Soil Management for Yield and Quality



FINAL REPORT to

GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION

Project Number: **SAR 04/02**

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Research Organisation: **South Australian Research and Development Institute**

Date: **May 2010**

Title: Soil management for yield and quality

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Published by: South Australian Research and Development Institute
Sustainable Systems
December 2009

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Authorised by: South Australian Government

Printed by: Sustainable Systems, SARDI, Urrbrae, South Australia

ISBN:

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Abstract

This project was initiated to investigate the influence of different soil management practices on vine performance and effective water use building on the current knowledge in this area. The project was essentially split into three parts: 1) manipulating access to stored soil water through either soil profile modification (ripping) or soil surface management (mulch), 2) using mid-row cover crops to reduce water availability in high rainfall areas, and 3) quantifying the impact of Australian native species on vine performance and biodiversity. Vine performance was assessed through measurement of yield parameters, canopy growth and grape quality parameters. Soil water status and changes in soil conditions were also assessed. Ripping of the mid-row soil profile tended to increase vine growth, however, the response could not be linked to the underlying soil properties. The addition of mulch increased vine growth for up to seven years. The peak response on light soils was two years after application whereas it was four to five years on heavy soils. Increasing the width of cover crops increased the reduction in vine growth. The potential for native grass and saltbush species to be use as mid-row cover crops is determined largely by location through the effects on yield. For most of the soil management treatments the effects on berry quality were not consistent.

Executive summary

The challenge the Australian Grape & Wine Industry is confronted with is to develop and adopt technologies that reduces reliance on irrigation allocation, reduces vineyard variability, remains economically and environmentally sustainable, and produces grapes to meet changing consumer preferences in a changing climate. Of particular relevance is the increased variability of water availability and the decline in soil conditions as a consequence of using moderately saline irrigation water. Climate change is likely to exacerbate the issue of water quality and availability increasing the importance of soil management practices that better utilize stored water, minimizes competition and improves the functional health of the soil. This project investigates the influence of different soil management practices on vine performance and water utilization building on current knowledge in this area. The project focused on 1) manipulating access to stored soil water through either soil profile modification or soil surface management, 2) quantifying the effect of mid-row cover crops on water availability, and 3) quantifying the impact of Australian native species on vine performance and biodiversity. Vine performance was assessed through measurement of yield parameters, canopy growth and grape quality parameters. Soil water status and changes in soil conditions were also assessed at selected study sites.

Soil profile modification and under vine surface management

Manipulating access to stored soil water through either soil profile modification (ripping) or soil surface management (mulch) had a significant effect on vine performance. The effect of ripping the mid-row on vine performance is influenced by the initial existence of roots in the mid row. If significant roots were present in the mid-row, ripping resulted in a dramatic reduction in vine yield and canopy size. Where significant roots were not present in the mid-row, ripping of the mid-row soil profile had little effect on vine performance initially. In both cases, whether roots were present or not in the mid-row, the yield and canopy growth of the vine increased after the first vintage although the amount of increase could not be attributed to any underlying soil condition. Where roots were pruned by ripping the vine recovered to its original performance within three vintages. Evidence from the experiment conducted over seven vintages suggests a continued increase in yield and canopy growth. Despite any increase or decrease in yield and canopy growth due to ripping, the impact on berry quality parameters were not consistent. Whilst there were some significant impacts on berry quality within the experimental area the variability in response both within and between vintages suggested that, in general, ripping did not affect berry quality. The effectiveness of ripping the mid-row in increasing vine access to the mid-row resources depended on season rainfall conditions. Post ripping irrigation of the mid-row area may provide a more suitable soil moisture environment so that vine roots can actively grow into the ripped soil profile before it reconsolidates.

It is generally accepted that the application of mulch universally increases the vines access to stored soil water and that this results in increased vine growth. Experimental evidence in this report does not support this generally held view. The evidence from the studies in this report suggests that the addition of mulch on heavy soils will take more than two vintages to show any effect on vine growth and yield. The effect on vine growth and yield then peaks in the fourth to fifth vintage with some residual effects still evident in the seventh vintage. In contrast, the response in vine growth and yield on light soils is immediate, with a peak in the second vintage which then dissipates by the seventh vintage. Unlike ripping, the addition of mulch influenced total soluble solids and grape pH. Soluble solids was generally reduced by the addition of mulch although this could be offset by delayed harvesting. Grape pH was increased after the application of surface mulch with the greatest impact occurring on the lightest soils. The increase in pH diminished with each vintage until the effect was negligible by the seventh vintage. Whilst the effect of the mulch on soluble solids and pH was minimal by the eighth vintage, differences in wine spectral and chemical attributes were still evident. These differences, however, were not strong enough to be detected organoleptically.

Cover crops, water use and vine performance

Variation in cover crop width had a significant inverse impact on vine vigour. The wider the cover crop the larger the reduction in vine vigour throughout the season. The reduction in vine vigour through the reduction in shoot length also resulted in improved berry quality parameters. Wider cover crops also reduced berry yield. The perceived benefits of the reduction in vine vigour and yield, and the

associated improvement in berry quality, was better marketability of the crop. Further, benefits include 1) better and less expensive canopy management due to the lessened canopy over-crowding, 2) better air circulation inside the canopy, 3) eventual reduction in the use of disease control agents, 4) improved exposure of berries to solar radiation and their early ripening, and 5) the potential for better soil ecology in the mid-row when using cover crops.

