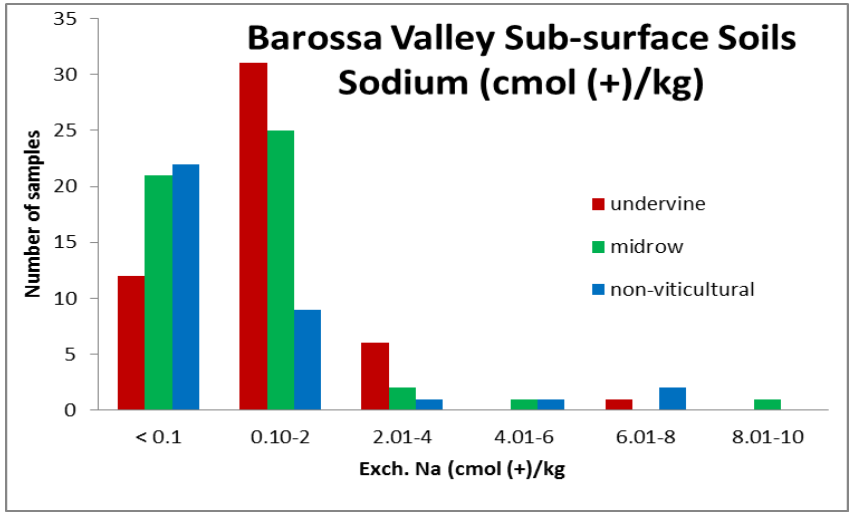
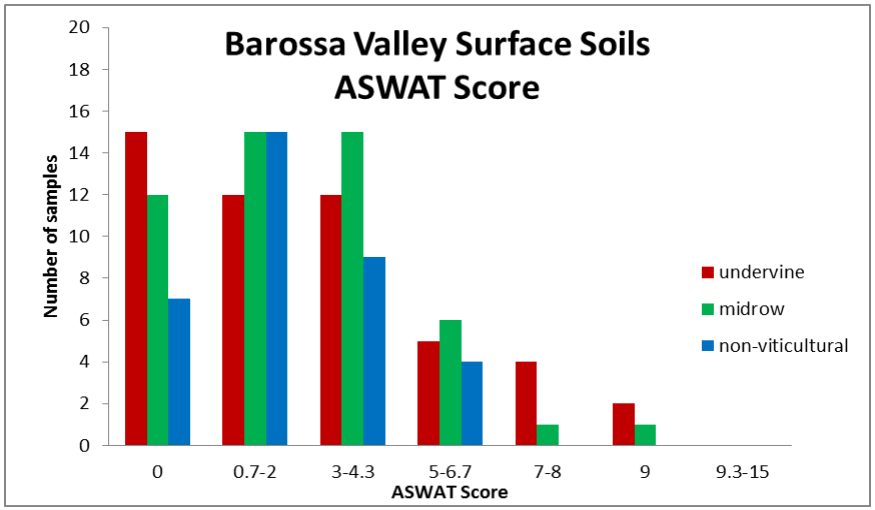
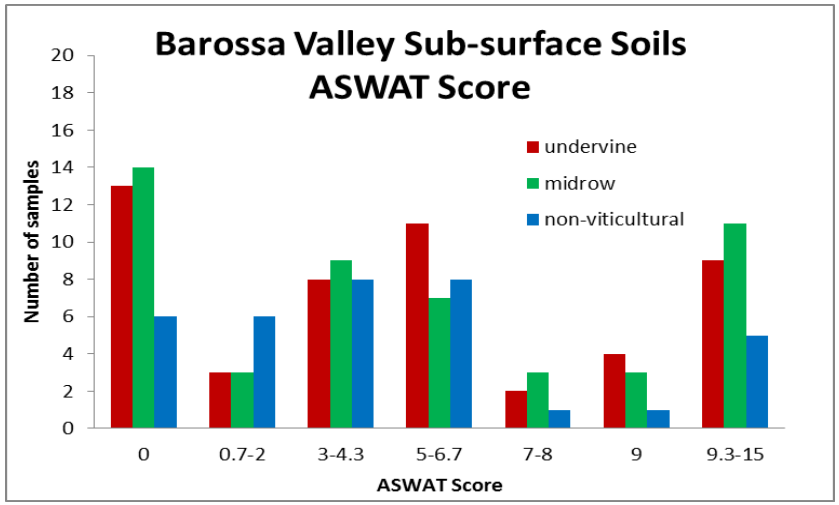
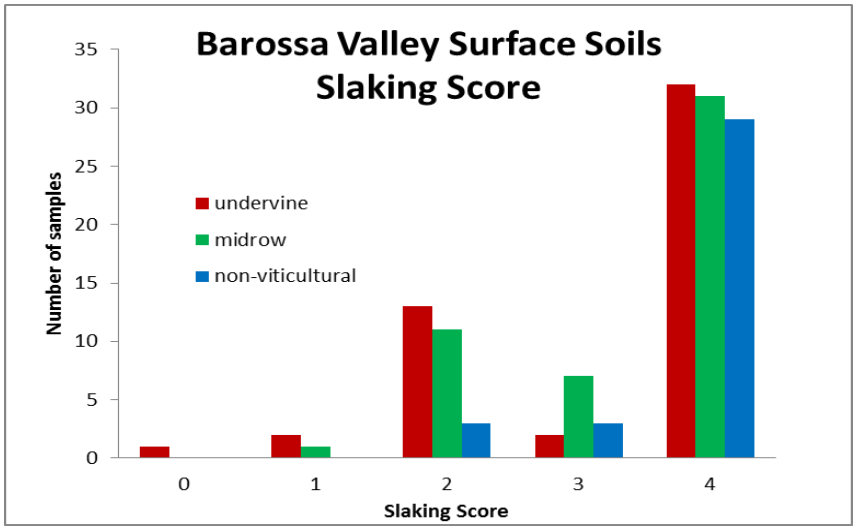


Figure 6.11 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Barossa Valley region in 2013 and 2014.







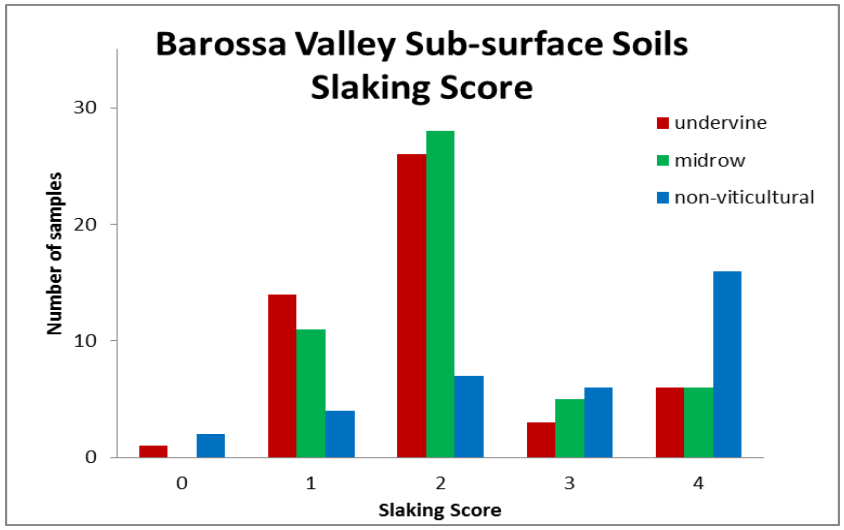
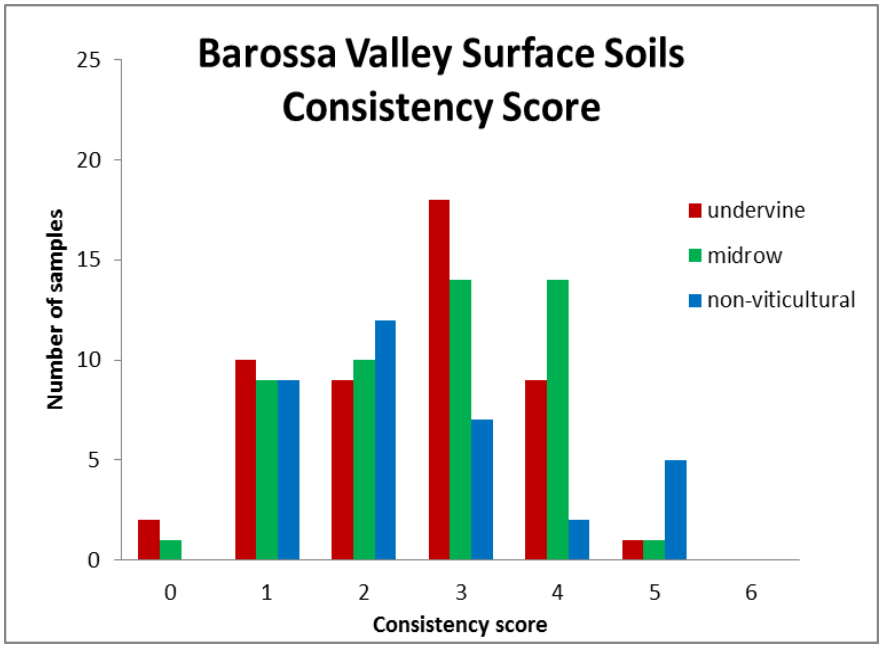
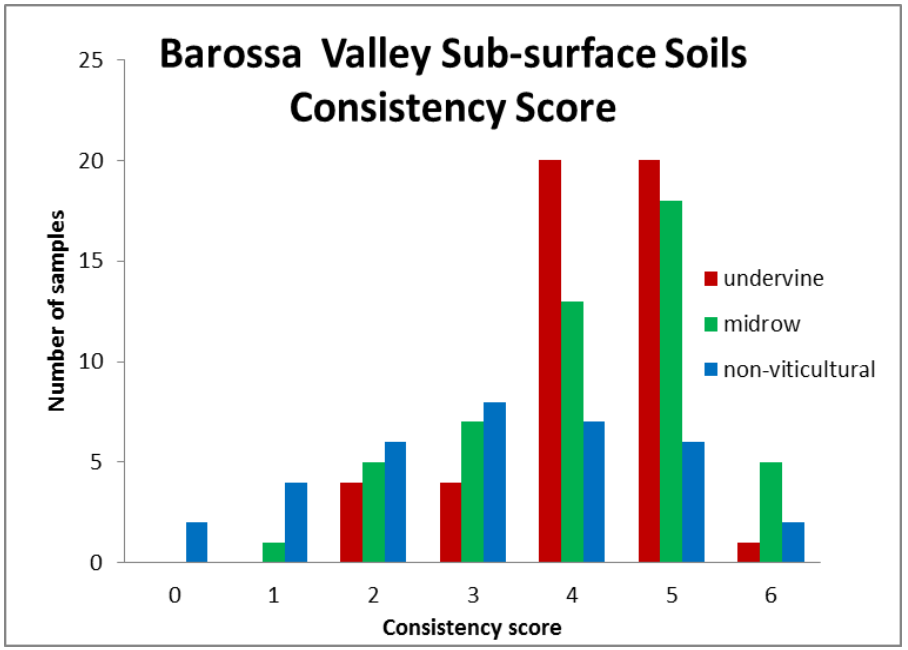


Figure 6.11 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Barossa Valley region in 2013 and 2014.





Chapter 7: Benchmarking indicators of soil quality at a regional scale - Murray Darling

7.1 Introduction

The Murray Darling region is located along the Murray River in north west Victoria and western New South Wales (Figure 7.1). The region extends from the border of Victoria with South Australia in the west, to Balranald in New South Wales in the east. The region's vineyards are mainly located on the southern, Victorian side.

The Murray Darling geographic indication is the second largest wine region in Australia and the biggest in Victoria, with more than 1000 growers and 25,000 hectares producing more than 400,000 tonnes annually. This area accounts for more than 20% of Australia's winegrape harvest.



Figure 7.1. Map of the Murray Darling wine region.

The climate is Mediterranean and well suited to growing grapes. Skies are clear on average 122 days a year, annual rainfall total is 292 mm and maximum temperatures average 23.6ºC, with extended periods over 30ºC in the summer months. The long, hot sunshine hours with negligible growing season rainfall make irrigation essential.

The region's main varieties are Chardonnay, Shiraz, Cabernet Sauvignon and Merlot.
There are three main soil categories used for viticulture in the region:

- Sodosols: texture contrast soils which have subsoils which are not strongly acid (i.e. pH >5.5 in water) but are sodic. Their surface texture ranges from sandy loam to clay loam over medium to heavy clay. Red Sodosols are the most common.
- Vertosols: clay soils that shrink and swell causing seasonal cracking as the soil dries out. They occur on alluvium and associated lake bed deposits, along creeks and rivers as well as on broad low-lying plains. Profiles are typically coarsely structured, sodic, gypseous and often saline. Grey Vertisols are the most common.
- Calcarosols: soils that do not have strong texture contrast between surface and subsoil horizons and are calcareous throughout the soil profile, often with accumulations of calcium carbonate (lime) in the soil profile. They range from brown to red-brown loamy sand, sandy loam or loam. The surface is neutral to moderately alkaline with increasing alkalinity at depth as textures become more clayey and calcareous. The surface soils are permeable, although perched water tables (attributable in part to soil properties and topography resulting from management practices associated with salinity build-up) can create problems in some areas. Overall, however, the soil supports the vigorous growth and high grape yields required.

This chapter provides data from the soil analyses and outlines the distribution of data for each soil property measured for soils collected from the Murray Darling region in Victoria and NSW. The objective was to establish benchmarks for typical regional values and their distribution, so that through repeat measures in the future, assessment can be made of the effect of continued viticultural production on these soil properties.

7.2 Method

7.2.1 Site selection

Vineyard sites were identified through local knowledge and assistance of Jenny Treeby, Project Manager Horticulture Industry Network (HIN) and Project Officer Productivity Services (Sunraysia), DEPI Victoria – Irymple. Twenty-two vineyards were selected across the Murray Darling region for soil sampling four weeks after harvest (March 2013). Property owners were asked to choose either a single site that represented their vineyard, or a paired site which represented the best performing (denoted good) and worst performing (denoted poor) areas within a vineyard. On this basis, eight paired sites were included in the sampling, giving a total of 31 vineyard sites (Table 7.1). This method was chosen to capture the range of soil properties for the region and to allow us to use the MDS to compare properties of poor and good performing sites to see if there were any significant differences that may help explain the vine performance difference.

The vineyards were chosen to cover the range of soil types used for grape growing in the region. The location of the vineyards is shown on a region map of the soil types (Figure 7.2).

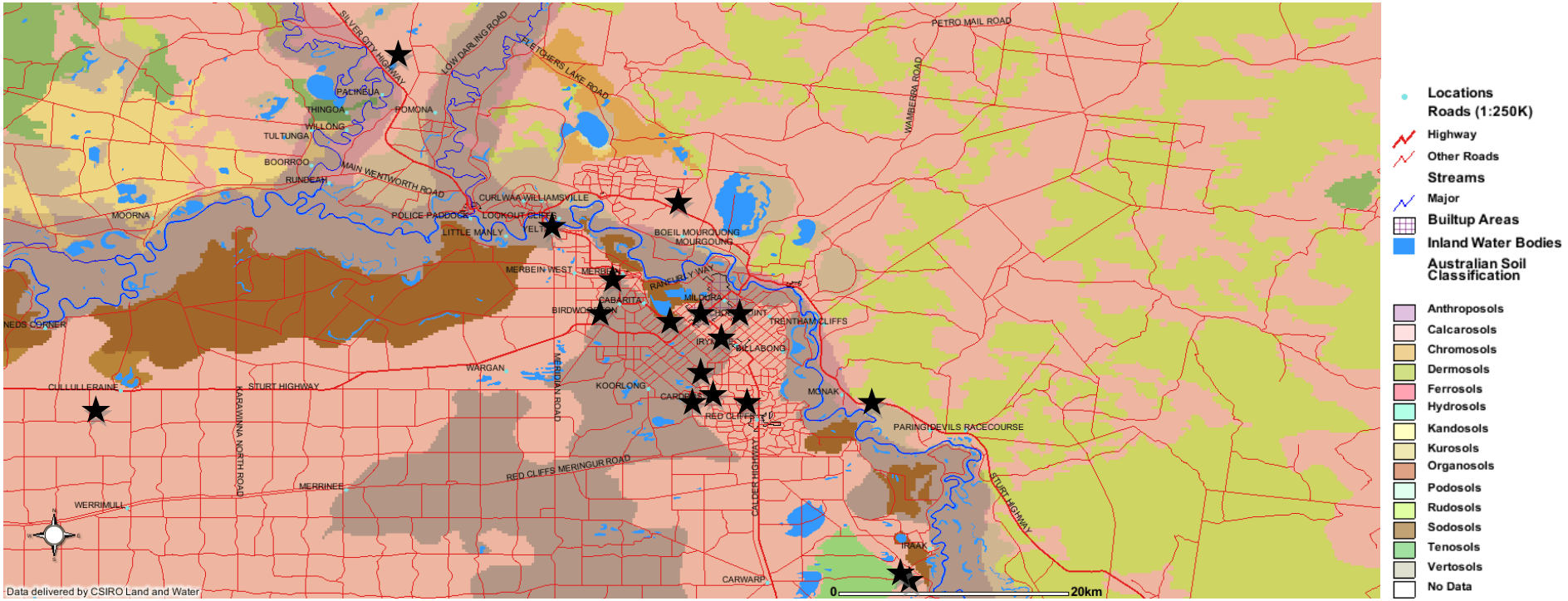


Figure 7.2. Approximate sampling locations ★ and generalised soil groups throughout the Murray Valley region. Map obtained from ASRIS. (2011).

Table 7.1. Thirty-one vineyard sites sampled in the Murray Darling region in 2013.

Name	Location	State	Paired performance	Cultivar
Mi1 A	Irymple	VIC	Good	Chardonnay
Mi1 B	Irymple	VIC	Poor	Chardonnay
Mi2	Irymple	VIC		Shiraz
Mi3	Red Cliffs	VIC		Chardonnay
Mi4 A	Cardross	VIC	Poor	Shiraz
Mi4 B	Cardross	VIC	Good	Shiraz
Mi5	Cardross	VIC		Merlot
Mi6	Cardross	VIC		Merlot
Mi7 A	Cardross	VIC	Poor	Colombard
Mi7 B	Cardross	VIC	Good	Colombard
Mi8	Merbein	VIC		Chardonnay
Mi9	Merbein	VIC		Chardonnay
Mi10 A	Mildura South	VIC	Poor	Cabernet Sauvignon
Mi10 B	Mildura South	VIC	Good	Cabernet Sauvignon
Mi11	Mildura South	VIC		Shiraz
Mi12 A	Lake Cullulleraine	VIC		Semillon
Mi12 B	Lake Cullulleraine	VIC	Good	Cabernet Sauvignon
Mi12 C	Lake Cullulleraine	VIC	Poor	Cabernet Sauvignon
Mi13	Yelta	NSW		Merlot
Mi14	Coomealla	NSW		*
Mi15 A	Yankabilly	NSW	Poor	Chardonnay
Mi15 B	Yankabilly	NSW	Good	Chardonnay
Mi15 C	Yankabilly	NSW		Cabernet Sauvignon
Mi16	Gol Gol	NSW		Shiraz
Mi17	Karadoc	VIC		Shiraz
Mi18	Karadoc	VIC		Cabernet Sauvignon
Mi19 A	Red Cliffs	VIC	Poor	Shiraz
Mi19 B	Red Cliffs	VIC	Good	Shiraz
Mi19 C	Red Cliffs	VIC		Shiraz
Mi20 A	Colignan	VIC	Poor	Chardonnay
Mi20 B	Colignan	VIC	Good	Chardonnay

7.2.2 Soil sampling

Soil sampling and analyses were performed as described previously.

7.2.3 Statistical analyses

There were two objectives for the analyses. The first objective was to test whether there were any significant differences between the vineyard positions (undervine, midrow and native) in the region with respect to the MDS variables: MB, labile carbon, PMN, organic carbon, total nitrogen, pH_{water}, pH_{CaCl2}, conductivity (EC), chloride, exchangeable cations calcium (Ca), potassium (K), magnesium (Mg) and sodium (Na), CEC and ESP. The second objective was to test whether there were any significant differences between poor and good sites within vineyards with respect to the MDS variables. These variables were tested for at both soil depths, except for the variables MB, labile carbon, PMN, organic carbon and total nitrogen which were tested only in the surface soils.

For objective 1, the MDS variables for the complete dataset were analysed using one-way analysis of variance in GenStat® v16.1. The treatment structure was vineyard position and the blocking structure was vineyard.

For objective 2, the MDS variables from the 8 paired sites were analysed using analysis of variance in GenStat® v16.1. The native position data were excluded. The treatment structure was specified as *Trt*PadPos* where the factors were *Trt:* poor or good, and *PadPos:* undervine or midrow. The blocking structure was vineyard. Physical variables were analysed using the Friedman Rank Test where *Trt*PadPos* was combined as a single factor giving four distinct classes: good MR, poor MR, good UV, poor UV.

Least significant differences (5% level) were used to separate the means, subject to significant F-tests.

Histogram and quantile plots of residuals, and graphs of residuals against fitted values, were used to check ANOVA distributional assumptions of normality and constant variance.

7.3 Results and Discussion

As described for the previous regions (Chapters 5 and 6), all the growers who had participated were provided their results in a booklet (Appendix 1 provides an example) containing figures illustrating the regional distribution of values for each measured soil property, along with a summary table containing the data for their own site. Note that it was not the objective of this project to provide detailed interpretations of these analyses in terms of desirable soil management options that might be implemented in response to them. Rather, we simply sought to establish a regional distribution of soil property values and to enable collaborating growers to see where their soils sat within that regional distribution with a view to considering whether any remedial action might be warranted. Growers are encouraged to seek expert advice separately if they felt that it was warranted.

7.3.1 Regional statistics of soil properties in the Murray Darling region

Table 7.2 presents the regional averages for each of the soil properties at the three locations (undervine, midrow, native) and the two soil depths (0-15 cm, 35-45 cm). Soils in this region are alkaline, particularly in the subsoil, with high levels of calcium, sodium and chloride, and low organic carbon and biological activity.

Table 7.2. Mean values for surface (0-15 cm) and sub-surface (35-45 cm) soil properties measured at 31 Murray Darling vineyard sites in 2013 and results of tests of the significance[A] of the paddock position differences (oneway analysis of variance).

	Surface soils (0-15 cm)				Sub Surface soils (35-45 cm)			
Soil Property	**Undervine**	**Midrow**	**Native**	**Sig[A]**	**Undervine**	**Midrow**	**Native**	**Sig[A]**
pH ($CaCl_2$)	7.50a	7.68b	7.86b	**	7.81a	8.09b	8.17b	**
pH (H_2O)	8.27a	8.38a	8.64b	**	8.67a	8.97b	9.05b	**
EC[B] dS/m	0.127a	0.298b	0.200ab	NS	0.160a	0.284b	0.271b	**
Total N %	0.090ab	0.104b	0.088a	*				
Total OC %	0.763a	0.974b	0.778a	**				
ECEC[C] meq/100g	15.29	15.41	14.35	NS	17.75	16.56	16.99	NS
Chloride mg/kg	36	176	98	NS	60	126	112	NS
Exch. Ca meq/100g	9.41ab	10.06b	8.84a	*	11.19	11.18	10.82	NS
Exch. K meq/100g	0.78a	0.96b	0.88ab	*	0.69	0.81	0.57	NS
Exch. Mg meq/100g	2.17	2.01	1.94	NS	3.26ab	3.58b	2.95a	*
Exch. Na meq/100g	2.93	2.38	2.69	NS	2.60b	0.99a	2.87b	*
ESP[D] %	19.1	15.3	17.1	NS	13.7b	5.8a	17.3b	**
MBC[E] mg/Kg Dry Soil	169a	212b	232b	**				
Labile C mg/kg	257b	284b	208a	**				
PMN (mg N/kg)	8.69a	12.93b	12.95b	**				
ASWAT[G]	2	2	3		2	3	5	
Slaking score	2	2	2		3	3	3	
Hardness	2	2	2		3	2	2	

[A]Significance is denoted by NS, not significant, * P < 0.05, ** P < 0.01 based on Fisher's LSDs at 5%. Yellow highlighting and different letters following values in rows indicate significant differences.

[B] EC = electrical conductivity; [C]ECEC = effective cation exchange capacity; [D]ESP = exchangeable sodium percentage; [E]MBC = microbial biomass carbon; [F]PMN = potentially mineralizable nitrogen; [G]ASWAT = a measure of dispersion

7.3.2 Comparison of paired sites using the MDS

Eight vineyard managers participated in the paired site comparison where a poor performing and a high performing site within their vineyards were both sampled. The combined dataset was analysed to examine whether there were significant differences between soil properties from the poor and good sites that may identify a constraint in common that was affecting vine performance. This approach had been used in the Yarra Valley where salinity was identified as a likely cause of the poor performance (see Chapter 4).

The MDS variables detected significant differences between good and poor sites in the Murray Darling dataset (Table 7.3). Exchangeable Ca and Mg were significantly higher in the poor sites than the good sites at both depths, and the cation exchange capacity was significantly higher in the sub-surface soil of the poor sites. The undervine surface soil was more prone to slaking than the midrow in the poor sites. The undervine subsurface soil had significantly higher consistency (strength) than the midrow in the poor sites. Although these differences occurred, it is difficult to interpret them as the cause of poor vine performance, unlike in the Yarra Valley where the soil property differences were clearly factors of salinity (see Chapter 4). The MDS does not include measures of water-holding capacity. Given the climate of this region, the deep sandy soils and the absence of any stand-out constraints identified, perhaps a water-related constraint was involved.

Table 7.3. Mean values for surface (0-15 cm) and sub-surface (35-45 cm) soil properties measured at eight Murray Darling paired sites in 2013 and results of tests of the significance[A] of the between-pair difference (analysis of variance; Friedman's test for physical data). Good = area identified by grower as consistently high-performing, Poor = area identified by grower as consistently under-performing.

Property	Units	Pair	0-15 cm		35-45 cm	
			Undervine	Midrow	Undervine	Midrow
EC	dS/m	Good	0.13	0.21	0.19	0.24
		Poor	0.13	0.37	0.18	0.31
			NS	NS	NS	NS
pH ($CaCl_2$)		Good	7.3	7.6	7.8	7.9
		Poor	7.4	7.7	7.8	8.2
			NS	NS	NS	NS
pH (H_2O)		Good	8.1	8.3	8.6	8.7
		Poor	8.2	8.4	8.6	9.1
			NS	NS	NS	NS
Cl	mg/kg	Good	32	112	90	101
		Poor	29	196	68	136
			NS	NS	NS	NS
Total N	%	Good	0.08	0.10		
		Poor	0.09	0.10		
			NS	NS		
Total OC	%	Good	0.67	0.90		
		Poor	0.83	0.92		
			NS	NS		
Exch. Ca	meq/100g	Good	8.20	8.71	9.87	9.15
		Poor	10.17	10.39	10.96	12.04
			*	*	*	*
Exch. K	meq/100g	Good	0.72	0.84	0.32	1.51
		Poor	0.83	0.95	0.48	0.60
			NS	NS	NS	NS
Exch. Mg	meq/100g	Good	1.72	1.58	2.15	2.04
		Poor	2.32	1.91	3.12	3.44
			*	*	**	**
Exch. Na	meq/100g	Good	2.28	3.15	2.22	0.49
		Poor	2.45	1.21	3.05	0.78
			NS	NS	NS	NS
CEC	meq/100g	Good	14.3	12.9	14.6	13.2
		Poor	14.5	15.8	17.6	16.9
			NS	NS	*	*

Property	Units	Pair	0-15 cm		35-45 cm	
			Undervine	Midrow	Undervine	Midrow
ESP	%	Good	18.52	21.07	14.01	2.78
		Poor	14.53	6.79	16.02	4.18
			NS	NS	NS	NS
Labile C	mg/kg	Good	231	276		
		Poor	278	301		
			NS	NS		
PMN		Good	7.94	10.94		
		Poor	9.90	15.21		
			NS	NS		
MB (SIR)		Good	146	197		
		Poor	196	219		
			NS	NS		
Consistency	0-7	Good	2.4	2.8	2.6	2.7
		Poor	2.3	2.6	3.2	1.6
			NS	NS	*	*
Dispersion	0-16	Good	2.6	2.7	2.5	2.5
		Poor	2.6	2.1	2.0	3.0
			NS	NS	NS	NS
Slaking	0-4	Good	3.3	1.9	2.4	2.8
		Poor	2.7	2.1	2.7	2.1
			*	*	NS	NS

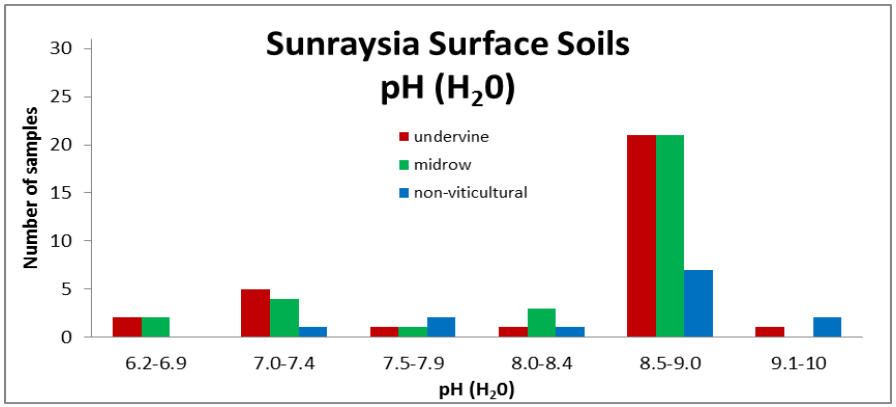
[A]Significance is denoted by NS, not significant, * P < 0.05, ** P < 0.01 based on Fisher's LSDs at 5%. Yellow highlighting indicates significant differences.

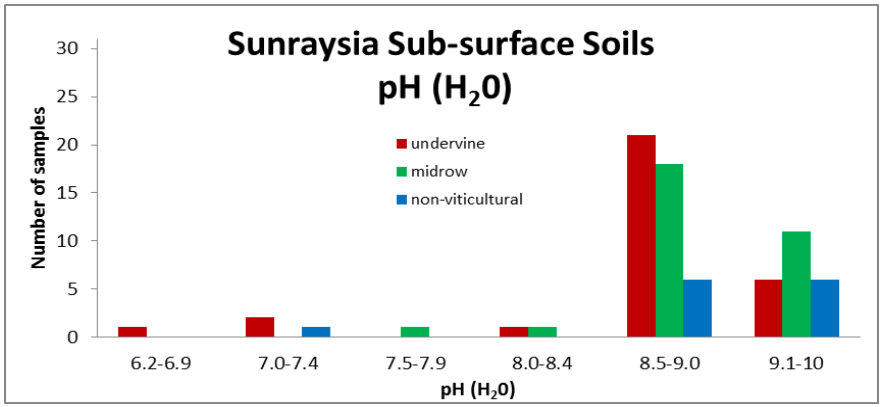
This example demonstrates that the MDS has been developed primarily as a tool to monitor soil quality and is useful for comparisons of where soil properties from a particular vineyard fit in relation to other vineyard soils within the same region. Although useful as a starting point for identifying constraints, this example serves as a reminder that other factors affect vine performance which are not captured by the MDS.

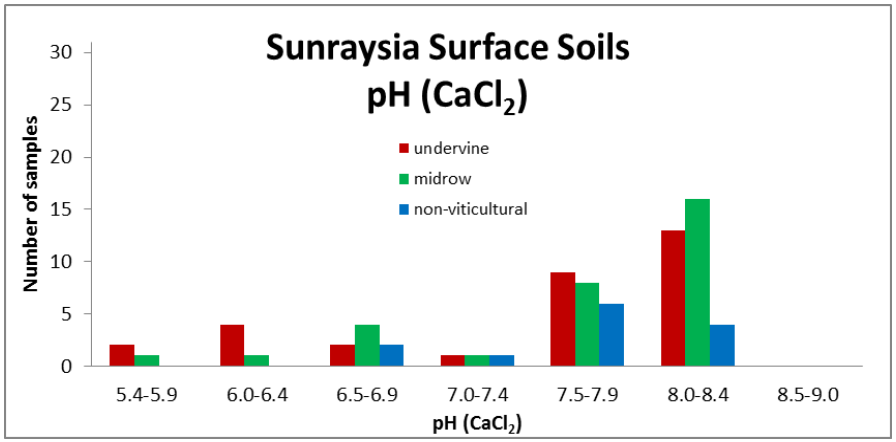
7.3.3 Regional distribution of soil property values

Figure 7.3 presents the regional distribution for each of the soil properties at the three locations (undervine, midrow, native) and the two soil depths (0-15 cm, 35-45 cm). As described previously, growers can use this information together with their own soil sampling results to establish where their vineyard soil sits in relation to other viticultural soils in the region.

Figure 7.3 Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Murray Darling region in 2013.







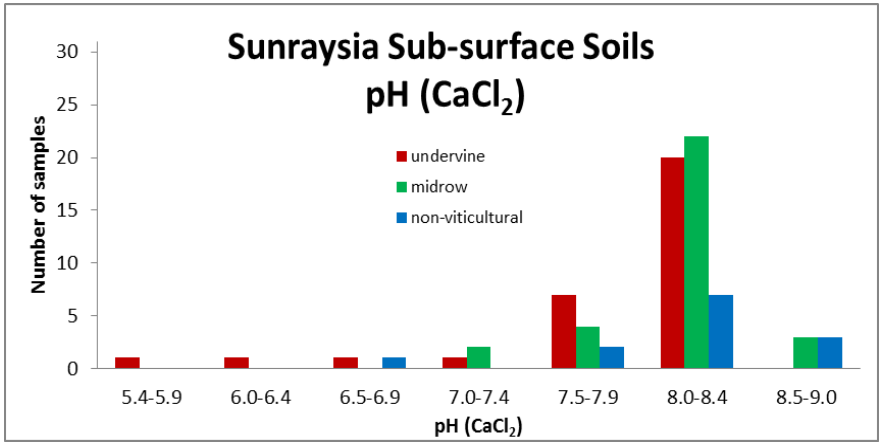
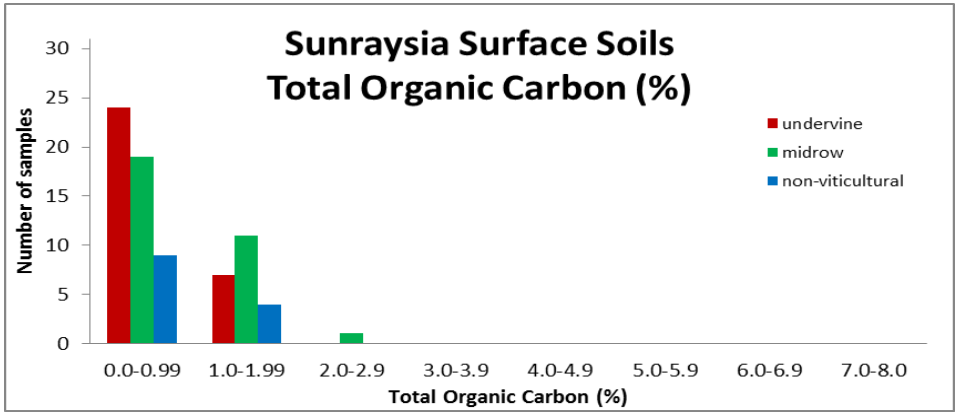
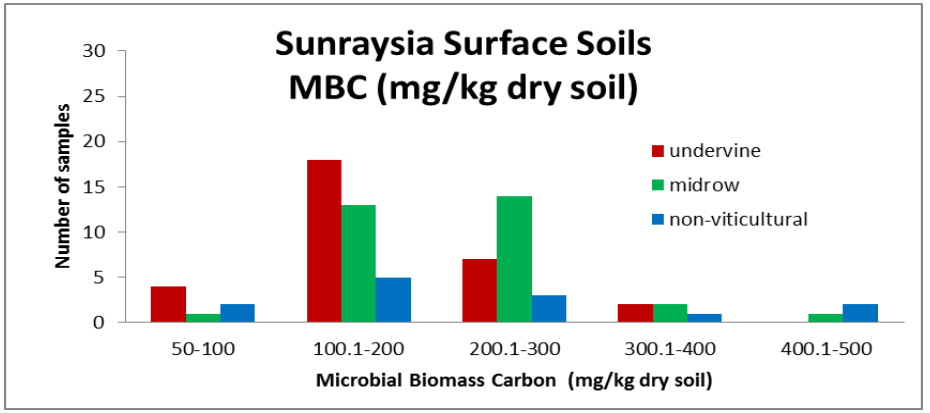
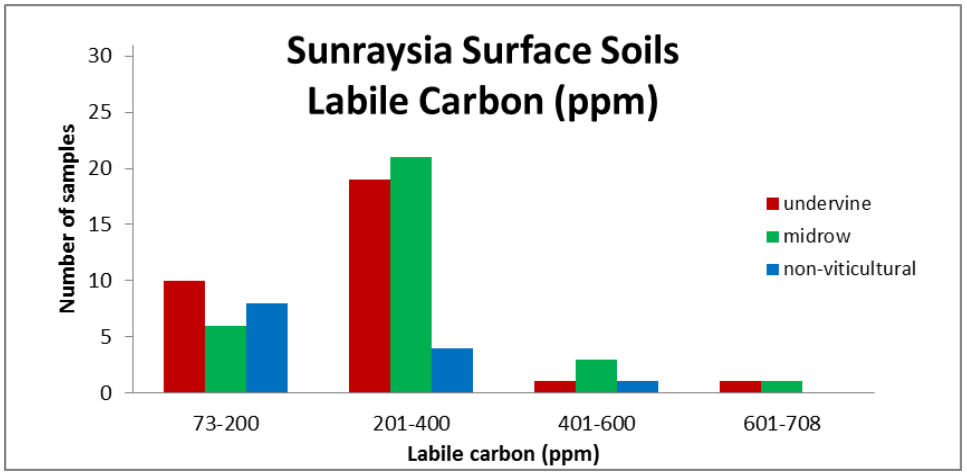


Figure 7.3 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Murray Darling region in 2013.