Australian native cover crop species and vine performance

The potential for replacement of conventional exotic annual cover crop species with native grass and saltbush species was investigated using a range of parameters to determine the worth of such a change in management. The principal species used were creeping saltbush, ruby saltbush and wallaby grass, which were compared over 5 sites and 3 years. Their fit within the vineyard system was determined largely by location. At Nuriootpa, both species were found to be very competitive with the vines, with 50% and 30% yield reductions caused by saltbush and wallaby grass respectively. In Coonawarra however, with wide spaced dry grown vines, wallaby grass had no effect on yield. The same was the case for Swan Hill, Loxton and Kingston-on-Murray where saltbush was growing in the mid-row, though the latter site did show a trend toward yield reduction. Where excess vigour creates issues of vine imbalance, over-cropping and consequent poor fruit quality, the use of wallaby grass or saltbush may be likely to be a very effective tool in vigour reduction. Other benefits attributable to native vs exotic species are the provision of habitat for beneficial invertebrates, potential for long term improvement in soil properties and reduced management costs. This project determined that native plant species such as wallaby grass and some species of saltbush can make an important contribution to improving vineyard sustainability, but care must be exercised in site selection to prevent yield loss. Further, the assessment of sustainability in vineyards involves many inter-related facets that must be taken into account.

Background

The challenge the Australian Grape & Wine Industry is confronted with is to develop and adopt technologies that reduces reliance on irrigation allocation, reduces vineyard variability, remains economically and environmentally sustainable, and produces grapes to meet changing consumer preferences in a changing climate. Of particular relevance is the increased variability of water availability and the decline in soil conditions as a consequence of using moderately saline irrigation water. This has been compounded by vineyard developments in marginal quality soils and climates. Climate change is likely to exacerbate the issue of water quality and availability and as a consequence vineyard variability caused by a decline in soil structure is likely to increase. Soil management practices that account for this by maximising stored water and minimising competition in a highly variable vineyard landscape (soil, water and climate) must be developed as a matter of urgency.

Managing the root zone

Approximately 87% of Australian wine grape plantings are irrigated with about 70% of the irrigated area by drip or micro jet systems. Drip irrigation is now virtually the only form of irrigation used in vineyards outside the Murray-Darling Basin. It is generally accepted that drip irrigation results in limited zones of soil water extraction by vine roots during a large part of the growing season and under such conditions there is potential for rootzone salinisation. This situation may be exacerbated by the widespread adoption of Regulated Deficit Irrigation (RDI) to improve wine grape quality. In addition, the imposition of water restrictions in parts of the MDB has meant growers are even further reducing irrigation applications. The long-term cumulative effects of RDI, water restrictions and potential higher water salinities on our ability to manage vine rootzone salinity without compromising wine grape quality is unclear.

Vine rootzones are further compromised by establishing vineyards on sites with low readily available water (RAW) in the belief that this will help control excessive vegetative growth in varieties such as Shiraz. As a consequence it is likely that vine root systems are probably restricted to only a small proportion of the total vineyard soil profile, especially in low rainfall regions, and are thus not utilising water and nutrient either in the inter-row area or below potentially restricted rootzones. Myburgh *et al*. (1996) showed that increasing available soil volume resulted in earlier production and therefore profitability. McClymont *et al.* (2006) also demonstrated that under non-limiting water and nutrient supply vine growth and yield decreased with decreasing available soil volume, suggesting that root volume per se and possibly root distribution have a direct effect on vine performance. However, there is concern that under Australian conditions the increased soil volume and hence vigour may negatively impact on wine grape quality. The consequences of this are unknown and the resiliency and sensitivity of the vine is unclear. This was supported in the outcomes of a scoping study (Grant 2003) to identify research priorities to improve the ability of horticulturalists to manage rootzones for desired outcomes viz: do we want to remove root zone constraints in all cases as there is a perception that production of quality wine grapes sometimes requires that vine potential be restricted in some way.

Many Australian vineyard soils have potentially restrictive rootzones that could negatively impact on vine performance, irrigation requirement and long term soil sustainability. Some growers have recognised this and attempted to improve the conditions of the rootzone by ripping and additions of surface mulches, but these practices are not widely used. Lanyon *et al* (2004) recognised that similar soil management techniques tend to be applied across all soil types and recommended that soil management practices, both surface and profile, should be aligned to variations in soil type and or profile characteristics and individual relevant soil properties. Lanyon and Bramley (2004) demonstrated that the vine response to different forms of soil management, be it surface or profile modification, was a function of soil texture. However, this study was limited to two seasons and changes in soil properties were not evaluated. Moreover, Lanyon and Bramley (2004) suggested that typical responses of the vine to different soil management practices would be a more valuable addition to the Australian Viticulture Soil Key (AVSK) (Maschmedt *et al* 2002) than the AVSK per se. This project therefore was initiated to establish a relationship between changes in vine performance to soil surface and profile management and soils conditions that they are applied to.

The impact of Cover crops

It is widely believed that cover crops have a role in maintaining soil structure and can, by their use of soil moisture, help control excessive vine vigour. However, in regions that predominantly rely on stored winter-spring rain the competitive effects of cover crops needs to be considered. Grant (2003) reported industry concerns about competitive effects between cover crops and vine water use, the role of cover crops in arid regions and the place of cover crops in drip irrigated vineyards. Evapotranspiration from cover crops in vineyards in the south west of Western Australia has been estimated at over 200 mm which is almost as great as the vine water requirement. Growers need more information to allow management of cover crops (species, time of mowing, herbicide, width of cover crop area etc) to optimise soil water available to the vine, while not compromising benefits such as vigour control, improving soil structure and nutrient cycling (Grant 2003). Cover crops and their management are also likely to have an important role in maintaining structural amelioration generated by practices such as ripping. The provision and utilisation of suitable species for maintaining a porous structure in the wheel tracks is a major challenge. In high rainfall zones in WA it is believed that vineyards may contribute significant recharge in the winter months resulting in a rise in the regional saline ground water. Different pasture management options have the potential to reduce recharge.