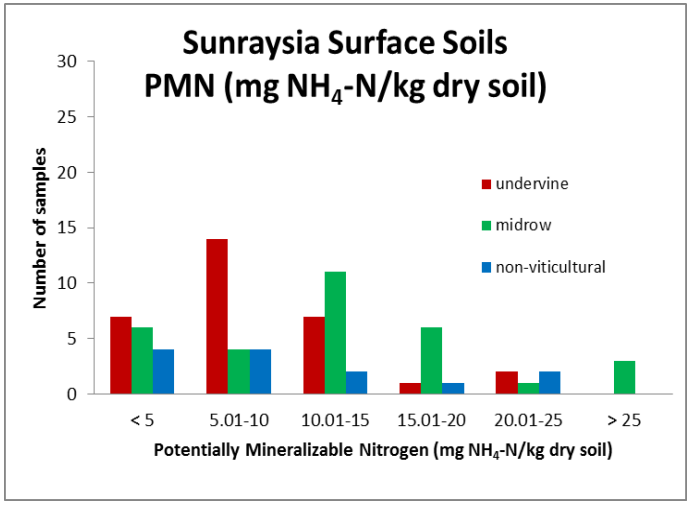
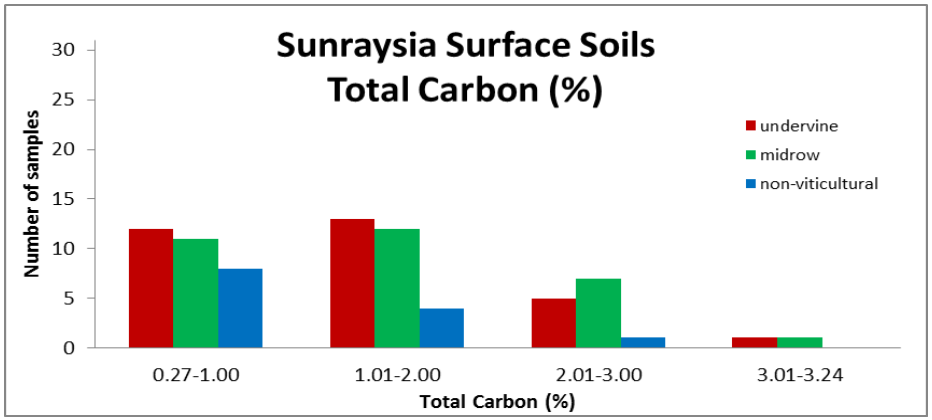
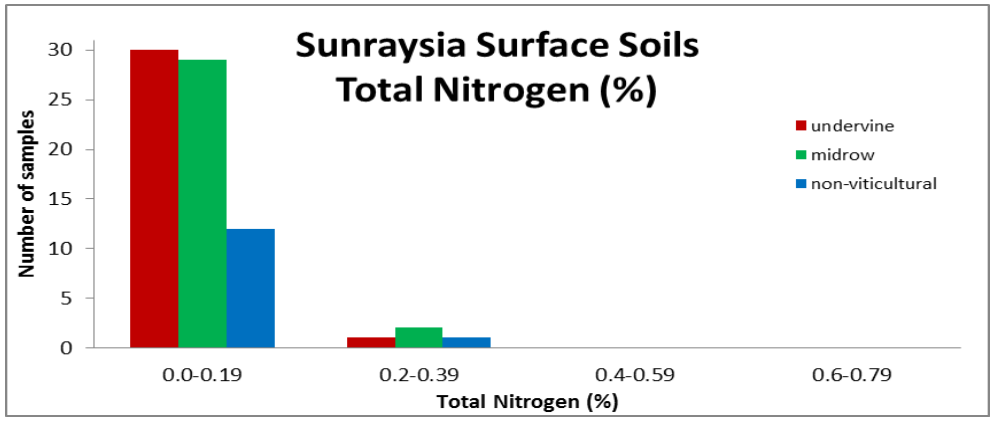
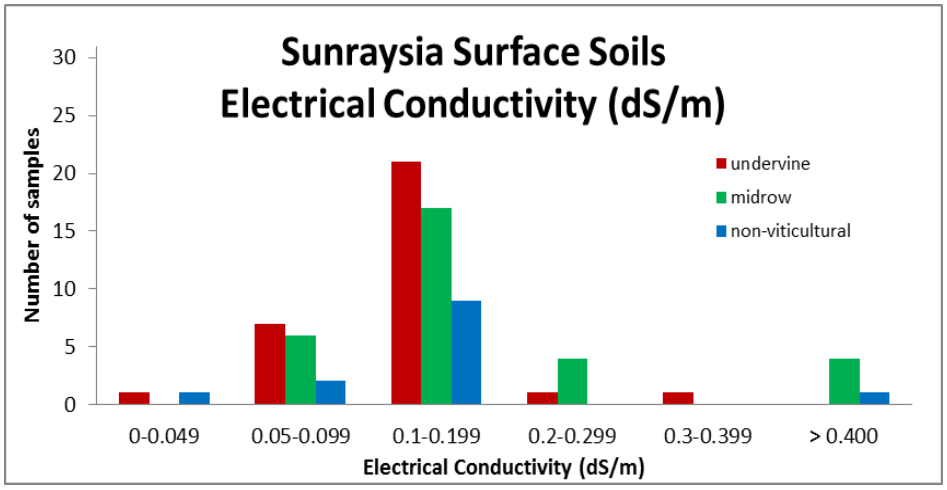


Figure 7.3 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Murray Darling region in 2013.







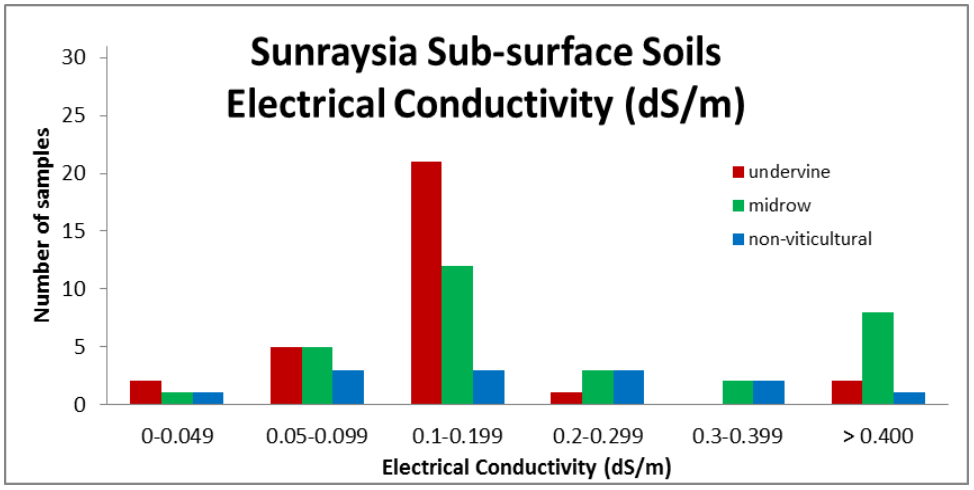
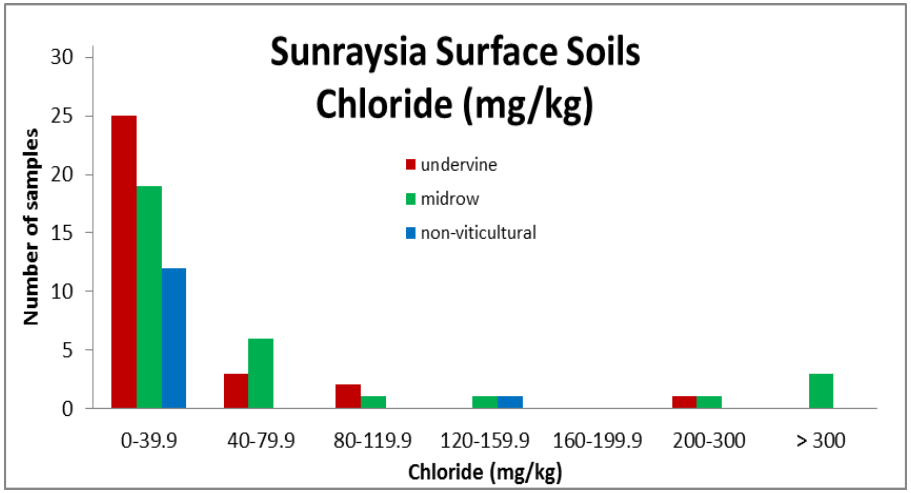
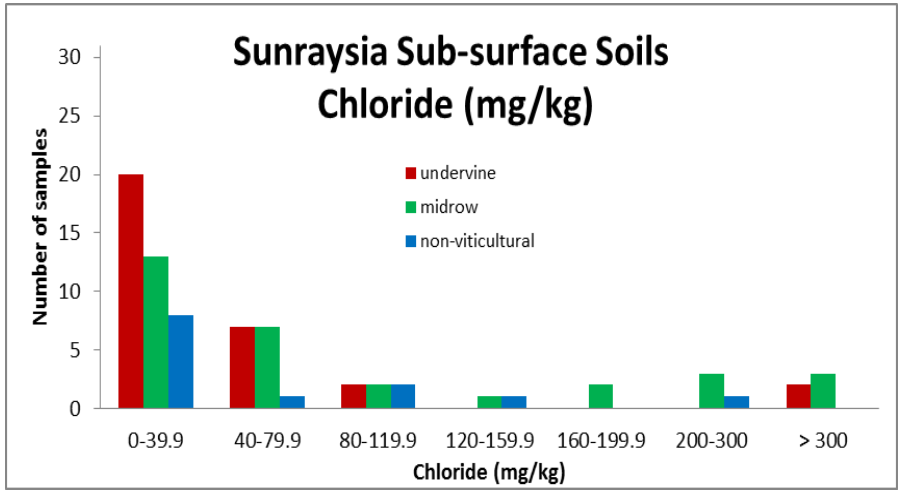
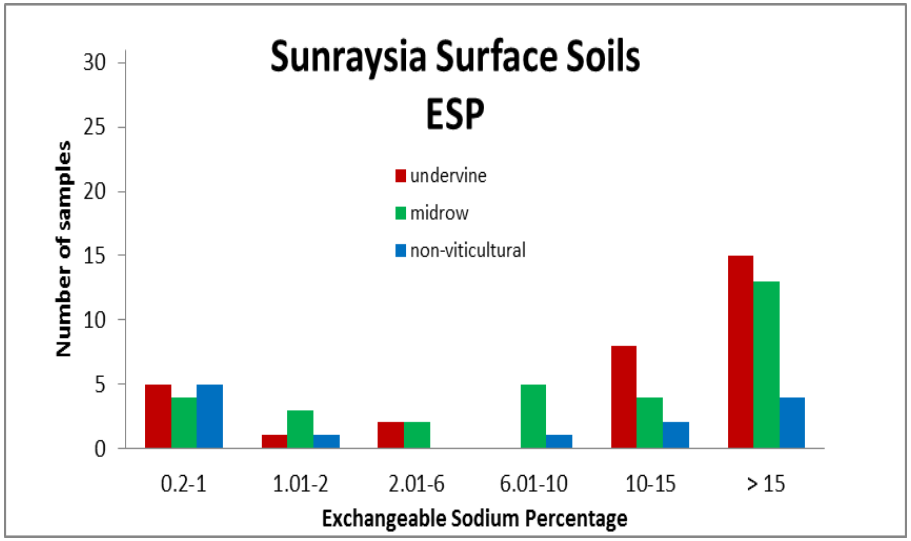


Figure 7.3 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Murray Darling region in 2013.







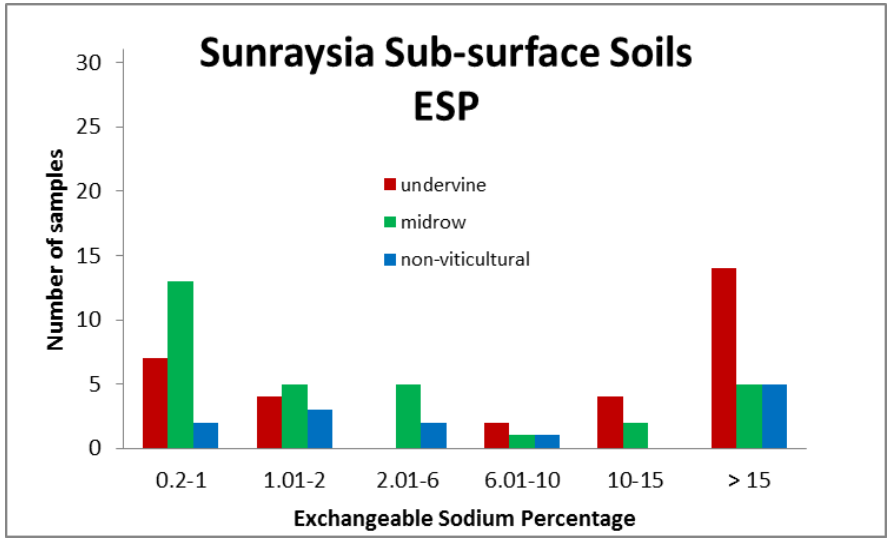
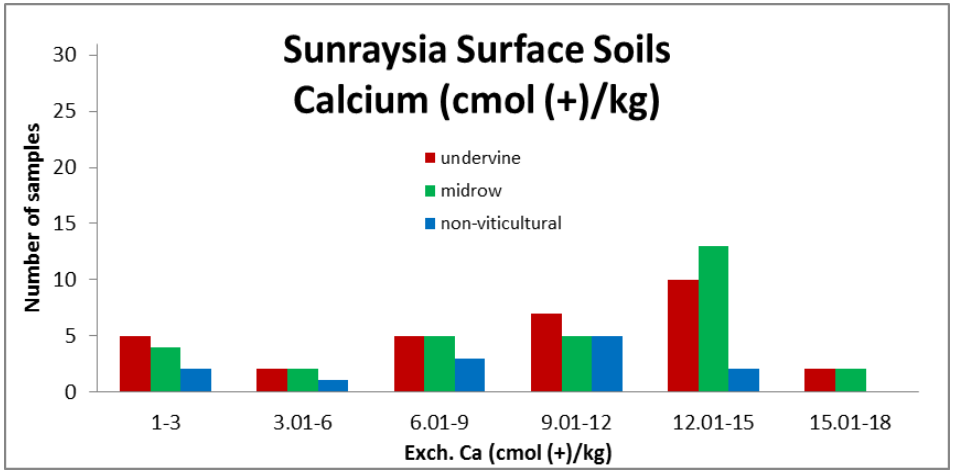
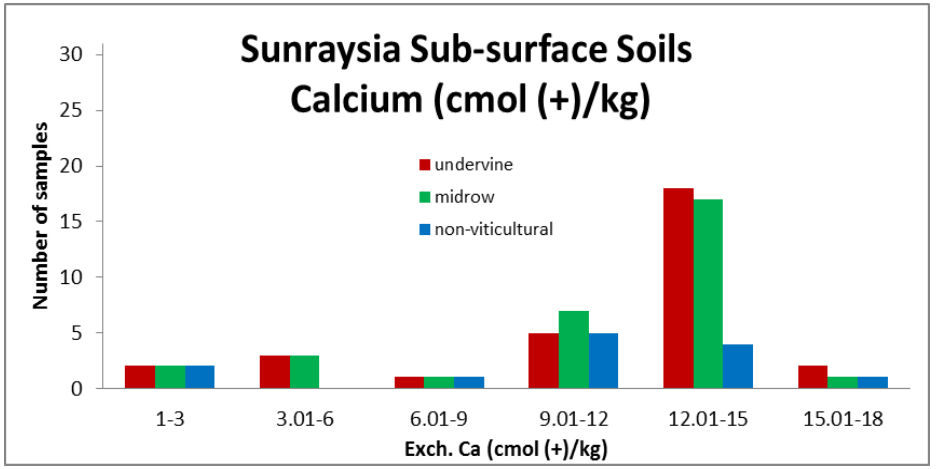
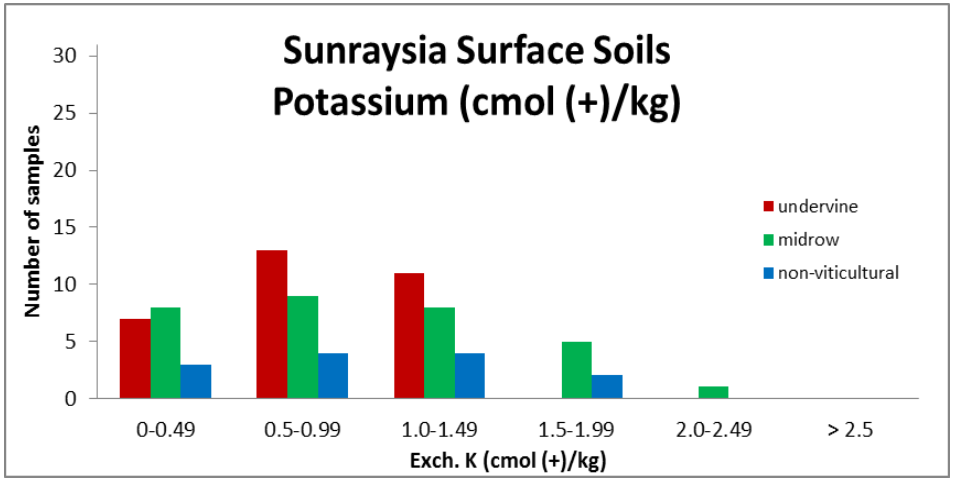


Figure 7.3 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Murray Darling region in 2013.







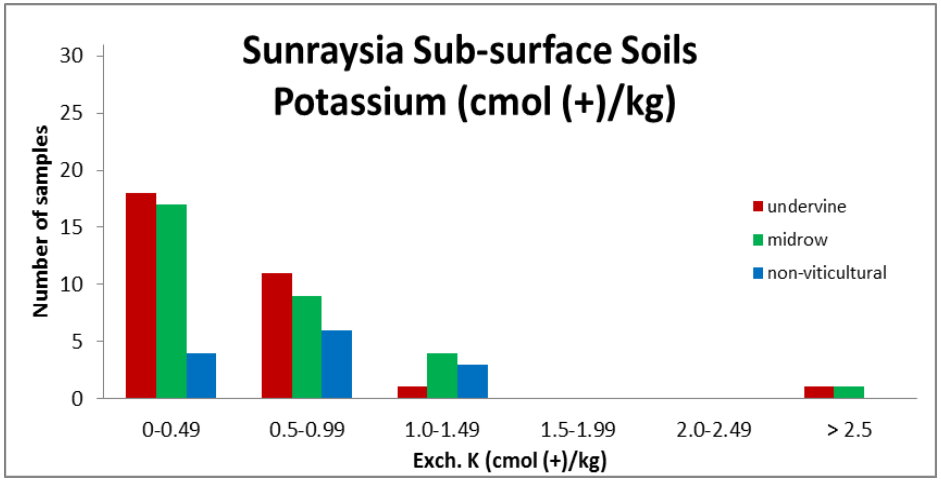
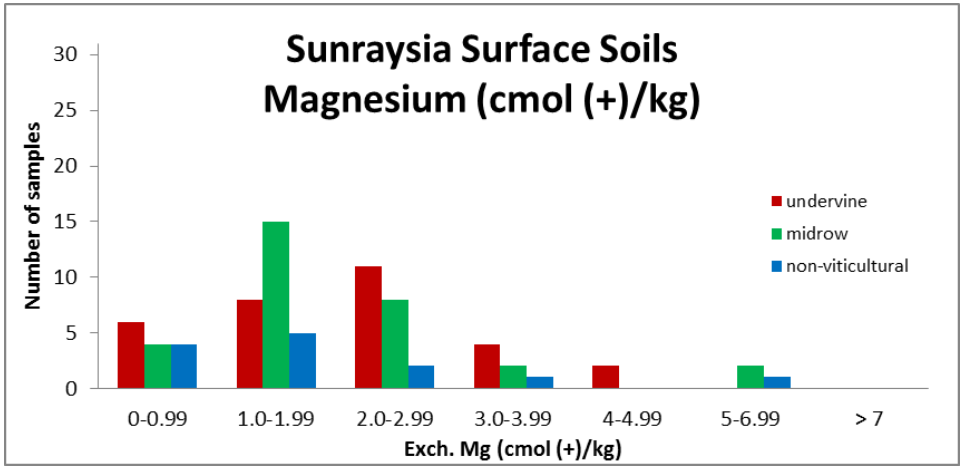
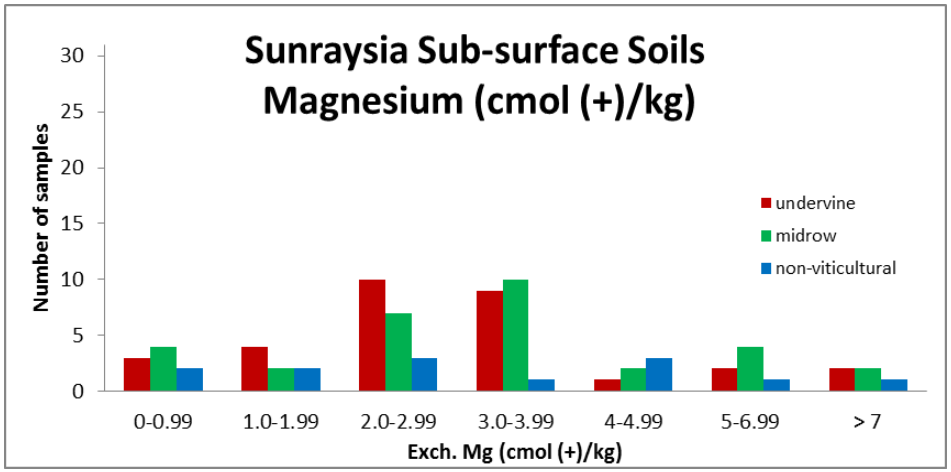
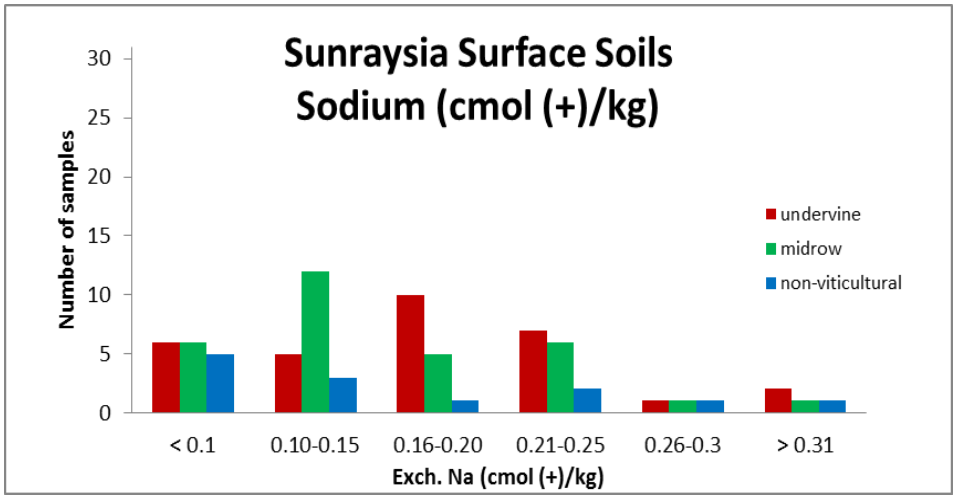


Figure 7.3 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Murray Darling region in 2013.