The question arises, however, as to the real improvement in soil structure and what are the competitive effects of the cover crop for winter rain and possible reductions in leaching salts applied in irrigation water. Previous studies on the role of cover crops have concentrated on agronomic features of the cover crop and did not examine effects on vine performance, water and nutrient balance and did not quantify any changes in soil physical or chemical conditions. Cover crops may significantly decrease the amount of water stored in the root zone of grapevines (Pritchard 1998; Morlat 1987; Van Huyssteen and Weber 1980). Increased irrigation may be necessary to meet vine water needs (Pritchard, 1998). Van Huyssteen et. al. (1984) showed that spraying the cover crop with herbicide at bud burst and leaving this material as mulch on the soil surface could conserve moisture as compared to cover crops that were allowed to complete their life cycle. Proffitt (2000) examined the ability of cover crops and root pruning to limit moisture availability to the vine and thus control vegetative vigour. In response to competition by the cover crops the vines extracted water from deeper depths within the vine row and a reduction in vegetative growth occurred. In contrast, Morlat and Jacquet (2003) found that in the inter row, the improvement in the physical and chemical properties of the soil through permanent grass cover does not directly benefit the grapevine root system, which is greatly reduced in the topsoil by competition with the cover crop.

Considerable work has been conducted in Australia to define species that are suitable for cover crops in different climatic regions (pasture evaluation research, Porter, 1998 and Porter 1999). Haynes (1980) reviewed the considerable research on competition effects of cover crops in orchards. However, little research has been done to define species and management strategies to limit cover crop competition with vines. This project was undertaken to determine the degree to which mid-row cover crops compete with the vine.

The use of Australian native species

The role of Australian native species as a mid-row cover crop has not been well considered. However, there is a growing interest in the use of Australian native species for cover crops/ground cover in vineyards, with early evidence suggesting long term cost reductions, improved soil water status and increased biodiversity. In general, the vineyard mid-row is usually sown to annual or perennial exotic plant species which provide soil cover and other benefits such as a source of mulch and / or nutrients, and competition for undesirable weed species. While these plant species have been bred to perform well in pasture or cropping systems, it does not mean they are necessarily the best species to grow in the vineyard. Common to all viticultural environments are indigenous plant species which have adapted to those conditions with minimal intervention from humans. It therefore seemed logical that there should be scope for the replacement of exotic with perennial native plant species that would confer the benefits of thousands of years of adaptation to the Australian environment. Potential benefits to the viticultural sector would possibly include improvements in soil health, reduced operating costs, enhanced invertebrate biodiversity and beneficial insect populations, reduced weed populations and aesthetically pleasing mid-row soil cover. This project therefore strived to quantify the potential role of native cover crop species for Australian viticulture. In doing so it has encompassed each of the criteria that are now being used in McLaren Vale for assessment of a vineyard's environmental credentials.

Project Aims and Performance targets:

This project had three major objectives that, together, investigate the effect of soil management, of both the vine row and mid-row, on water utilisation and vine performance. Vine performance in this instance refers to changes in yield and its components, vine growth parameters, and grape composition. The three major objectives are detailed below:

Objectives

1. Determine the effect of soil profile modification and under-vine surface management on vine performance

2. Determine the effect of cover crops on vineyard water balance and vine performance.

3. Determine the adaptability of selected Australian native species for vineyard floor management and its consequential affect on vine performance.

Output and performance targets

Outputs and Performance Targets 2005- 06

Output	Performance Targets
Appoint staff	Define new positions, advertise & interviews.
Site establishment	Identification & establishment of cover crop site(s).
Site establishment	Establish soil texture x rootzone amelioration experimental site on participating winery vineyard
Site establishment	Establish experimental site to examine soil amelioration/vine traffic on Nuriootpa Research Centre

Outputs and Performance Targets 2006- 07

Output	Performance Targets
Preliminary information for industry on effects of cover crop management on competition with the vine	First season data generated on the effects of soil amelioration and cover crops/mulch on vineyard water use & vine response
Key sites across major production regions utilising native ground cover species	Establish additional sites for native species evaluation
An industry with an expanding knowledge & understanding of improved systems of vineyard floor management and soil profile modification with a known vine performance response	Presentation at 2007 Wine Industry Technical Conference

Outputs and Performance Targets 2007- 08

Output	Performance Targets
Knowledge on vineyard floor management and its effect on yield and quality	Second season data generated on the effects of soil amelioration and cover crops on vineyard water use & vine response
Industry publication on soil management & cover cropping	Collate & summarise trial results and publish in industry media
An understanding of the longevity that soil management has on vine performance manipulation	Publish findings in popular industry magazine and/or scientific journal

Outputs and Performance Targets 2008- 09

Output	Performance Targets
Recommendations on vine rootzone management cover cropping with native species and cover crop management	Third season data generated on the effects of soil amelioration and cover crops/mulch on root distribution, vineyard water requirement & vine response
Improved knowledge of soil and water management that allows winegrape growers to improve their ability to meet specifications	Published/upgrade booklet on soil and water management guidelines
New knowledge on the effects of soil and water management on grape and wine composition	Publish results in scientific journals
Final Report	Final report submitted by Dec 2009

Soil profile modification and under vine surface management

Dean Lanyon, Shannon Andrews (nee Pudney), Carolyn Howell

Methods

Experiments investigating the impacts of soil profile modification and under vine surface management on vine performance were undertaken according to three separate objectives 1) what is the impact of full profile soil modification by ripping, 2) what are the relative impacts of ripping and surface mulching when applied to different soil profiles, and 3) how long do the effects of ripping and surface mulching last. Three separate experiments, implemented at Nuriootpa, McLaren Vale and Langhorne Creek, were developed around these objectives and are described below.

Full soil profile modification

Site setup and design

The full profile ripping experiment was conducted on the SARDI Nuriootpa Viticulture Centre utilising an existing Shiraz clonal trial which was established in 1988 (3.5 m row space, 2.25 m vine spacing). Treatment selection was based on the notion that traffic would re-compact the soil rapidly after ripping limiting the opportunity for the profile modification to have an effect on vine performance in the long term. Hence, the treatment design was based on profile modification (ripping and no ripping) and the removal of all heavy traffic (traffic and no traffic). This resulted in four treatments replicated 4 times in a restricted randomised design (Figure 1). Randomisation in this instance was restricted by the traffic being confined to rows.

The initial data collected from the clonal trial, prior to the implementation of the treatments, was used to test whether the vine performance from the existing clonal trial had a significant effect on the impending treatment design. The results of this analysis showed no significant effect of the existing clones on the experimental design.

Ripping of the mid-row was undertaken in Autumn 2006 using an oscillating ripper designed by Agricultural Machinery Research and Design Centre at the University of South Australia (Plate 1). This ripper also allowed the injection of GypFlo™ (superfine calcium carbonate with elemental sulphur, 35% Ca, 25% S). Gypflo™ was applied as a slurry at a rate of 100 l/ha (recommended rate for sodic clays see http://www.ultimateagri.com.au/). The combination of ripping and GypFlo™ injection was aimed at improving the stability of the modified soil profile. Physical disturbance of the soil profile was measured using a penetrometer before and after ripping. The reduction in penetration resistance due to ripping is shown Figure 2 and demonstrates that whilst the intention of ripping was to loosen the soil profile to a depth of 1 metre measurements of penetration resistance (Figure 2) indicate that loosening occurred only to a depth of 50 cm. What is also clear is that the compacted areas due to wheel traffic were loosened by ripping. For the non-trafficked treatment all subsequent vineyard operations involving heavy machinery (eg tractor use during spraying) were undertaken with a 4-wheel motorbike.

Irrigation was applied uniformly to all treatments according to the requirements of the trafficked non-ripped treatment. Moderately saline bore water (1.2 dS/m; Clark 2004) was mainly used throughout the experiment period with small supplementary BIL water used at the end of the season. Weather data was collected using the SILO patch point data drill (www.longpaddock.qld.gov.au/silo/) using station 23773 (Nuriootpa viticulture) located on the research station.

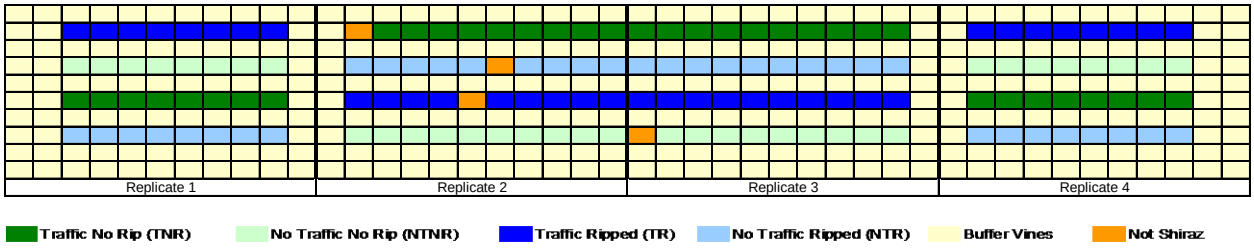


Figure 1: Schematic representation of the treatment layout of the Nuriootpa trial, a restricted randomised design. Each unit represents a single vine.



Plate 1: The oscillating ripper used in the implementation of the ripping treatments at Nurioopta and McLaren Vale experimental sites. The ripper was design by Agricultural Machinery Research and Design Centre at the University of South Australia