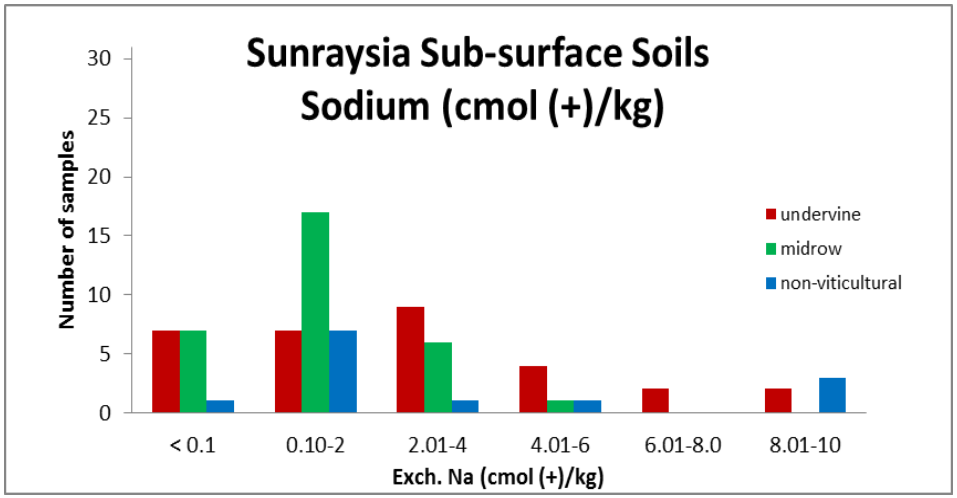
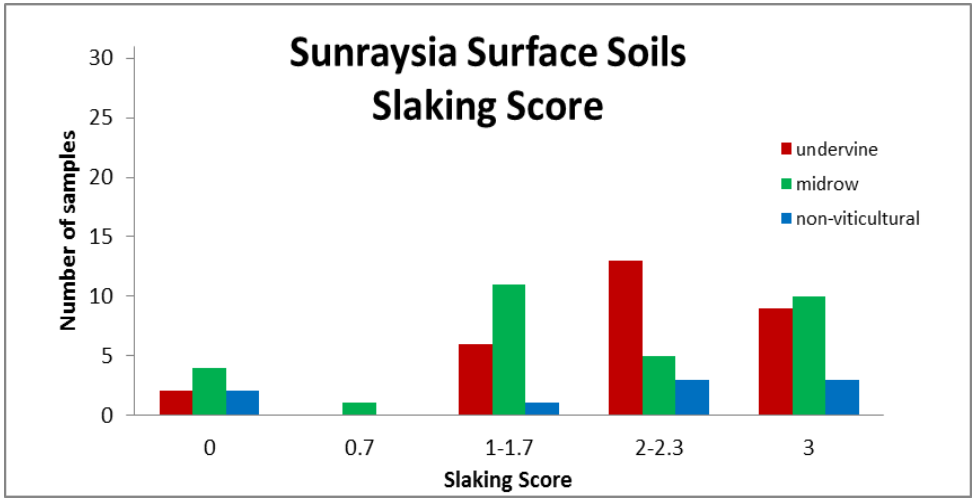
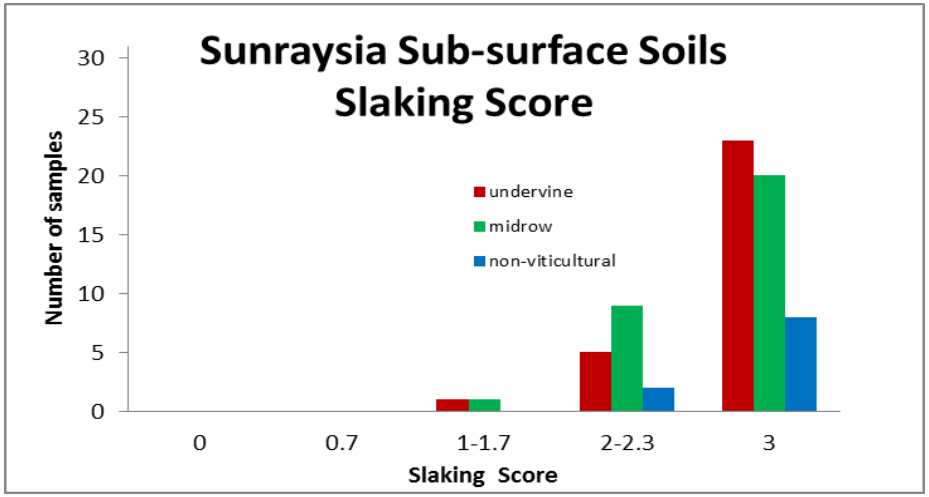
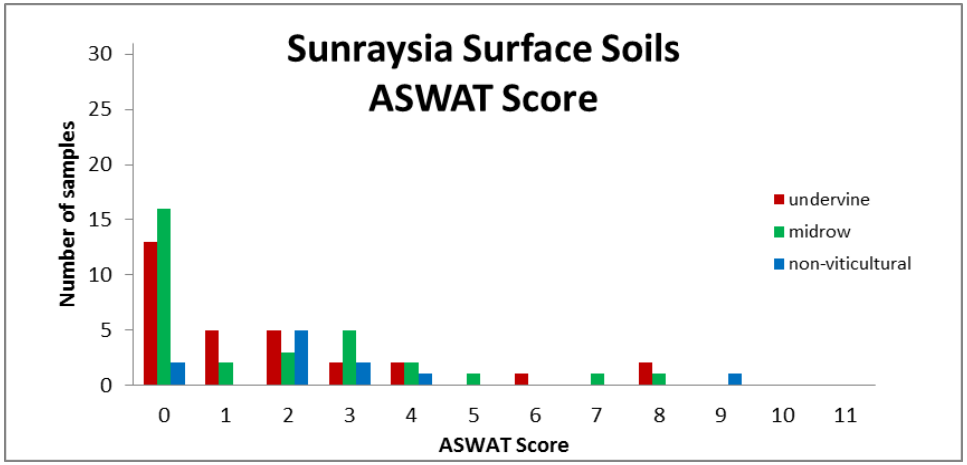


Figure 7.3 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Murray Darling region in 2013.







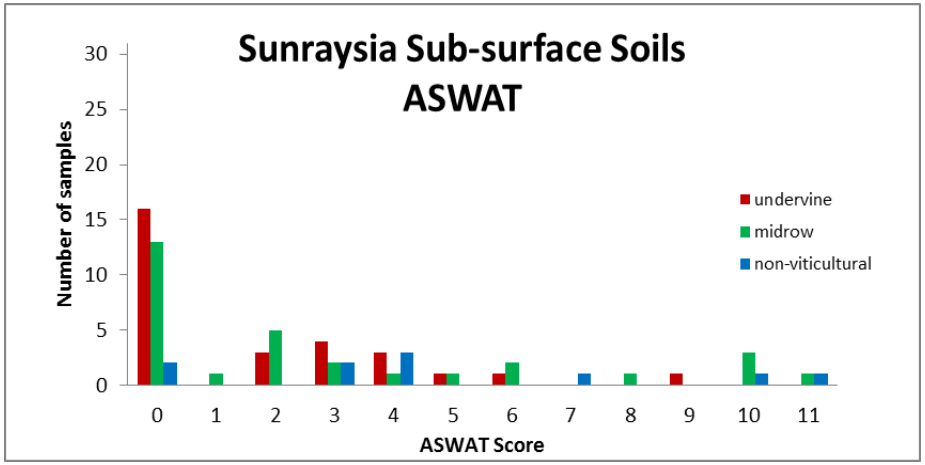
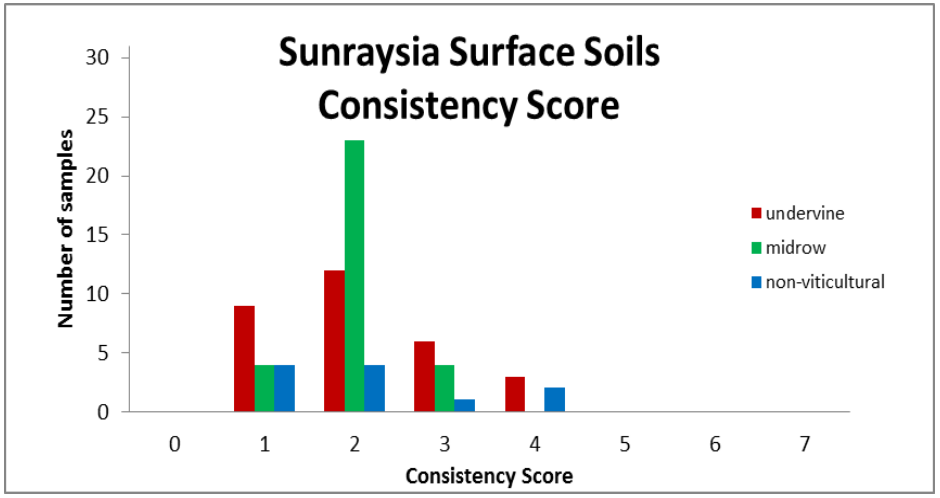
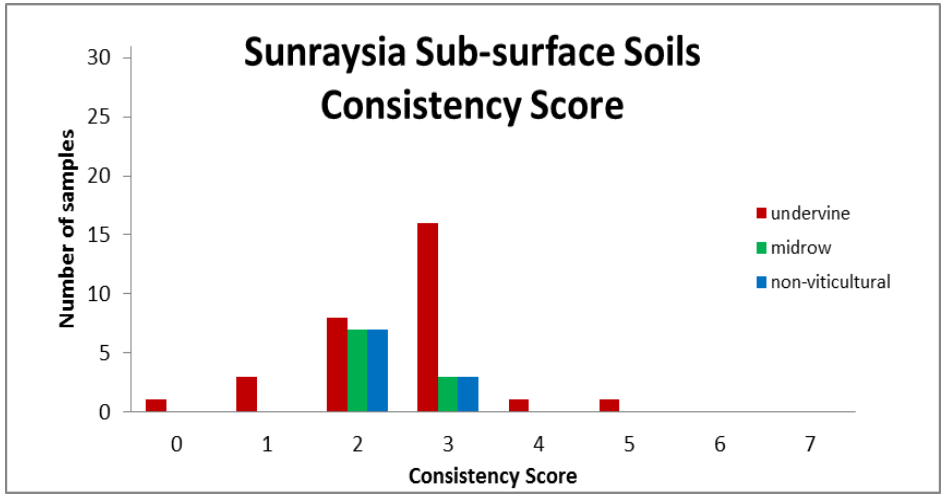


Figure 7.3 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Murray Darling region in 2013.





Chapter 8: Benchmarking indicators of soil quality at a regional scale - Yarra Valley

8.1 Introduction

Victoria's Yarra Valley geographic indication is located less than one hour's drive east of Melbourne (Figure 8.1). The western boundary begins just 45 kilometres east of Melbourne's CBD. This wine region is bordered by the towns of Gembrook in the south, Kinglake in the north, Wantirna in the west and Mount Gregory in the east(Figure 8.2).

The Yarra Valley produces premium Chardonnay and Pinot Noir (Figure 8.3), particularly for sparkling wine in the Champagne style. The total area under vine is 2,500 ha producing 15,000 tonnes annually. Although Chardonnay is the region's most planted white variety, other white varieties grown include Sauvignon Blanc, Semillon, Pinot Gris and Riesling. Pinot Noir is the region's most widely planted red variety, followed by Cabernet Sauvignon, Shiraz, Merlot, Malbec, Petit Verdot, Cabernet Franc, Sangiovese and Nebbiolo.

The Yarra Valley is cool in relation to most of Australia's viticultural regions. Elevation varies from 50 – 400 m. Rainfall is winter/spring dominant, with the summer relatively cool, dry and humid. There is limited maritime influence. The small diurnal temperature range reflects the proximity of the sea.

Harvest typically commences in early March with Pinot Noir and finishes with Cabernet Sauvignon in early May. Frost is rarely a problem, but can affect the lower vineyards on the valley floor from time to time.

With a seven month growing season, rainfall of between 750-950 mm and restricted water holding capacity in some soils, irrigation is considered essential, although the extent of its use varies significantly between producers.

The topography of the Yarra Valley varies enormously and so the region encompasses a wide range of soil types. Soils range from sandy clay loam to well-drained volcanic red. The soils in the middle section of the Yarra Valley are ancient, mountain-derived sandy clay loams interspersed with broken sandstone. The other dominant soil type is much younger in origin and is a highly friable, brilliantly coloured red volcanic soil found in both the Upper and Lower Yarra Valley.

As for the previous benchmarking chapters, this chapter provides data from the soil analyses and outlines the distribution of data for each soil property measured for soils collected from the Yarra Valley region in Victoria. The objective was to establish benchmarks for typical regional values and their distribution, so that through repeat measures in the future, assessment can be made of the effect of continued viticultural production on these soil properties.

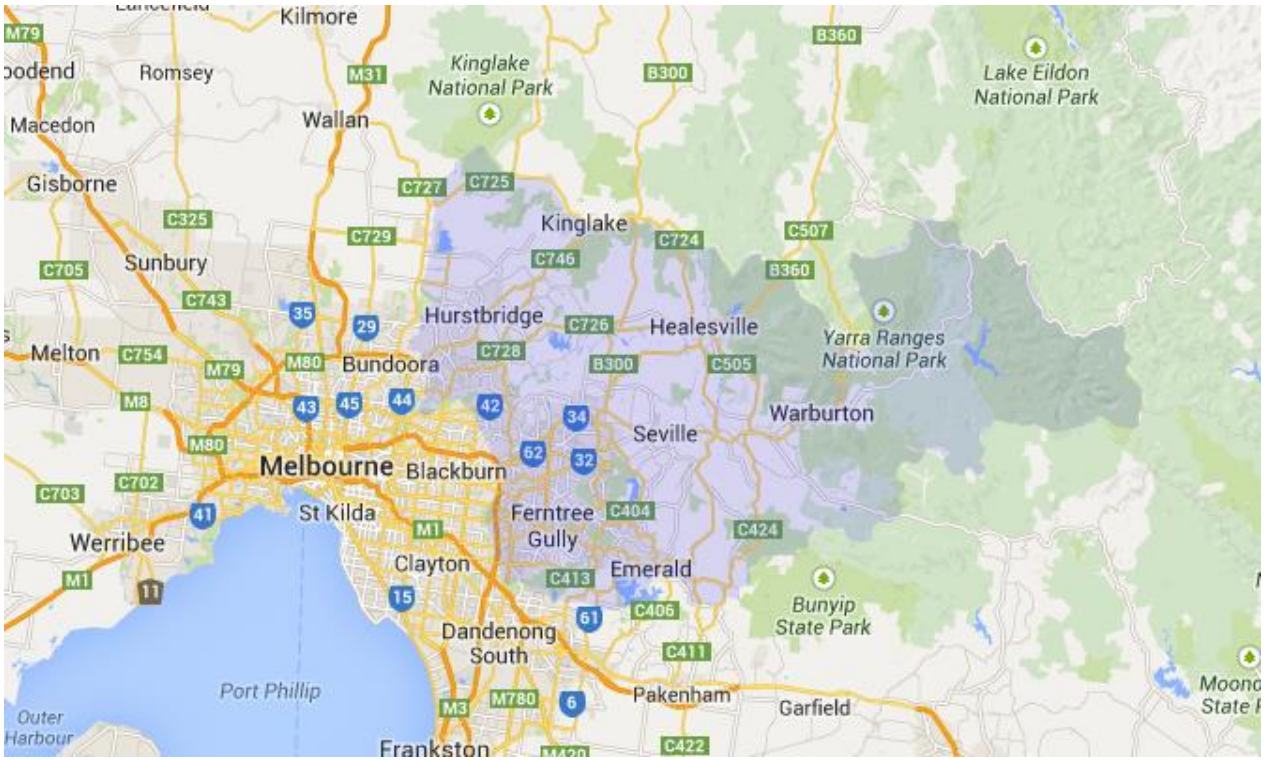


Figure 8.1. The Yarra Valley wine region of Victoria. The grey shaded area shows the Yarra Valley GI in relation to Melbourne.



Figure 8.2. The Yarra Valley Geographic Indication



Figure 8.3. View of the Yarra Valley from Innocent Bystanders Giant Steps vineyard, Gruyere. (Photo courtesy of Adam Dimech)

8.2 Method

8.2.1 Site selection

Vineyard sites were identified through local knowledge and assistance of the Yarra Valley Wine Growers Association, Mark Krstic (AWRI) and Lee Duffy (Viticultural Consultant, E. E. Muirs &Sons). Property owners were asked to choose either a single site that represented their vineyard, or a paired site which represented the best performing and worst performing areas within a vineyard. This method was chosen to capture the range of soil properties for the region. A total of 56 sites were sampled over both years (Table 8.1), with 17 sites repeated in both 2013 and 2014 in order to investigate year-to-year variation (as described in Chapters 5 and 6). The vineyards were chosen to cover the range of soil types used for grape growing in the region. The location of the vineyards is shown on a region map of the soil types (Figure 8.4).

8.2.2 Soil sampling

Soil sampling and analyses were performed as described previously. The majority of the Yarra Valley vineyard sites were within a phylloxera inclusion zone (PIZ) and one vineyard was linked (by water) to a known infested potato cyst nematode (PCN) property. Strict biosecurity protocols as prescribed by DEPI Victoria were adhered to in order to comply with all quarantine requirements. This added considerable time and complexity to the soil sampling and soil assessments, something which needs to be taken into consideration for future sampling in such regions. The order of sampling was scheduled so that all vineyards outside the PIZ were visited before any vineyards within the PIZ. Vineyards owned by the same company were grouped so that they could be visited and personnel could go home and shower, vehicles and equipment be thoroughly decontaminated and allowed to dry overnight before returning to the Yarra Valley and moving onto a vineyard owned by another company. Visits to known infested properties were scheduled last. Permits were required to accompany soil from PIZ sites to the various laboratories. Vehicles and all equipment had to be thoroughly washed and disinfected between sites. Personnel had to wear disposable overalls that could be bagged, autoclaved and correctly disposed of. The biological assay, PMN, could not be performed on the Yarra Valley soils in 2014, as the commercial laboratory offering the test did not have quarantine accreditation to receive such soils. The laboratory that performed the test in 2013 was no longer offering the test. The physical assessments conducted by the Victorian project team were required to be carried out within a QC2 laboratory and all soil appropriately destroyed afterwards.