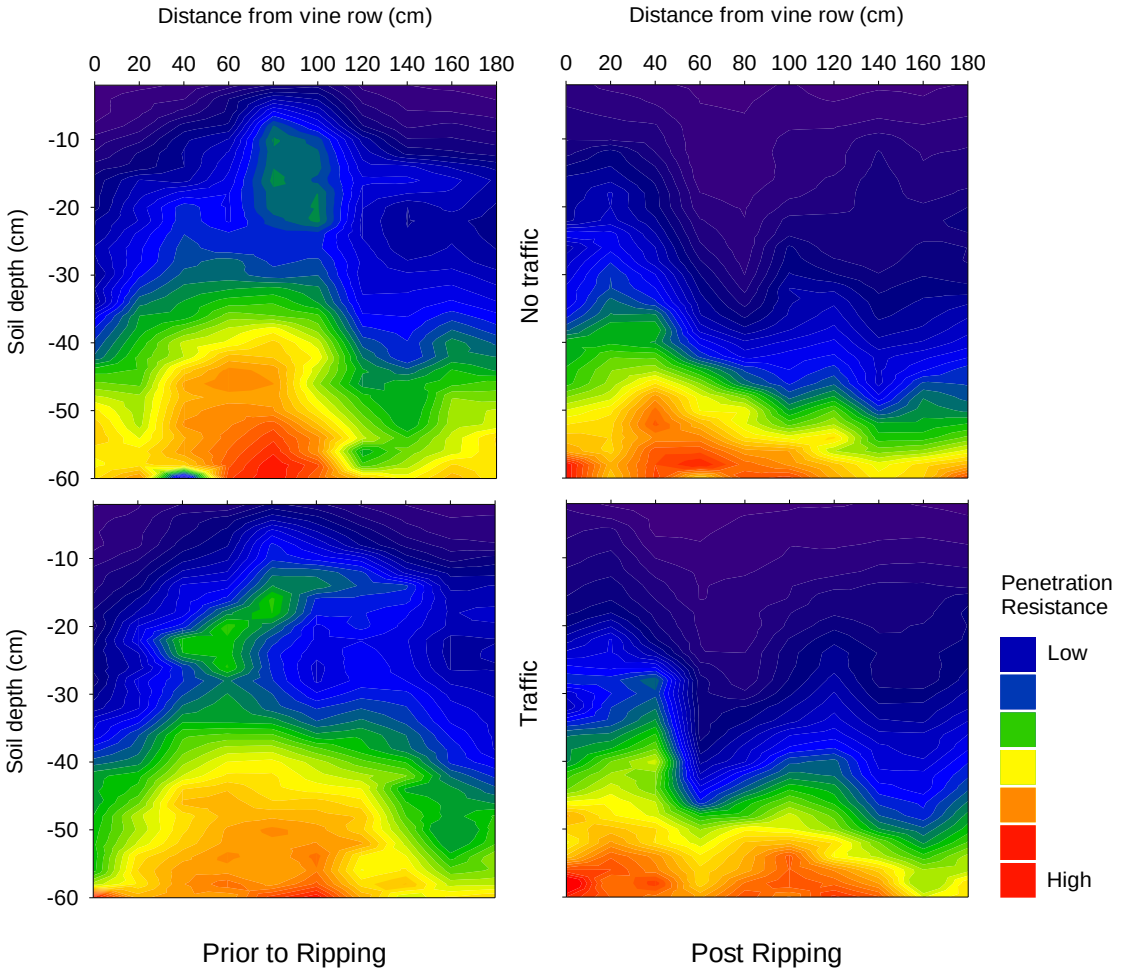


Figure 2: Transects, perpendicular to the vine row, of penetration resistance before and after deep ripping for the trafficked and non-trafficked treatments only.

Vine performance

Vine and grape properties were recorded over vintage years 2007, 2008 and 2009. This included berry growth and development from veraison to harvest, vine yield and berry properties at harvest and pruning weight. Berry juice total soluble solids (TSS), pH and titratable acid (TA), and whole berry tannin, anthocyanin, and phenolic concentration were measured at harvest in all three years. Berry juice TSS (°Brix), pH, TA (g tartaric acid equivalents/l berry juice), total N (mg/l) and Cl (mg/l) were measured after crushing and centrifuging the fresh berry sample from harvest. TSS, pH and TA were

measured following the methods of Iland *et al* (2004). Whole berries were homogenised and anthocyanins (mg malvidin-3-glucoside equivalents/g fresh berry weight), phenolics (au/g fresh berry weight) and tannins (mg catechin equivalents/g fresh berry weight) were determined by spectrophotometry following the methods of Iland *et al* (2004).

Basal petioles were also collected at flowering, veraison and harvest to assess differences in plant nutrition. Samples were analysed for NO_3-N, P, K, Ca, Mg, Na, Cl, Zn, Mn, Fe, Cu, B, and S. Samples were analysed by ACML Analytical Services, Loxton. Nitrate N (%) was determined by ion specific electrode. P (%), K (%), Ca (%), Mg (%), Na (%), S (mg/kg), B (mg/kg), Cu (mg/kg), Fe (mg/kg), Mn (mg/kg), and Zn (mg/kg) were determined by inductively coupled plasma optical emission spectroscopy (SPECTRO ARCOS, SPECTRO Analytical Instruments, Kleve, Germany). Cl (%) was determined by colorimetric method (APHA, 2005 – method 4500-Cl^- E).

Aerial imagery was also collected at veraison using a digital multi-spectral camera (High Resolution Airborne Multispectral System, SpecTerra Services Pty Ltd, Perth, WA, Australia) at a spatial resolution of 0.5 m. Data pre-processing, (band-to-band registration, radiometric correction for removal of vignetting and bi-directional reflectance distribution effects, and geo-referencing) was carried out by SpecTerra services using in-house software (Frank Honey, Pers. Comm.). The pre-processed data were used to create a surface of normalised difference vegetation index (NDVI) calculated as (NIR-Red)/(NIR+Red). Image processing and data extraction was conducted using ArcView software (ESRI, 1996).

Shoot lengths were measured on 4 shoots collected from each of 5 vines within each replicate of the NTR and TNR treatments. Canopy porosity was measured at veraison during the 2009 vintage using the canopy porosity device described by Bramley *et al* (2007). Porosity measurements and spatial position was recorded simultaneously.

Soil properties

Soil profile analysis of the vine row, wheel track and mid-row was undertaken after the final harvest in 2009. Samples were analysed by CSIRO Analytical Services, Adelaide Laboratories. Total C (%) and Total N (%) were determined by high temperature combustion in an atmosphere of oxygen (CNS2000, LECO Corporation, St Joseph, Michigan, USA). Soil electrical conductivity ($EC_{1:5}$), pH (in water and $CaCl_2$) and chloride were determined using a 1:5 soil:water extract following the procedure of Rayment and Higginson (1992). Exchangeable cations and were determined using NH_4Cl solution analysed by Flame Atomic Absorption Spectrometry (906AA, GBC Scientific Equipment Pty. Ltd., Melbourne, Australia) following the methods detailed in Rayment and Higginson (1992).