Table 8.1. Fifty-six vineyard sites sampled in the Yarra Valley region in 2013 and 2014.

Name	Location	Year	Paired performance	Cultivar
YV1	Seville	2013		Shiraz
YV2A	Seville	2013	Good	Cabernet Sauvignon
YV2B	Seville	2013	Poor	Cabernet Sauvignon
YV3	Woori Yallock	2013		Pinot Noir
YV4	Gruyere	2013		Shiraz
YV5A	Coldstream	2013 & 2014	Good	Cabernet Sauvignon
YV5B	Coldstream	2013 & 2014	Poor	Cabernet Sauvignon
YV5C	Coldstream	2013	Good	Pinot Noir
YV5D	Coldstream	2013	Poor	Pinot Noir
YV5E	Coldstream	2014	Good	Shiraz
YV5F	Coldstream	2014	Poor	Shiraz
YV6A	Dixons Creek	2013 & 2014	Poor	Shiraz
YV6B	Dixons Creek	2013 & 2014	Good	Shiraz
YV6C	Dixons Creek	2013 & 2014	Poor	Shiraz
YV6D	Dixons Creek	2013 & 2014	Good	Shiraz
YV7A	Coldstream	2013 & 2014	Good	Pinot Noir
YV7B	Coldstream	2013 & 2014	Poor	Pinot Noir
YV7C	Yarra Glen	2013	Good	Chardonnay
YV7D	Yarra Glen	2013	Poor	Chardonnay
YV8A	Gruyere	2013 & 2014	Poor	Cabernet Sauvignon
YV8B	Gruyere	2013 & 2014	Good	Cabernet Sauvignon
YV9A	Gruyere	2013 & 2014		Chardonnay
YV9B	Gruyere	2014	Good	Pinot Noir
YV9C	Gruyere	2014	Poor	Pinot Noir
YV10	Gruyere	2013 & 2014		Pinot Noir
YV11A	Gruyere	2013 & 2014	Poor	Shiraz
YV11B	Gruyere	2013 & 2014	Good	Shiraz
YV12A	Coldstream	2013 & 2014	Good	Cabernet Sauvignon
YV12B	Coldstream	2013 & 2014	Poor	Cabernet Sauvignon
YV12C	Coldstream	2013 & 2014		Cabernet Sauvignon
YV13A	Yarra Glen	2014		Cabernet Sauvignon
YV13B	Yarra Glen	2014		Chardonnay
YV14A	Yarra Glen	2014	Poor	Merlot
YV14B	Yarra Glen	2014	Good	Merlot
YV14C	Yarra Glen	2014		Shiraz
YV15A	Christmas Hills	2014	Good	Chardonnay
YV15B	Christmas Hills	2014	Poor	Chardonnay
YV15C	Christmas Hills	2014	Good	Cabernet Sauvignon
YV15D	Christmas Hills	2014	Poor	Cabernet Sauvignon
YV16A	Coldstream	2014	Good	Chardonnay
YV16B	Coldstream	2014	Poor	Chardonnay
YV16C	Coldstream	2014	Good	Chardonnay
YV16D	Coldstream	2014	Poor	Chardonnay
YV16E	Coldstream	2014		Chardonnay
YV17A	Gladysdale	2014	Good	Pinot Noir
YV17B	Gladysdale	2014	Poor	Pinot Noir
YV18A	Yarra Glen	2014	Good	Merlot
YV18B	Yarra Glen	2014	Poor	Merlot
YV19A	Gembrook	2014	Good	Sauvignon Blanc
YV19B	Gembrook	2014	Poor	Sauvignon Blanc
YV20A	Gladysdale	2014	Good	Pinot Noir
YV20B	Gladysdale	2014	Poor	Pinot Noir
YV21A	Coldstream	2014	Poor	Cabernet Sauvignon
YV21B	Coldstream	2014	Good	Cabernet Sauvignon
YV22A	Yarra Glen	2014	Poor	Cabernet Sauvignon
YV22B	Yarra Glen	2014	Good	Cabernet Sauvignon

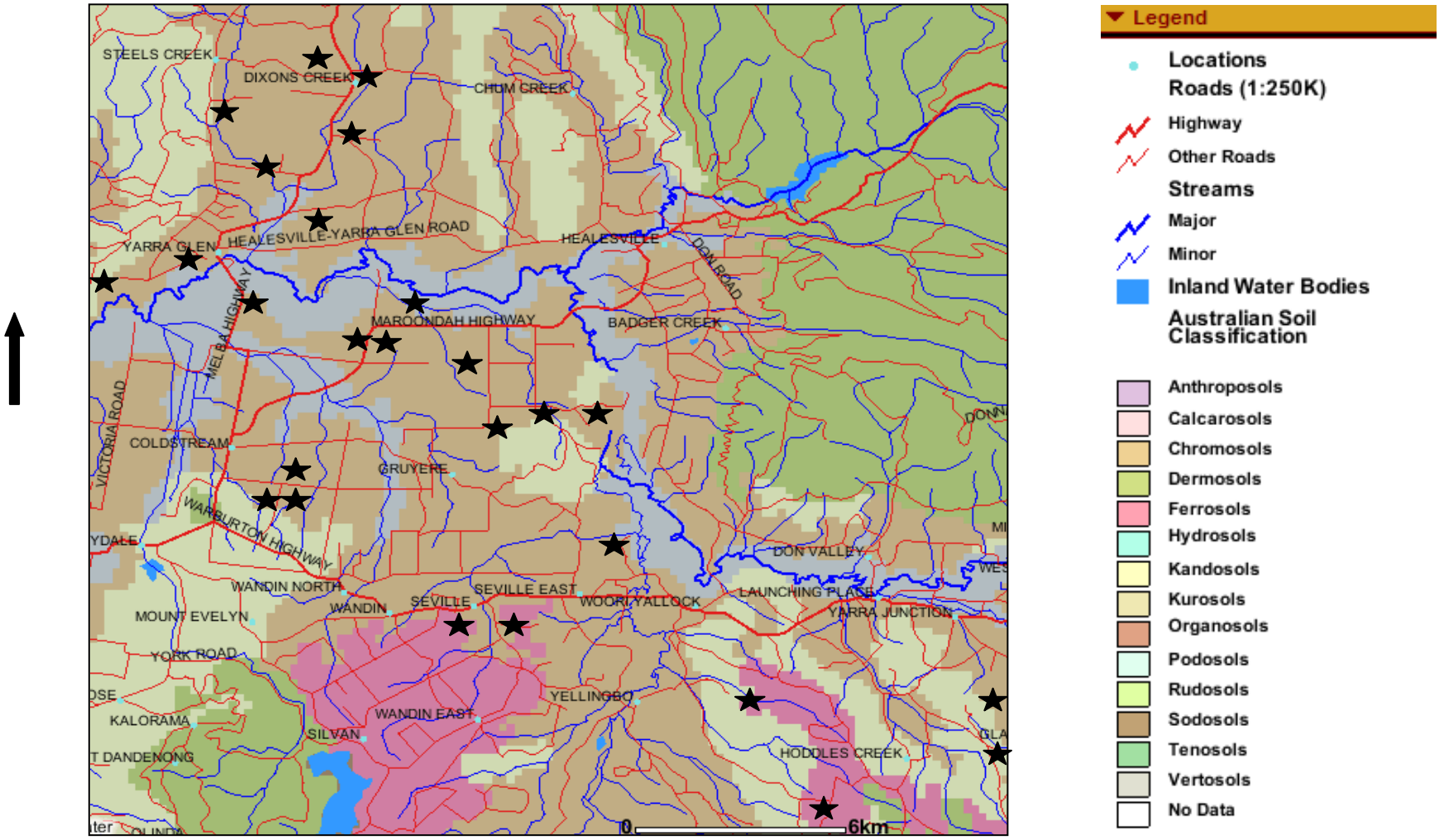


Figure 8.4. Approximate sampling locations (★) and generalised soil groups throughout the Yarra Valley region. Map obtained from ASRIS. (2011).

8.2.3 Year to year variation

A key component of the 2014 sampling was the repeat analysis of soils taken from 17 sites that had been sampled in 2013. Our assumption was that, in the absence of deliberate actions aimed at changing soil condition, soil properties were unlikely to change markedly in just one year. Thus, such a repeat sampling would allow us to determine whether we had robustly characterised the distribution of soil property values as a basis for enabling growers to assess how their own soils compared with regional mean values.

8.2.4 Statistical analysis

In this section, the objective was to look at MDS variables from vineyard positions (undervine, midrow and native) with respect to time i.e. were there any significant differences between 2013 and 2014? We also looked at whether there were any significant differences between vineyard positions and their interactions (*PadPos*Year*). Surface and subsurface soil depths were analysed separately.

The mean MDS data per vineyard were analysed using analysis of variance (ANOVA) in the GenStat® statistical package (GenStat® release 16.1, Copyright 2008, VSN International Ltd.). The treatment structure was specified as *PadPos*Year*, where *Year* is time and *PadPos* is the sampling position i.e. undervine, midrow and native. The blocking structure was specified as *Vineyard.*

Histogram and quantile plots of residuals, and graphs of residuals against fitted values, were used to check ANOVA distributional assumptions of normality and constant variance.

Least significant differences (5% level) were used to separate the means, subject to significant F-tests.

8.3 Results and Discussion

As described for the previous regions (Chapters 5 -7), the participating growers will be supplied with a booklet (Appendix 1 provides an example) containing figures illustrating the regional distribution of values for each measured soil property, along with a summary table containing the data for their own site. Note that it was not the objective of this project to provide detailed interpretations of these analyses in terms of desirable soil management options that might be implemented in response to them. Rather, we simply sought to establish a regional distribution of soil property values and to enable collaborating growers to see where their soils sat within that regional distribution with a view to considering whether any remedial action might be warranted. Growers were encouraged to seek expert advice separately if they felt that it was warranted.

8.3.1 Year-to-year variation

Analysis of variance of these data (Table 8.2) confirms that for these 17 sites, there were few significant differences between the values obtained in the two years.

Table 8.2 Mean values for surface (0-15 cm) and sub-surface (35-45 cm) soil properties measured at 17 Yarra Valley sites in 2013 and 2014 and results of tests of the significance[A] of the between-year difference (analysis of variance).

Property	Units	Year	0-15 cm			35-45 cm		
			Undervine	Midrow	Native	Undervine	Midrow	Native
EC	dS/m	2013	0.19	0.14	0.11	0.12	0.10	0.08
		2014	0.21	0.10	0.11	0.12	0.10	0.06
			NS	NS	NS	NS	NS	NS
pH ($CaCl_2$)		2013	5.9	5.8	4.7	4.8	4.6	4.3
		2014	5.9	5.7	4.6	4.7	4.5	4.3
			NS	NS	NS	NS	NS	NS
pH (H_2O)		2013	6.7	6.6	5.6	5.6	5.4	5.3
		2014	6.6	6.4	5.4	5.4	5.2	5.2
			NS	NS	NS	NS	NS	NS
Cl	mg/kg	2013	161.3	106.5	101.5	102.4	108.9	79.2
		2014	196.0	60.6	102.7	150.6	101.4	54.3
			NS	NS	NS	NS	NS	NS
Total N	%	2013	0.23	0.23	0.30			
		2014	0.26	0.26	0.34			
			NS	NS	NS			
Total OC	%	2013	3.10	3.01	4.12			
		2014	3.47	3.48	4.68			
			NS	NS	NS			
Exch. Ca	meq/100g	2013	5.64	5.19	2.56	1.98	1.39	0.44
		2014	6.51	6.00	2.79	1.91	1.49	0.39
			NS	NS	NS	NS	NS	NS
Exch. K	meq/100g	2013	0.26	0.19	0.30	0.11	0.11	0.11
		2014	0.31	0.24	0.31	0.13	0.12	0.13
			*	*	NS	NS	NS	NS
Exch. Mg	meq/100g	2013	1.52	1.38	1.46	1.25	1.41	0.77
		2014	2.04	1.76	1.77	1.50	1.97	1.02
			**	**	**	NS	NS	NS
Exch. Na	meq/100g	2013	0.10	0.08	0.05	0.13	0.12	0.03
		2014	0.11	0.08	0.05	0.16	0.16	0.07
			NS	NS	NS	NS	NS	NS
CEC	meq/100g	2013	7.6	6.8	4.4	3.5	3.0	1.4
		2014	9.0	8.1	5.0	3.7	3.7	1.6
			*	*	NS	NS	NS	NS
ESP	%	2013	1.30	1.05	1.48	3.54	3.96	3.49
		2014	1.28	1.00	1.52	3.67	3.85	4.65
			NS	NS	NS	NS	NS	NS
Labile C	mg/kg	2013	596	570	651			
		2014	355	381	362			
			**	**	**			
Consistency	0-7	2013	4	4	4	5	4	5
		2014	5	4	4	5	5	5
			NS	NS	NS	NS	NS	NS

Property	Units	Year	0-15 cm			35-45 cm		
			Undervine	Midrow	Native	Undervine	Midrow	Native
Dispersion	0-16	2013	2	2	1	3	4	6
		2014	1	0	1	1	2	3
			NS	NS	NS	**	**	**
Slaking	0-4	2013	0	0	0	1	1	1
		2014	0	0	0	2	2	1
			NS	NS	NS	*	*	NS

[A]Significance is denoted by NS, not significant, * P < 0.05, ** P < 0.01 based on Fisher's LSDs at 5%. Yellow highlighting indicates significant differences.

As expected, the values for most soil properties did not change from one year to the next. Significant differences occurred in 2014 compared to 2013 as increased exchangeable Mg and decreased labile carbon in all surface (0-15 cm) soils, increased exchangeable K and CEC in the vineyard surface soil, increased slaking in the sub-surface (35-45 cm) vineyard soil but not the native soil, and decreased dispersion in the subsurface soil of all vineyard positions.

Labile carbon assessments were conducted by a different laboratory in each year, which may account for the disparity across the years. In 2013, labile carbon measurements were conducted by the University of Western Australia, a research laboratory, and in 2014 were conducted by AgVita, a commercial laboratory in Tasmania. Differences between biological measurements of the same soils analysed by different laboratories was highlighted by Rawnsley (2008).

8.3.2 Regional statistics of soil properties in the Yarra Valley region

Table 8.3 presents the regional averages for each of the soil properties for the three vineyard positions (undervine, midrow, native) and the two soil depths (0-15 cm, 35-45 cm). Soils in this region are acidic, particularly in the subsoil. They contain reasonably high levels of organic carbon, but the consistency (hardness) is higher than optimal (2-3), particularly in the subsoil. Chloride is three times higher undervine than in the native soils, which is something growers in the region may wish to monitor, given the emergence of salinity as an issue in the region in recent years.

Table 8.3 Mean values for surface (0-15 cm) and sub-surface (35-45 cm) soil properties measured at 56 vineyard sites in the Yarra Valley. One-way analysis of variance was used to detect significant differences in soil properties analysed in samples taken from either undervine, the midrow or from an adjacent (within approx. 50 m) native site.

	Surface soils (0-15 cm)				Sub Surface soils (35-45 cm)			
Soil Property	**Undervine**	**Midrow**	**Native**	**Sig[A]**	**Undervine**	**Midrow**	**Native**	**Sig[A]**
pH ($CaCl_2$)	5.8b	5.7b	4.9a	**	4.7b	4.6b	4.5a	**
pH (H_2O)	6.4b	6.4b	5.6a	**	5.5	5.5	5.4	NS
EC[B] dS/m	0.141b	0.106ab	0.094a	*	0.077b	0.073b	0.054a	*
Total N %	0.24a	0.25a	0.33b	**				
Total OC %	3.11a	3.26a	4.49b	**				
ECEC[C] meq/100g	7.83b	7.48b	5.22a	**	3.47b	3.52b	2.73a	**
Chloride mg/kg	95b	60ab	41a	*	61b	64b	30a	*
Exch. Ca meq/100g	5.88b	5.61b	3.45a	**	1.93b	1.68b	1.12a	**
Exch. K meq/100g	0.28b	0.22a	0.35c	**	0.11a	0.12a	0.19b	**
Exch. Mg meq/100g	1.60b	1.58b	1.38a	*	1.31	1.60	1.33	*
Exch. Na meq/100g	0.07b	0.07b	0.05a	*	0.11	0.11	0.08	NS
ESP[D] %	0.97a	0.97a	1.46b	**	3.34	3.47	4.25	NS
MBC[E] mg/kg dry soil	168a	222b	274c	**				
Labile C mg/kg	432	444	436	NS				
PMN (mg N/kg)	30a	44b	57c	**				
ASWAT[G]	0	0	0		2	2	2	
Slaking score	0	0	0		2	2	1	
Consistency	4	4	4		5	5	5	

[A]Significance is denoted by NS, not significant, * P < 0.05, ** P < 0.01 based on Fisher's LSDs at 5%. Yellow highlighting and values not connected by the same letter indicates significant differences.

[B] EC = electrical conductivity; [C]ECEC = effective cation exchange capacity; [D]ESP = exchangeable sodium percentage; [E]MBC = microbial biomass carbon; [F]PMN = potentially mineralizable nitrogen; [G]ASWAT = a measure of dispersion

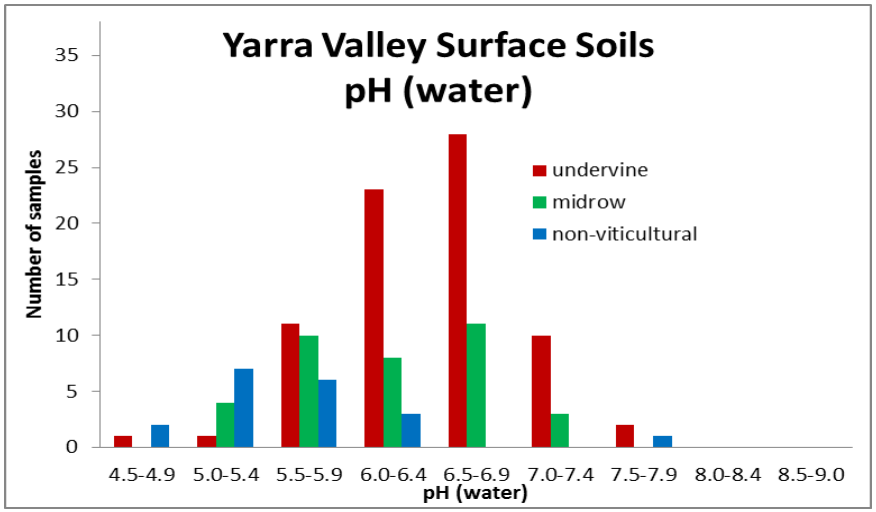
8.3.3 Regional distribution of soil property values

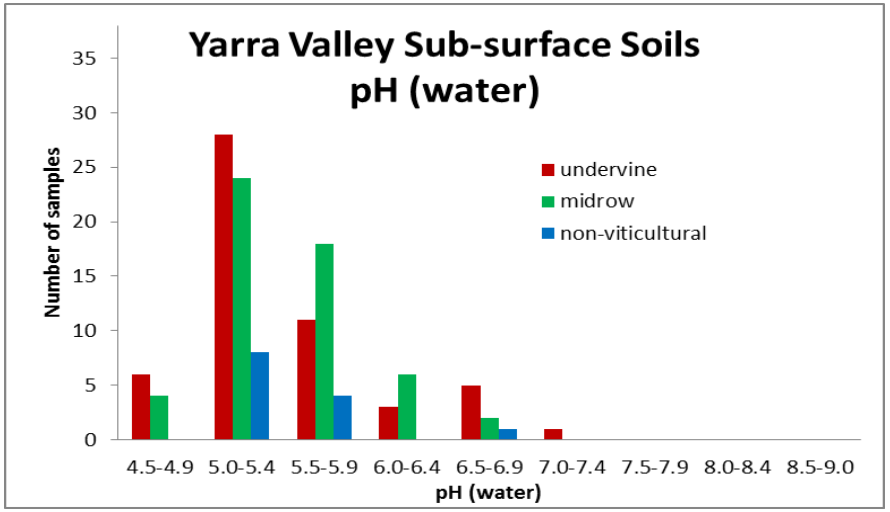
Figure 8.5 presents the regional distribution for each of the soil properties at the three locations (undervine, midrow, native) and the two soil depths (0-15 cm, 35-45 cm). As described previously, growers can use this information together with their own soil sampling results to establish where their vineyard soil sits in relation to other viticultural soils in the region.

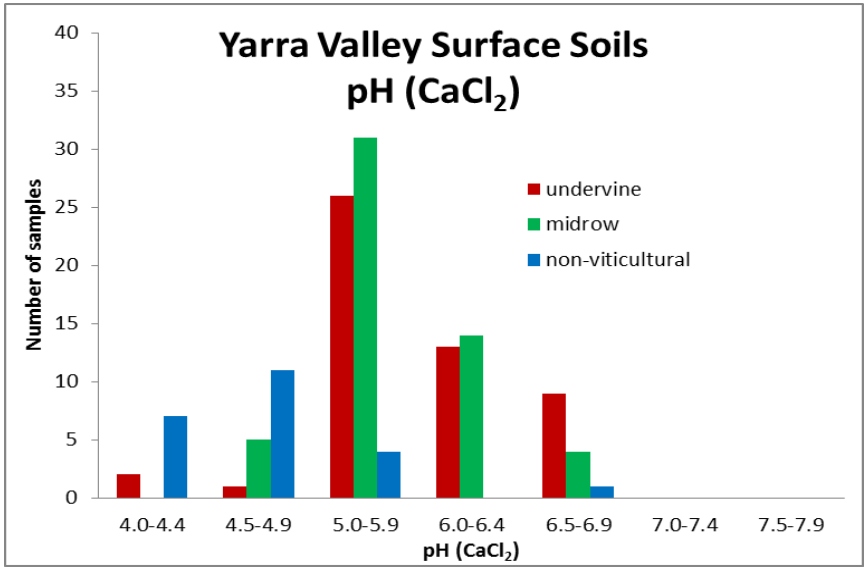
8.3.4 Accessibility of the biological tests chosen for the MDS

The biological tests chosen for the MDS proved to be difficult to access reliably during the life of the project. In Year 1 during the validation phase (Chapter 2), labile carbon, PMN and microbial biomass (SIR) analyses were undertaken commercially by a laboratory in Western Australia. In Years 2 and 3, this laboratory no longer offered the biological tests due to lack of demand. Therefore during the first year of regional benchmarking, we accessed microbial biomass (CFE), labile carbon and PMN analyses from the soilquality.org.au team at the University of Western Australia. This is not a commercial laboratory and they were unable to provide these analyses for the 2014 sampling and would not be able to provide them for the viticulture industry. Microbial biomass testing, by either CFE or SIR, had to be omitted from our suite of tests in 2014 due to inability to find a commercial provider. Labile carbon testing was sourced from AgVita in Tasmania but they were unable to provide the PMN methodology required. PMN tests were conducted by Nutrient Advantage (Incitec-Pivot, Victoria), but they could not accept soils from within a Phylloxera Inclusion Zone. Neither could the State Chemistry Laboratory within DEPI Victoria. Therefore, the Yarra Valley soils were not analysed for microbial biomass or PMN in 2014.

Figure 8.5 Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Yarra Valley region combining 2013 and 2014 data.







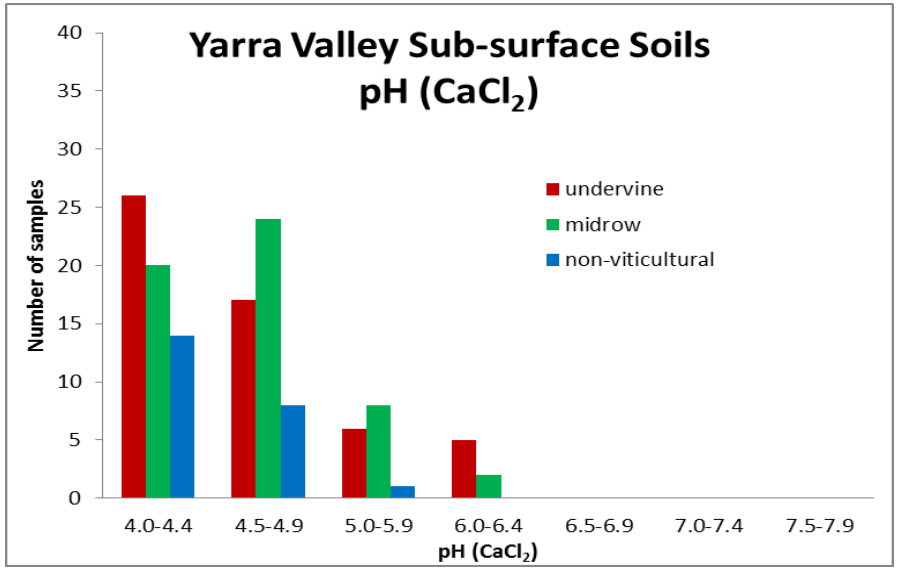
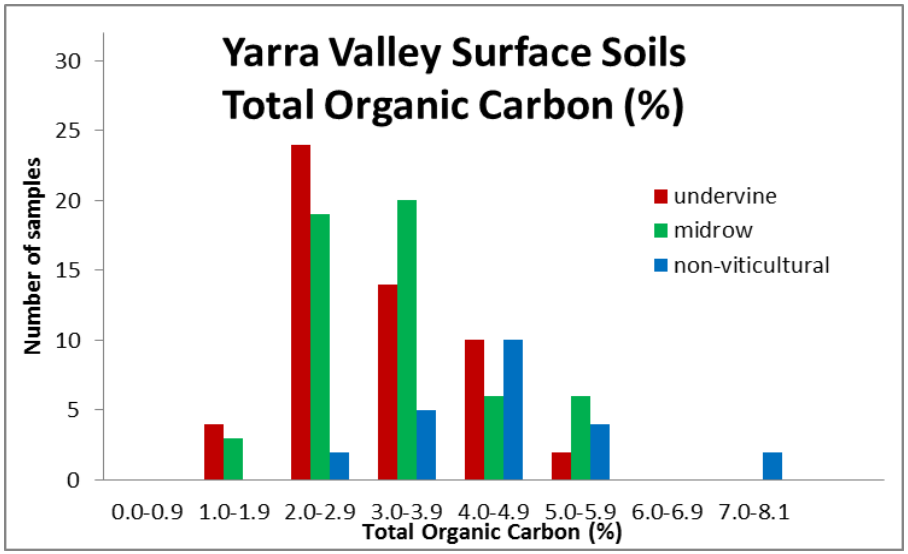
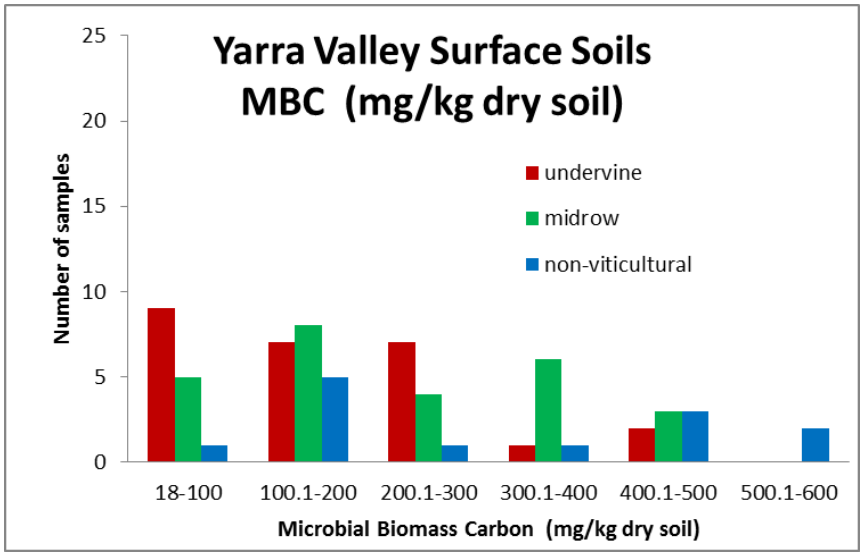
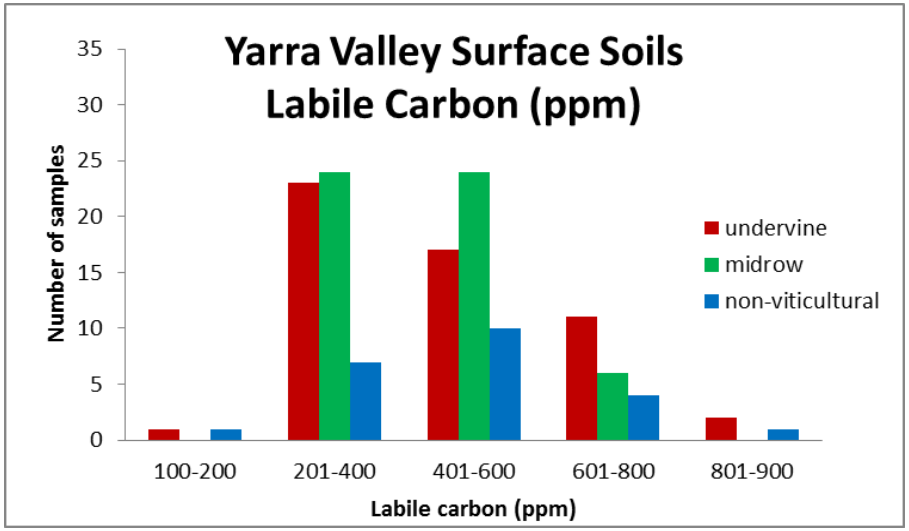


Figure 8.5 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Yarra Valley region combining 2013 and 2014 data.







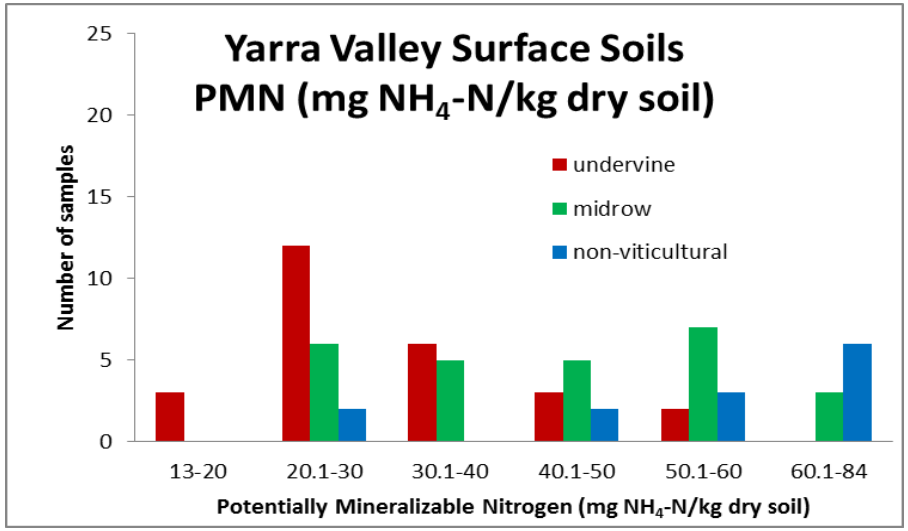
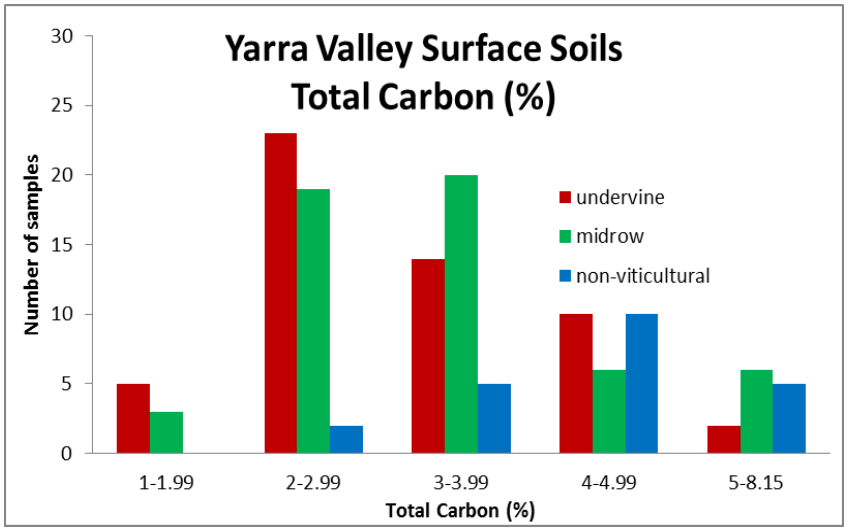
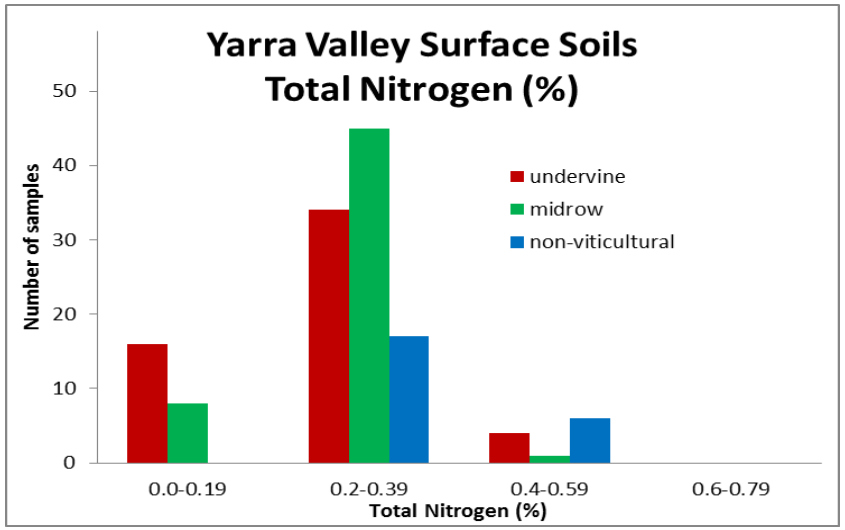
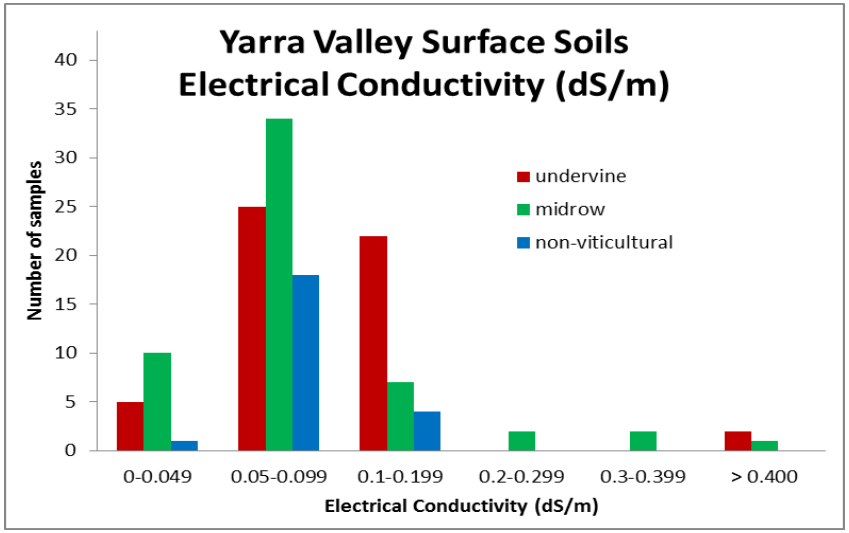


Figure 8.5 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Yarra Valley region combining 2013 and 2014 data.







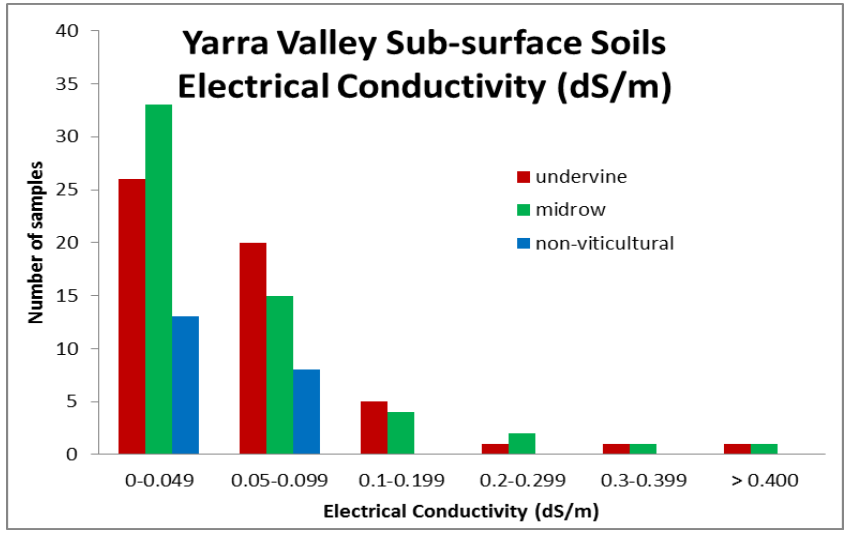
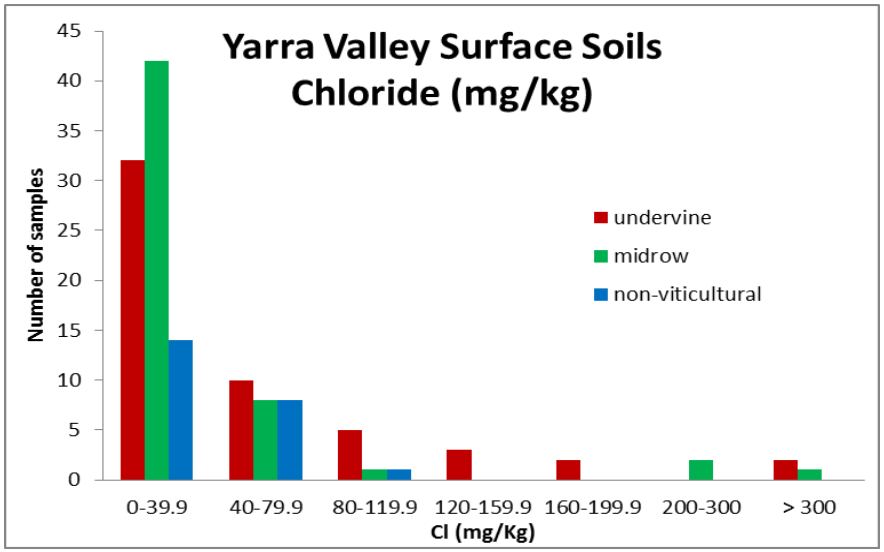
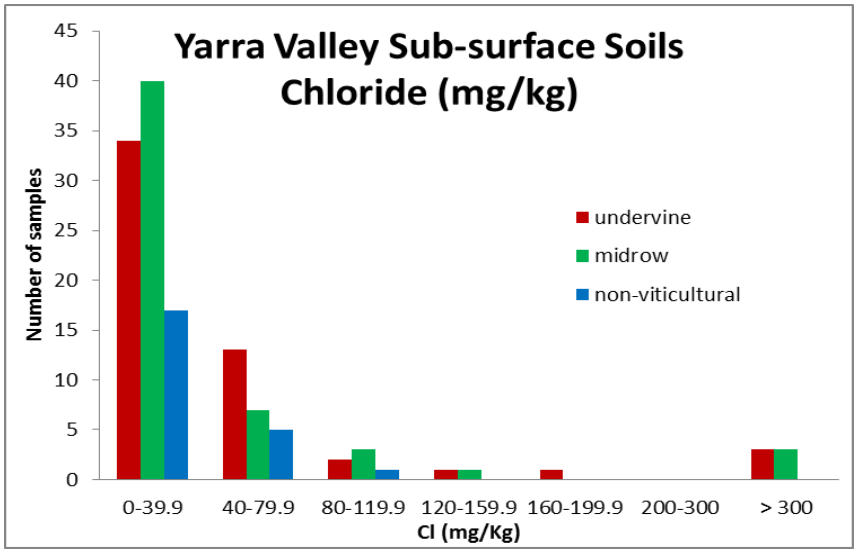
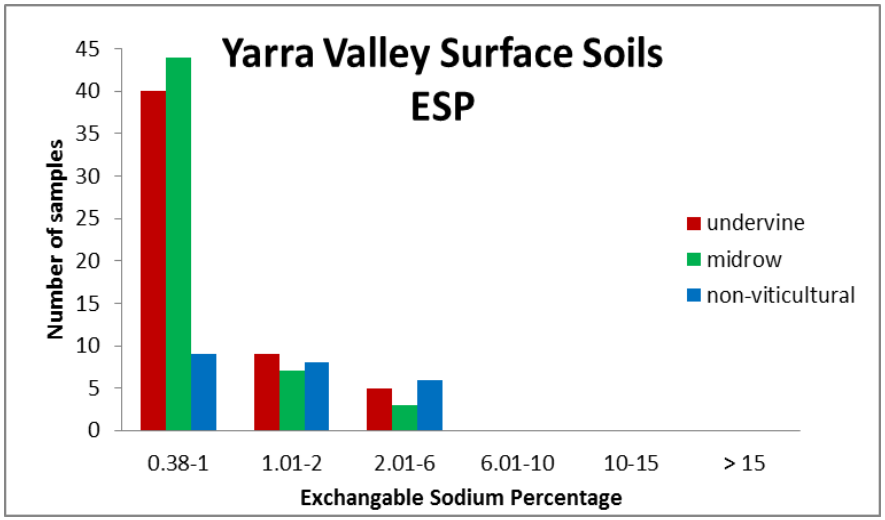


Figure 8.5 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Yarra Valley region combining 2013 and 2014 data.