Penetration resistance was measured along transects perpendicular to the vine row in Spring 2009. Apparent soil electrical conductivity data were also collected in Spring 2009 using an electromagnetic induction sensor (EM38, Geonics, Mississauga, Ontario, Canada). Spatial position and EM38 data in the vertical and horizontal dipoles were collected simultaneously.

Statistical analysis

Treatment effects on vine, grape and soil parameters were analysed using a general ANOVA (Genstat 2008).

Relative impacts of ripping and surface mulch

Site setup and design

The trial investigating the effects of mulch and ripping on vine performance applied to different soil types was conducted in an 8 year old Cabernet Sauvignon vineyard in McLaren Vale (2.75 m row space, 1.8 m vine spacing). Existing soil surveys and visual soil inspections were used to identify 4 sites within the vineyard representing four different soil profiles. Three treatments consisting of control (normal vineyard practice), mulch and ripping were applied to two opposing panels (6 vines in total) with a panel and row as a buffer between treatments. Each treatment was duplicated at each of the four sites in an unrandomised block design (Figure 3). Randomisation in this instance was restricted by the requirement to have one continuous ripping pass[1].

[1] The lack of randomisation was an oversight of the chief investigator at the time of setup

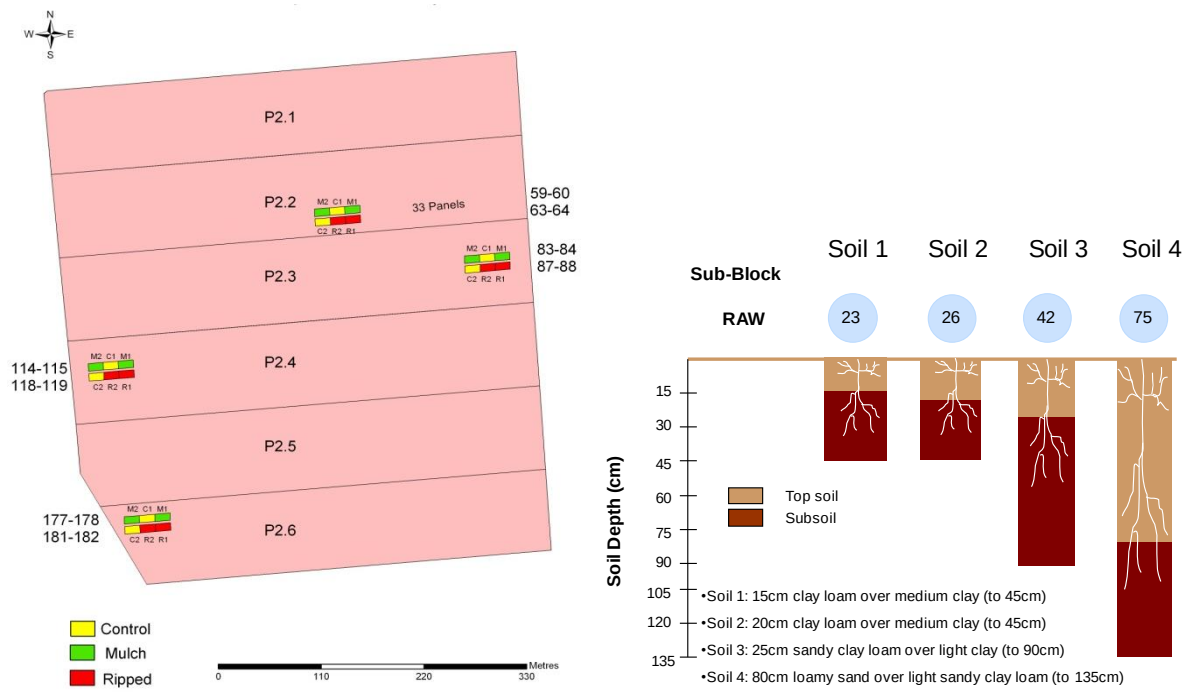


Figure 3: Schematic of treatment layout and soil profile description at the experimental site in McLaren Vale.

Forest mulch (Table 1) was applied in spring 2005 at a rate of 150 m^3/ha along the vine row. Ripping of the mid-row was undertaken in autumn 2006 using an oscillating ripper designed by Agricultural Machinery Research and Design Centre at the University of South Australia (Plate 1). This ripper also allowed the injection of GypFlo™ (superfine calcium carbonate with elemental sulphur, 35% Ca, 25% S). Gypflo™ was applied as a slurry at a rate of 100 l/ha (recommended rate for sodic clays see http://www.ultimateagri.com.au/). The combination of ripping and GypFlo™ injection was aimed at improving the stability of the modified soil profile. Physical disturbance of the soil profile was measured using a penetrometer before and after ripping. The reduction in penetration resistance due to ripping is shown Figure 4 and demonstrates that whilst the intention of ripping was to loosen the soil profile to a depth of 1 metre measurements of penetration resistance shown in Figure 4 indicate that loosening occurred only to a depth of 60 cm. What is also clear is that the compacted areas due to wheel traffic were loosened by ripping.

Irrigation was applied uniformly to all treatments as per usual vineyard management. Irrigation water derives from a domestic reclaimed water scheme delivered through the Willunga Basin Water Company. Water quality is relatively consistent with an average salinity of 1.26 dS/m, sodium dominant, and pH of 8.0. Weather data was collected using the SILO patch point data drill (www.longpaddock.qld.gov.au/silo/) using station 23729 (McLaren Vale).