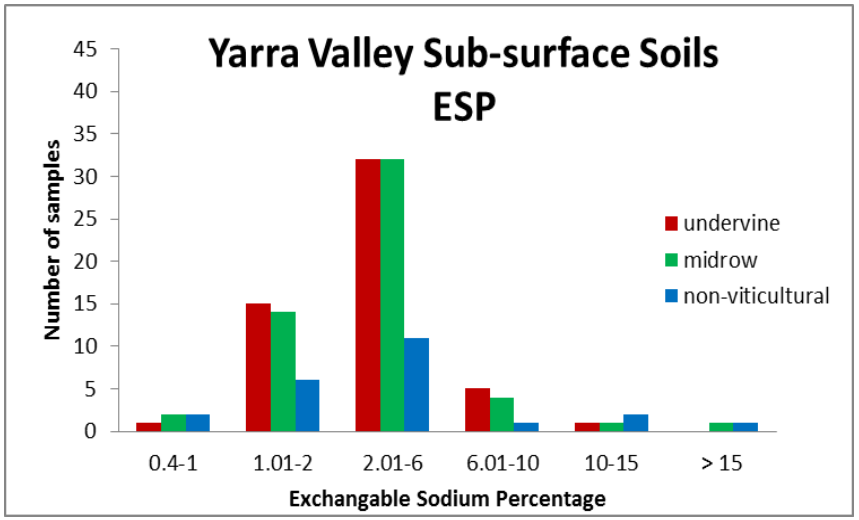
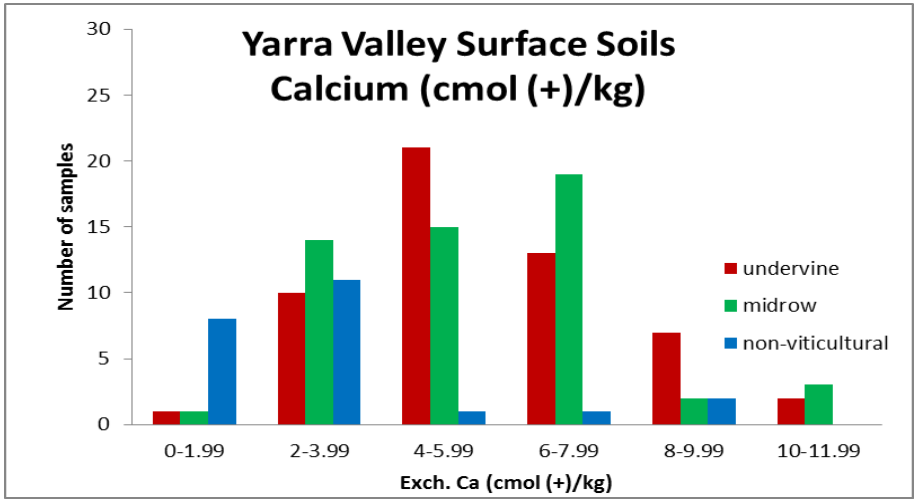
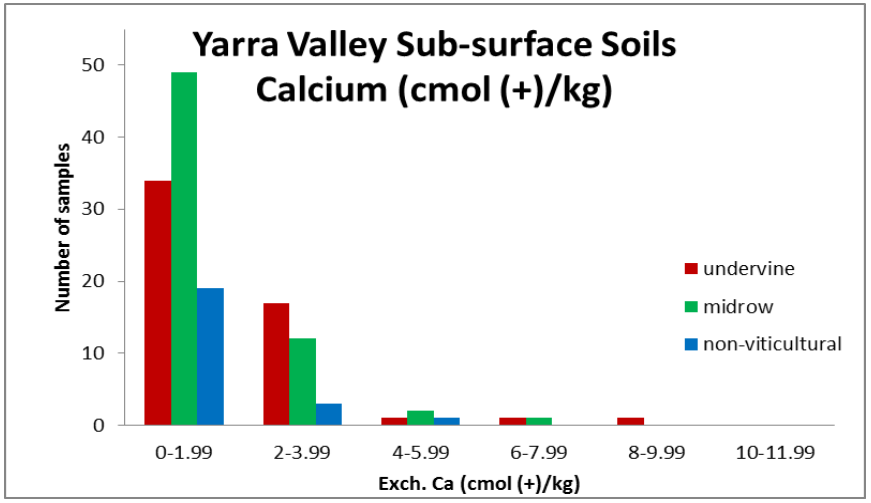
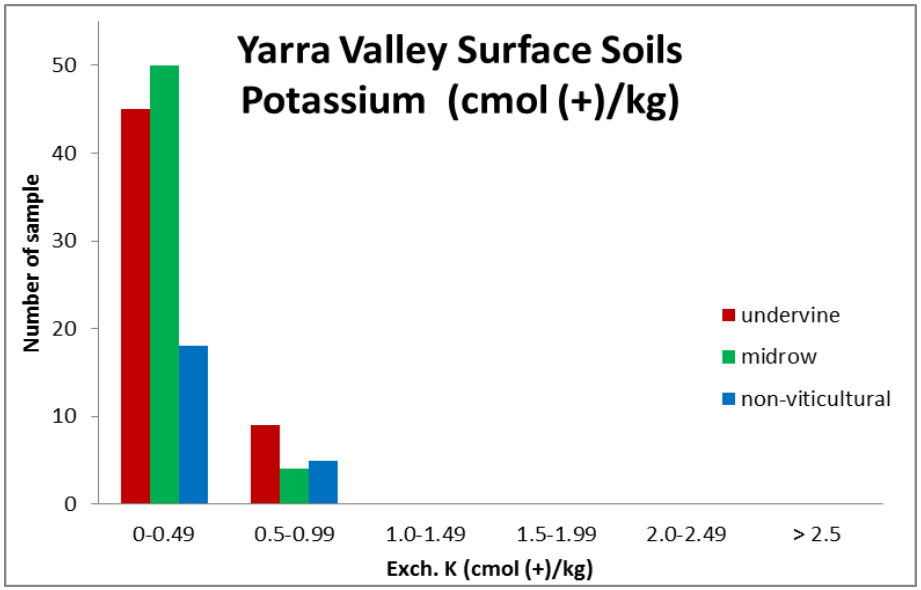


Figure 8.5 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Yarra Valley region combining 2013 and 2014 data.







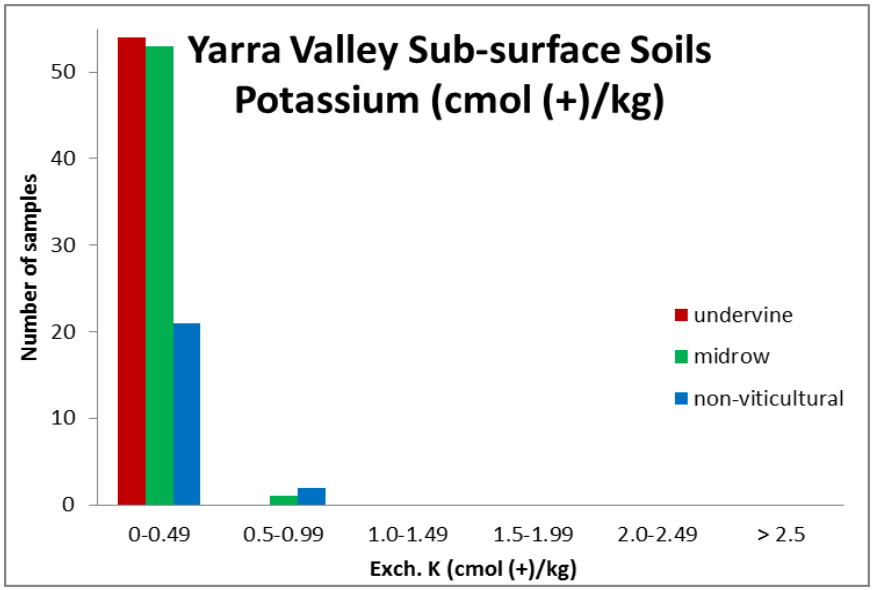
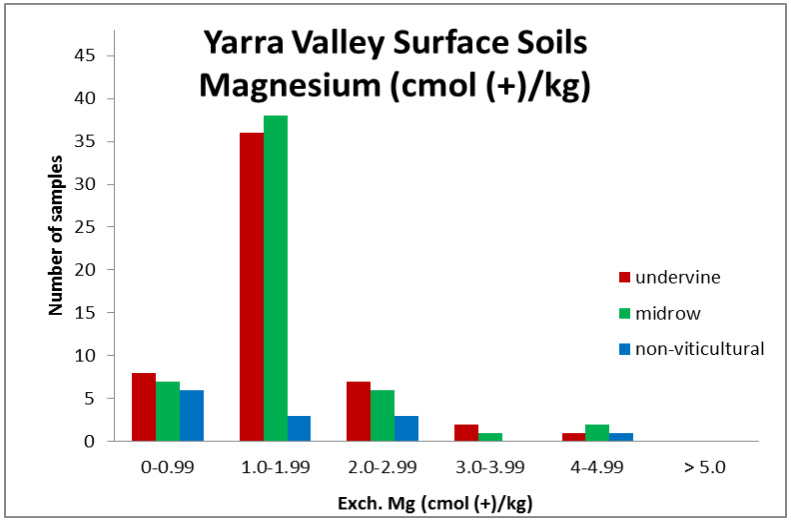
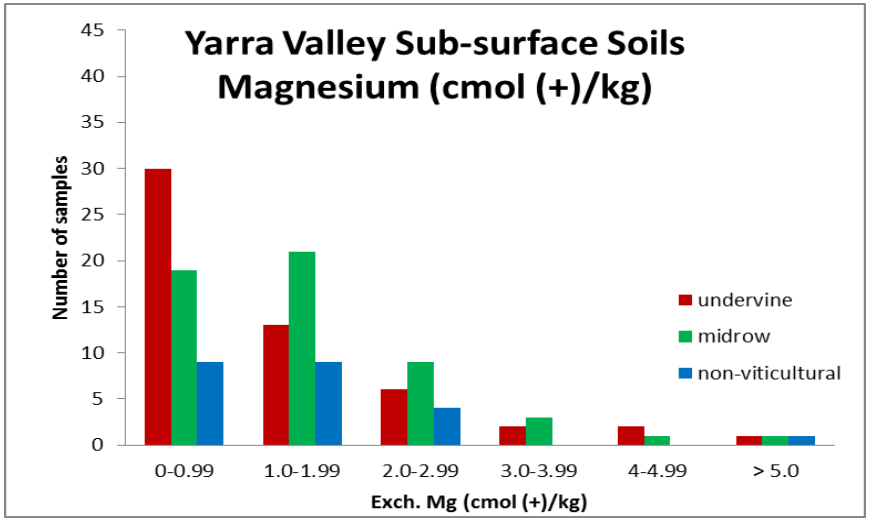
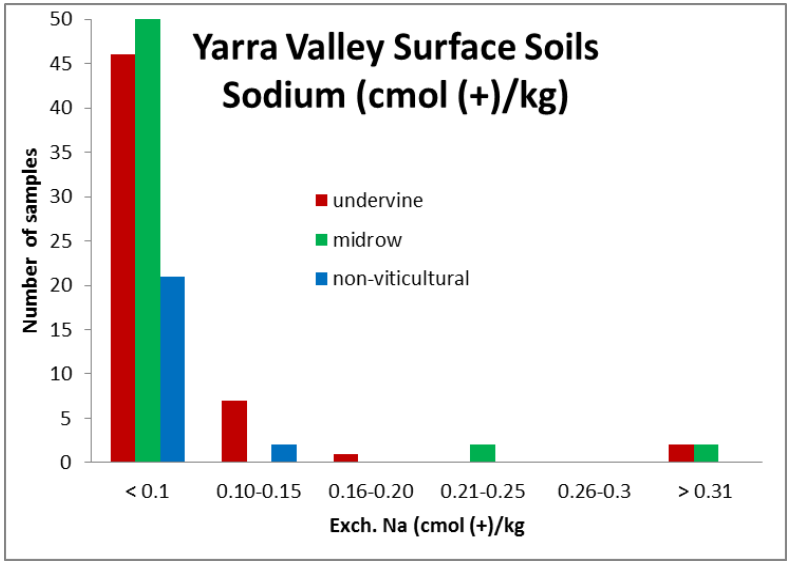


Figure 8.5 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Yarra Valley region combining 2013 and 2014 data.







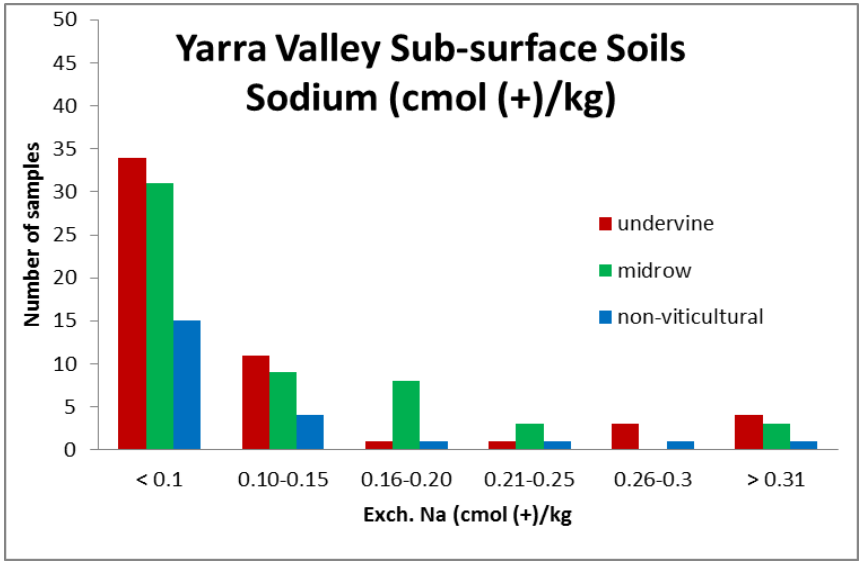
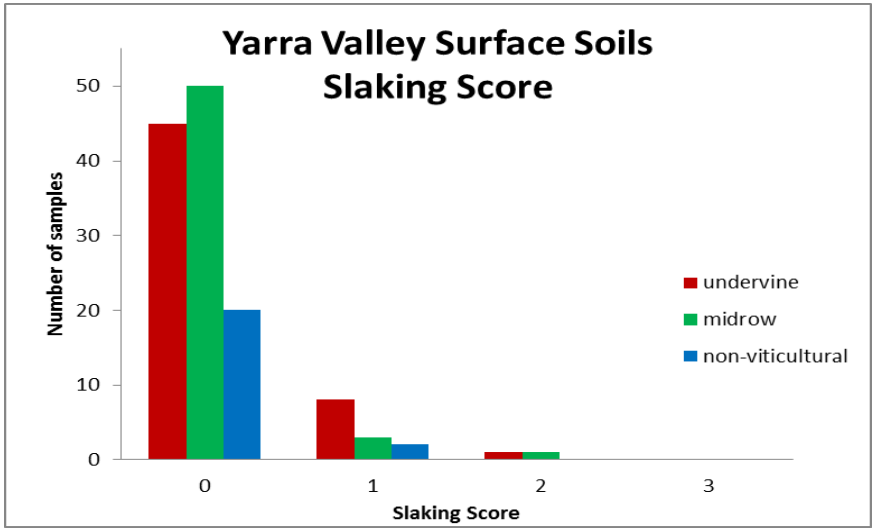
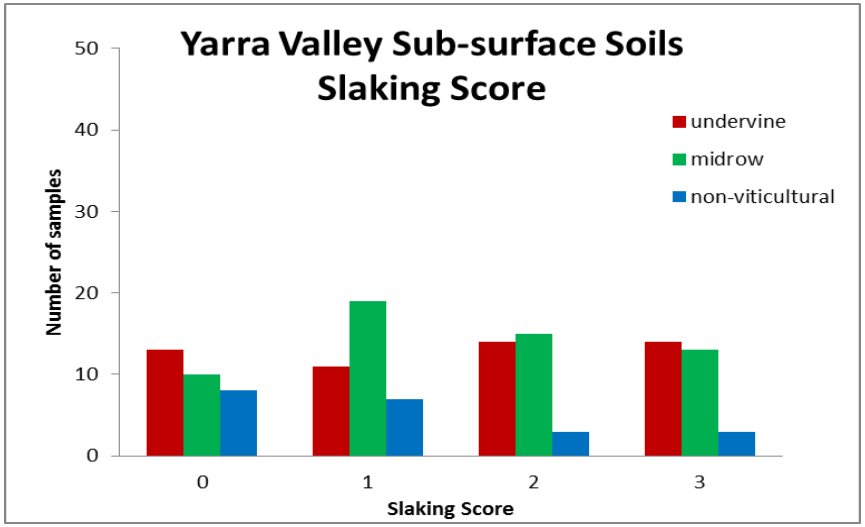
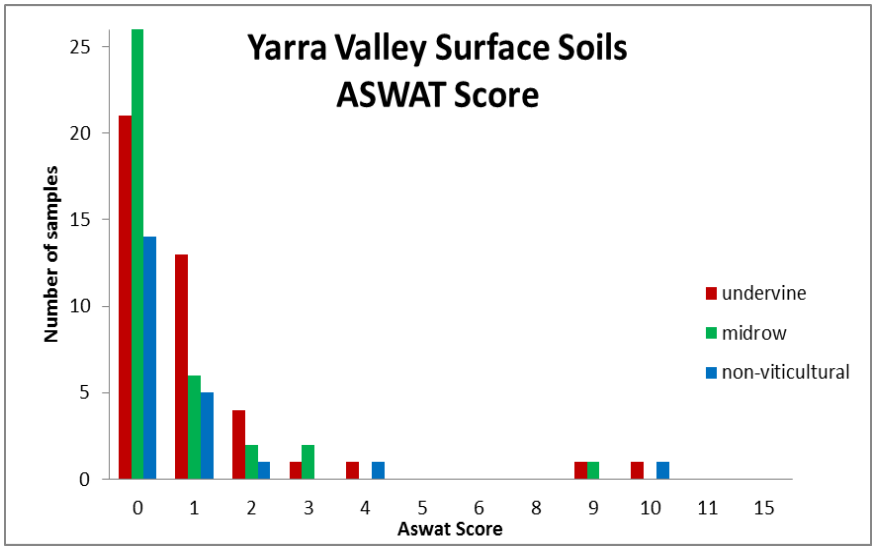


Figure 8.5 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Yarra Valley region combining 2013 and 2014 data.







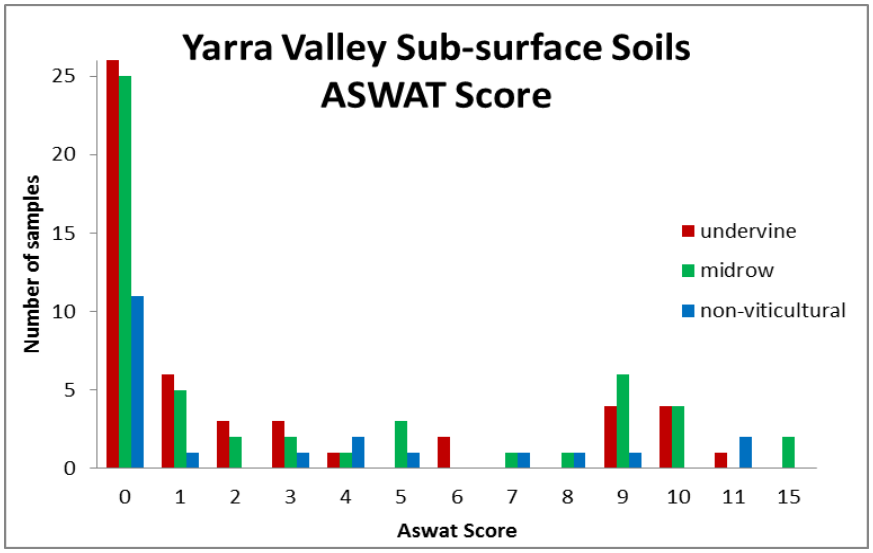
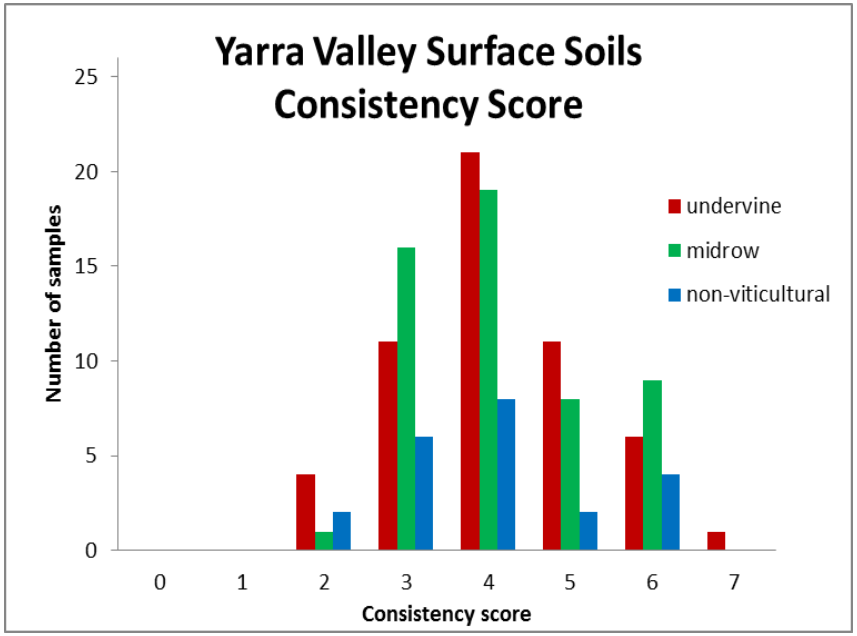
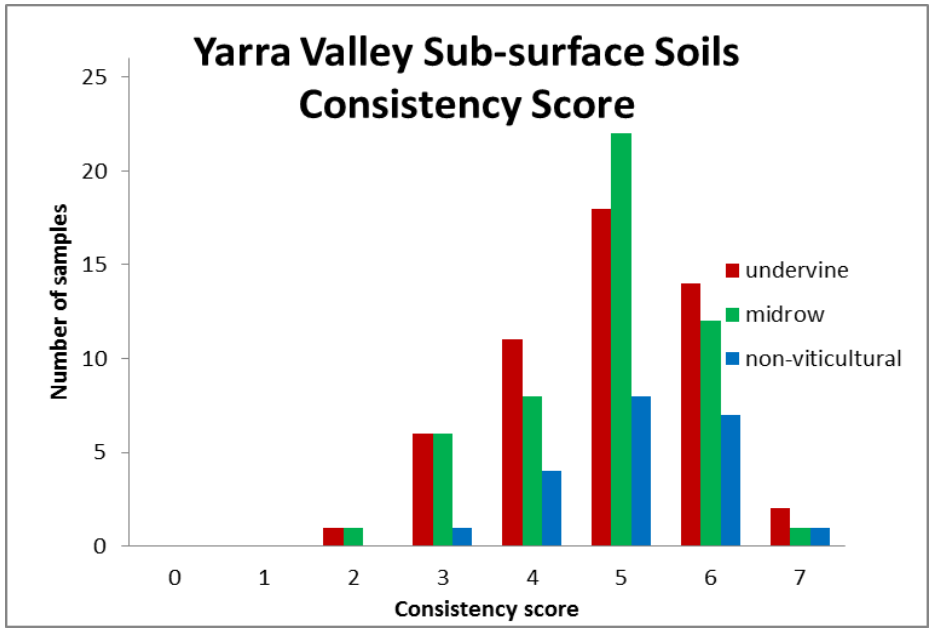


Figure 8.5 (cont.) Distributions of surface (0-15) and sub-surface (35-45 cm) soil properties in the Yarra Valley region combining 2013 and 2014 data.





Outcomes / Conclusion and Recommendations

This study has laid the foundations for the monitoring of soil quality within a winegrowing region. It has demonstrated how the coordinated analysis of soil samples collected from individual locations can be used to establish distributions of soil properties at the regional scale against which growers can assess how their soil quality compares with that of their neighbours and peers, and with known threshold values for grapevine production. It is the first time the industry has standardized comparisons of soil quality for the midrow, undervine and an adjacent native site. This information is important for correct management within vineyards and can also be used by the industry as a whole to support industry stewardship. Supported by appropriate consultant advice, such comparisons might inspire remedial management based on divergence from the regional mean. The study has also demonstrated how development of such a database could be undertaken over a two year period rather than relying on a single year of sampling.

The extensive literature review used to determine the soil indicator tests for the minimum dataset (MDS) was published as two companion papers in the *Australian Journal of Grape and Wine Research*. The soil properties selected in the MDS provide sufficient information to assess soil quality in a vineyard environment. The MDS has been tailored to be able to measure the effect of soil management, such as the use of irrigation, fertilisers, composts and soil additives. The MDS variables were demonstrated to be affected by such treatments and therefore can be expected to measure improvement associated with management practices. The data generated between two seasons shows benchmarking soils can be on-going as annual environmental conditions did not significantly affect soil properties and that the MDS variables were stable from year to year when no practice change is applied. The results also highlighted regional data is adequate to cover sub-regional variations that may be expected.

Soil properties were largely affected by the location of soil collection within the vineyard. For this reason, it is important to standardize soil sampling and enable accurate interpretation of soil tests. An industry standard for soil sampling will ensure regional benchmarking provides the growers with information that is practical and reliable for use in soil management strategies.

Because interpretation of the magnitude of change in soil property values over longer periods of time can be problematic and is impacted by the effects of laboratory error, we have also demonstrated the need for a sound basis for interpreting such change. Accordingly, we conclude that soil quality monitoring programs would best be coordinated at a regional level by the appropriate industry associations, drawing on national programs to assist in the assessment of whether or not differences in soil properties measured at different times are real, or artefacts of laboratory error. The assistance of appropriately accredited soil science professionals in such endeavours is recommended.

The biological tests chosen for the MDS proved to be difficult to get from commercial laboratories. Many less robust biological tests are readily available but the project team does not recommend their use for soil monitoring on a regional scale. A companion project ‘DPI 1102 Harnessing soil biological functions to improve grapevine management for a sustainable industry’ is examining this in detail and may provide more options for consideration. In 2012, labile carbon, potentially mineralizable nitrogen (PMN) and microbial biomass analyses were sourced from a commercial provider but were no longer offered in 2013 due to lack of demand. For the purpose of developing the regional databases, we accessed these analyses in 2013 from a research laboratory. In 2014, microbial biomass tests were not available, and labile carbon and PMN analyses were sourced from two separate commercial providers. Due to the quarantine restrictions for soils from within a Phylloxera Inclusion Zone, the Yarra Valley soils could not be analysed for PMN in 2014. Our experience highlighted a need to be proactive with commercial laboratories to encourage the biological test methods identified for the MDS.

The project outputs were showcased at “Workshop 19: How to interpret soil health tests to assess vineyard performance” as part of the 15th Australian Wine Industry Technical Conference held in Sydney in July 2013. This Workshop reached full capacity of 50 participants from many Australian wine regions and included several from overseas. The keen interest from the grape and wine industry to have access to such a soil monitoring system is evidenced by the response that the project team has had even before the project was completed. Information on using the MDS to assess soil quality has been included in Wines of Western Australia Fact Sheet 3

"Assessing soil quality and interpreting soil test results' funded through GWRDC's Regional Program. The sampling methodology and MDS was requested by the Treasury Wine Estates technical viticulture team in April 2014 to be integrated into their current company-wide soil health monitoring program so that they can contribute to the regional benchmarking databases. Treasury Wine Estates Ltd is one of Australia's largest companies and their interest in the outcomes of this project has been very encouraging for the project team. Similar requests were received in June 2014 from the Mornington Peninsula Vignerons Association in Victoria to help them benchmark their own region (analyses are currently being completed and the data prepared for delivery to soilquality.org.au), and from Peter Lehmann Wines in South Australia so they can continue to expand the Barossa Valley database.

The key recommendation arising from this project is to ensure that momentum is maintained and the pilot soil monitoring program set up in this project is expanded for use by the whole industry. To date, four regions have been benchmarked and a fifth is underway (Mornington Peninsula). To be nationally relevant, the database should be expanded to include regional datasets of all geographical indications. The soil monitoring system is expected to be utilized by growers in partnership with consultants who can ensure that the standardized sampling methods and soil tests are followed and, equally important, provide interpretation on how to use the information for on-farm management decisions. Further analysis of the data obtained in this project with consultants and other industry experts will assist the industry to better define regional thresholds for soil quality and ensure the national industry can address significant soil quality constraints to grapevine production. To realize this outcome, engagement with and training of consultants is strongly recommended in the next stage to ensure continued uptake and expansion of the soil monitoring program developed by this project.

It is recommended that industry consider providing resources to:

- Expand the use of the standardized sampling and protocols to more regions throughout the national industry, through regional workshops and investment
- Continue to analyze and evaluate the information gained in this project, particularly to identify regional constraints and appropriate management actions, and
- Ensure the data is fully developed as a module that growers can access and use on the soilquality.org.au website.

Appendix 1: Communication

The two review papers, industry articles, speaker presentations from the project workshops and an example of the booklet provided to growers who participated in the regional benchmarking are attached in the Appendix 1 pdf.

Publications

Oliver DP, Bramley RGV, Riches D, Porter IJ, Edwards J (2013) Review: soil physical and chemical properties as indicators of soil quality in Australian viticulture. *Australian Journal of Grape and Wine Research* 19:129-139.

Riches D, Porter IJ, Oliver DP, Bramley RGV, Rawnsley B, Edwards J, White RE (2013) Review: soil biological properties as indicators of soil quality in Australian viticulture. *Australian Journal of Grape and Wine Research* 19: 311-323.

Edwards J, Porter IJ, Oliver DP, Bramley RGV, Rawnsley B, White RE. Setting benchmarks for soil quality in Australian viticulture. Proceedings of the 15th Australian Wine Industry Technical Conference, Sydney, 14-18 July 2013.

Oliver DP, Bramley RGV, Porter IJ, Rawnsley B, Edwards J (2013) Healthy approach to soil quality hits pay dirt. *Australian and New Zealand Grapegrower and Winemaker* 599, 37-39.

Edwards J, Porter IJ, Riches D, Oliver DP, Bramley RGV, Rawnsley B, White RE (2014). Choosing biological indicators for monitoring vineyard soil quality. *Wine and Viticulture Journal,* March/April 48-51.

Porter IJ, Bramley RGV, Oliver DP, Rawnsley B, Edwards J. A standardized indicator set of physical, chemical and biological tests sets benchmarks for soil quality monitoring in the National wine industry. National Soil Science Conference, Melbourne, 23-27 November 2014.

Prideaux B. Enjoying the fruits of sharing. Good Fruit and Vegetables, February 2013, p 27.

Soil properties of vineyards in the McLaren Vale region. The Grower's Voice, September 2013.

Presentations, Workshops and Extension Activities

November 2011: Face-to-face meetings with Bethany Collins, Treasury Wine Estates, to discuss the company's current program for monitoring vineyard performance and soil health. As one of Australia's largest 250 companies, they are required to report annually to the Federal Government Environmental Reporting System and to EntWine, so could see benefit in having a standardized and recognised set of soil indicators that will allow them to benchmark their soil management programs.

14-15 December 2011: The project team organised the National Viticulture Industry Soil Quality Workshop at Knoxfield, Victoria (see chapter 1). Pdfs of the presentations are included in the attachment named Appendix 1.

May 2012: Dr Ian Porter delivered three talks about the program to over 70 viticulturists in the Yarra Valley, Red Hill and the Bellarine Peninsula as part of the AWRI field days in Victoria.

May 2012: Dr Porter and David Riches were invited to take part in a field day that was held at the site used in Case Study 3 (Chapter 4) to highlight and discuss the salinity problems in the Yarra Valley.

2 June 2012: The project team organised a Project Review Workshop with presentation to key viticulture industry representatives at the Waite Research Precinct in Adelaide (see chapter 3). Pdfs of the presentations are included in the attachment named Appendix 1.

19 June and 21 June 2012. Dr Belinda Rawnsley was invited speaker at two workshops held by the Department of Agriculture, Fisheries and Forestry in partnership with the Adelaide and Mount Lofty Ranges Natural Resources Management Board at Hahndorf and Gawler, SA respectively. Dr Rawnsley discussed soil biology under viticultural and perennial systems and the relevance to soil carbon. The field day was attended by over 80 growers and industry personnel at each session.

24 October 2012: Dr Jacky Edwards presented an overview of 'DPI 1101: Setting benchmarks and recommendations for management of soil health in Australian viticulture' at the Soil quality web-based monitoring and decision support tool workshop for the Grape and Wine industry, organised by Dr Pauline Mele as part of DPI 1102, AgriBio, Bundoora.

14 December 2012. Dr Belinda Rawnsley gave a two-part presentation on organic matter and improving soil condition to Riverland winegrape and almond growers in Loxton, SA. The invited presentation formed a component of the Hortex Alliance Step-Up Soil Condition program, funded by Caring for Our Country, DAFF and was attended by 28 growers.

17 December 2012. Dr Belinda Rawnsley gave a presentation to winegrape growers about soil health options at Temple Bruer Wines, Langhorne Creek. Growers were also shown on site examples of compost production and use in the vineyard. The event was attended by 26 growers from the Barossa.

9 May 2013. Dr Belinda Rawnsley co-organised and attended the Step-up Soil Condition Symposium on Compost and Soil Condition held in Nuriootpa, Barossa Valley. Eight speakers provided information on compost, waste recycling, legislation, case studies and soil health. The event was attended by 50 participants.

29–30 May 2013. Dr Belinda Rawnsley attended the two-day Barossa Grounds Shiraz Symposium held at Angaston, SA. Day one involved vineyard visits to inspect soil pits in the north and south of the Barossa Valley where Belinda provided information on soil biology and soil health; day two provided information on soil mapping and relationship with wine quality. Approximately 80 participants attended.

20 June 2013: Drs Ian Porter and Jacky Edwards presented an update on the progress of DPI 1101 Project to GWRDC in Adelaide.

26 June 2013. Dr Belinda Rawnsley presented an understanding of soil health at Peter Lehmann Wines. The presentation was attended by 66 Peter Lehmann contract grape growers.

14 July 2013. The project team organised "Workshop 19: How to interpret soil health tests to assess vineyard performance" as part of the 15th Australian Wine Industry Technical Conference held in Sydney, NSW. This Workshop reached full capacity of 50 participants from all Australian wine regions and included several from overseas.

27 August 2013: Drs Ian Porter and Jacky Edwards presented to Treasury Wine Estate vineyard technical team at Great Western, Victoria. More than 30 staff from Victoria, Tasmania and South Australia attended. Paul Dakis, TWE Regional Vineyard Manager, expressed keen interest for the company to become actively involved in using the project's protocols on their sites to extend the regional databases for soil monitoring.

26 November 2013: Dr Ian Porter presented "Benchmarking regional vineyard soil health" as part of the AWRI Webinar series.

11 December 2013. Dr Belinda Rawnsley organised a field day and presented how to improve soil condition at Gawler, SA. The event was attended by 26 Barossa and Clare Valley grapegrowers.

5 February 2014: Drs Edwards and Porter discussed the soil monitoring system for Australian viticulture with the Mornington Peninsula Vigneron Association. Dr Porter followed this up a few weeks later to discuss the detail of the sampling methods and train their consultant in how to co-ordinate sampling for benchmarking purposes.

4 Feb 2014: Dr Porter presented an update of the project with recommendations for the future to the GWRDC Program Managers in Adelaide.

27 May 2014. Dr Belinda Rawnsley was invited speaker for an Improving soil health workshop held at the Tanunda, SA. The presentation was attended by 80 grape growers and industry personnel.

18 June 2014: Dr Ian Porter presented an update of the project at the Vineyard Futures Workshop, Beechworth Vignerons Association / AWRI. 35 growers in attendance.

2 July 2014: Dr Porter presented an update of the project at the Vineyard Futures Workshop, Grampians Vignerons Association / AWRI. 30 growers in attendance.

2 July 2014. Dr Belinda Rawnsley gave a brief update of project outcomes at the Barossa Grounds Shiraz discussion group held at Rowland Flat, SA. The event was attended by 32 participants.

Dates not recorded but throughout the project, Dr Rob Bramley and Danni Oliver have been in close partnership with the McLaren Vale Grape Wine and Tourism Association (MVGWTA) setting up the McLaren Vale regional study.

Appendix 2: Intellectual Property

Intellectual property is held by participating organisations.

Appendix 3: References

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In addition, a further 290 references were referred to in the two literature reviews to choose the minimum dataset (see Appendix 1).

Appendix 4: Staff

Name	*Title*	*Position in this project*	*Agency*
Dr Jacqueline Edwards	Research Leader	Principal Investigator	DEPI Victoria
Dr Ian J Porter	Principal Research Scientist	Chief Investigator	DEPI Victoria
Dr Rob Bramley	Senior Principal Research Scientist	Chief Investigator	CSIRO
Dr Belinda Rawnsley	Senior Research Officer	Scientist – Barossa Valley	SARDI
Danni Oliver	Environmental Chemist	Scientist – McLaren Vale	CSIRO
David Riches	Research Scientist	Scientist – Victoria	DEPI Victoria
Dean Harapas	Research Scientists	Scientist – Victoria	DEPI Victoria
Jackie Ouzman	Technical Officer	Technician – SA	CSIRO
Damian Mowat	Technician	Technician – SA	CSIRO
Professor Robert White	Soil Scientist	Consultant	University of Melbourne
Dean Lanyon	Soil Scientist	Consultant	Arris Pty Ltd
Dr Sorn Norng	Biometrician	Statistical advice	DEPI Victoria
Adam Dimech	Research Scientist	Soil sampling – Vic	DEPI Victoria
Jianghui Wang	Research Scientist	Soil sampling - Vic	DEPI Victoria
Ehab Mohamaden	Scientist	Soil sampling – Vic	DEPI Victoria
Yihan Lin	Scientist	Soil sampling – Vic	DEPI Victoria
Bernadette Carmody	Technical Officer	Soil sampling – Vic	DEPI Victoria
David Pearce	Technical Officer	Soil sampling – Vic	DEPI Victoria

Appendix 5: Other relevant material including raw data

The spreadsheets with the benchmarking data in the format required for uploading onto the soilquality.org.au website are provided in the accompanying pdf named Appendix 5. Details of grower names and properties have been removed.