Table 1: Analysis, as provided by Collex Laboratories, of the forest mulch compost used in the McLaren Vale experiment. pH was analysed on a 1:5 compost:water extract and electrical conductivity (EC) was analysed on a 1:1.5 compost:water extract. Nutritional elements are expressed on a dry weight basis.

$pH_{1:5}$	OM	$EC_{1:1.5}$	N	P	K	Na	Cu	Zn
	%	dS/m	---------- % ----------				--- mg/kg ---	
7.4	91	1.5	1.1	0.13	0.5	0.14	15	120

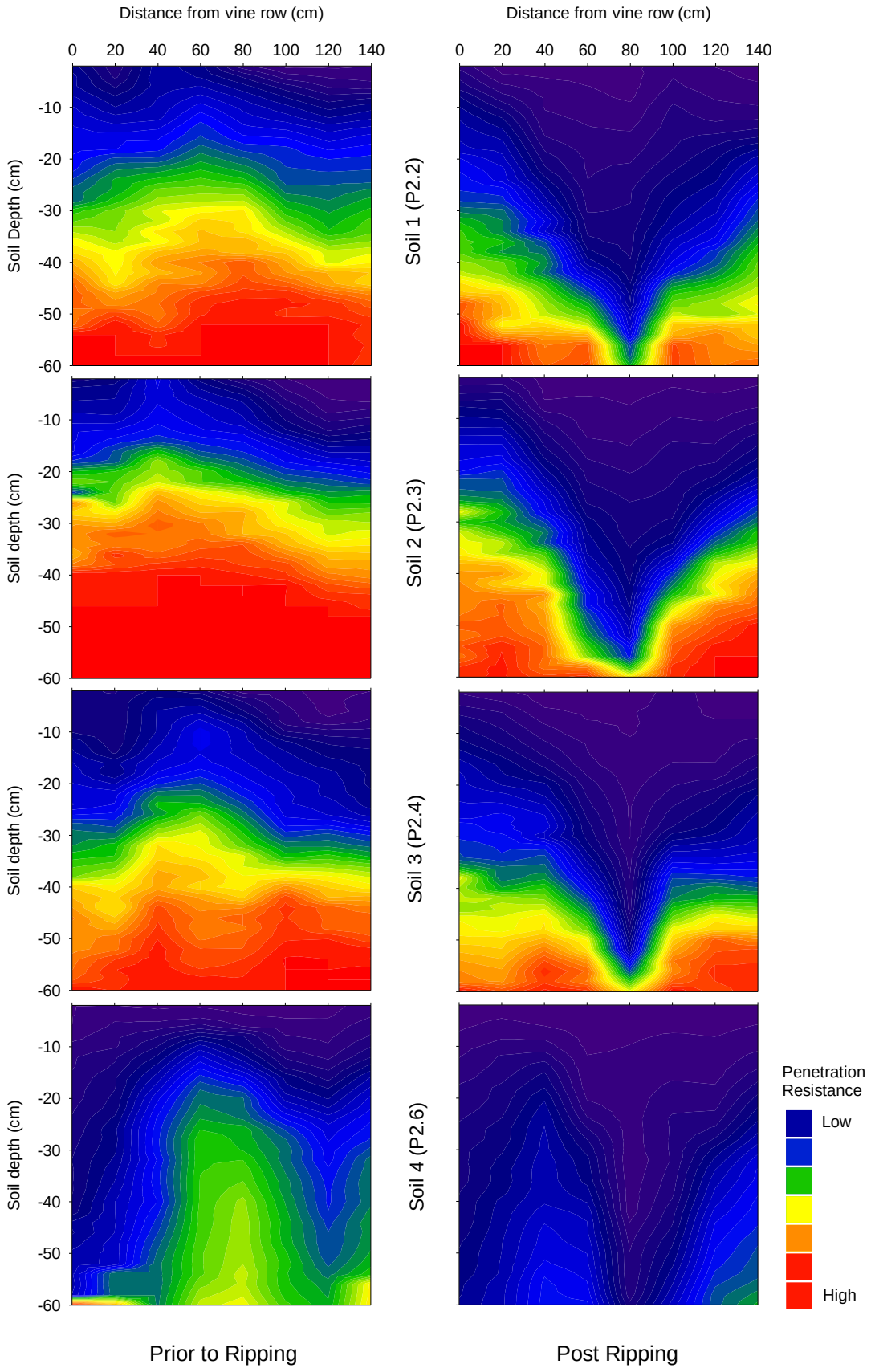


Figure 4: Transects, perpendicular to the vine row, of penetration resistance before and after deep ripping for the 4 different soil profiles at the McLaren Vale experimental site.

Vine performance

Vine and grape properties were recorded over vintage years 2007, 2008 and 2009. This included berry growth and development from veraison to harvest and vine yield and grape properties at harvest. Berry juice total soluble solids (TSS), pH and titratable acid (TA), and whole berry tannin, anthocyanin, phenolic concentration was measured at harvest in all three years. Berry juice TSS (°Brix), pH, TA (g tartaric acid equivalents/l berry juice) were measured after crushing and centrifuging the fresh berry sample from harvest. TSS, pH and TA were measure following the methods of Iland *et al* (2004). Whole berries were homogenised and anthocyanins (mg malvidin-3-glucoside equivalents/g fresh berry weight), phenolics (au/g fresh berry weight) and tannins (mg catechin equivalents/g fresh berry weight) were determined by spectrophotometry following the methods of Iland *et al* (2004).

Basal petioles were also collected at flowering, veraison and harvest to assess differences in plant nutrition. Samples were analysed for NO_3-N, P, K, Ca, Mg, Na, Cl, Zn, Mn, Fe, Cu, B, and S. Samples were analysed by ACML Analytical Services, Loxton. Nitrate N (%) was determined by ion specific electrode. P (%), K (%), Ca (%), Mg (%), Na (%), S (mg/kg), B (mg/kg), Cu (mg/kg), Fe (mg/kg), Mn (mg/kg), and Zn (mg/kg) were determined by inductively coupled plasma optical emission spectroscopy (SPECTRO ARCOS, SPECTRO Analytical Instruments, Kleve, Germany). Cl (%) was determined by colorimetric method (APHA, 2005 – method 4500-Cl^- E).

Soil properties

Soil profile analysis of the vine row and wheel track was undertaken after the final harvest in 2009. Samples were analysed by CSIRO Analytical Services, Adelaide Laboratories. Total C (%) and Total N (%) were determined by high temperature combustion in an atmosphere of oxygen (CNS2000, LECO Corporation, St Joseph, Michigan, USA). Soil electrical conductivity ($EC_{1:5}$), pH (in water and $CaCl_2$) and chloride were determined using a 1:5 soil:water extract following the procedure of Rayment and Higginson (1992). Exchangeable cations and were determined using NH_4Cl solution analysed by Flame Atomic Absorption Spectrometry (906AA, GBC Scientific Equipment Pty. Ltd., Melbourne, Australia) following the methods detailed in Rayment and Higginson (1992).

Penetration resistance was measured along transects perpendicular to the vine row in spring 2009. Apparent soil electrical conductivity data were also collected in spring 2009 using an electromagnetic induction sensor (EM38, Geonics, Mississauga, Ontario, Canada). Spatial position and EM38 data in the vertical and horizontal dipoles were collected simultaneously.

Root distribution

Root distribution was assessed at only one soil type location (Soil 3). One metre deep soil pits were excavated between vine rows in each treatment area. Total root numbers were counted within 100 mm square grids for each size class F<2mm, M=2-5mm, C=5-10mm, T>10mm following the procedure of van Huyssteen (1988).

Statistical analysis

The compromised randomised design was analysed for treatment location effects using data collected for three vintages. The treatment design and lack of randomisation had no bias effect on treatment results for all measured parameters (data not shown). Hence, treatment effects on vine, grape and soil parameters were analysed using a general ANOVA (Genstat 2008).

Longevity of ripping and surface mulch

Site setup and design

An existing experiment established as part of GWRDC project CSL 01/01 on a Langhorne Creek vineyard was continued to ascertain the longevity of ripping and surface mulch effects on vine performance. The Langhorne Creek site was a 7 hectare block of Shiraz planted in 1992 and was characterised by a large variation in surface soil texture. The vines were drip irrigated but generally only received 1-2 ML of water per hectare per year. The treatments implement were 1) deep ripping of the wheel tracks to 400mm deep with the incorporation of composted grape marc, 2) use of a composted grape marc applied along vine the row as a surface mulch at a rate of 150 m^3/ha and 3) a control (Plate 2).

Treatments were imposed along replicated strips 4 rows wide over the entire vineyard area in spring 2002 (Figure 5). Target vines were selected systematically throughout the vineyard with 100 target

vines per treatment (Figure 5). Deep ripping was implemented using a 'Soilworks' oscillating winged tine (Plate 3). Prior to ripping, 150 m^3/ha of composted grape marc was incorporated into the top 5 cm along the wheel track to aid in the stabilization of the ripped soil (Cockroft and Olsson, 2000). The oscillation of the winged tine aided the incorporation of the composted grape marc into the ripped soil. Analysis of the composted grape marc is shown in Table 2. No additional compost or ripping occurred after treatment implementation in spring 2003.



Control Mulch Ripped

Plate 2: Representation of each treatment applied at the Langhorne Creek experimental site.

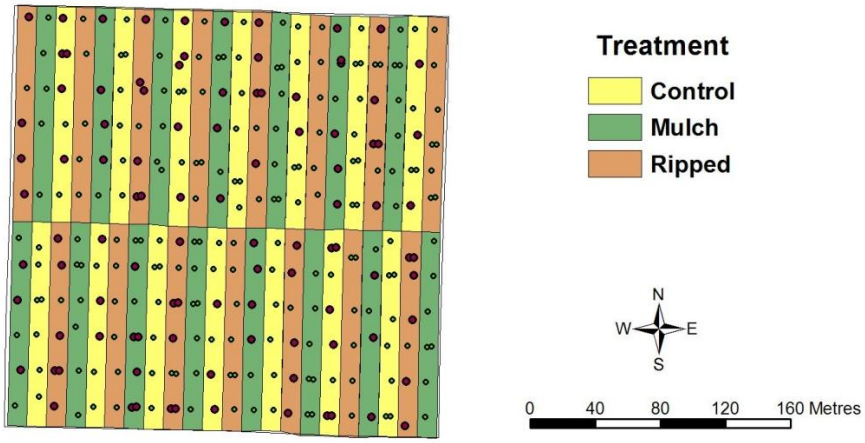


Figure 5: Experimental layout and location of target vines at Langhorne Creek. Red dots represent locations where soil samples were collected along-side a target vine.



Plate 3: Oscillating winged tine used to rip the wheel tracks at the Langhorne Creek experimental site to help incorporate surface applied organic matter

Table 2: Analysis, as provided to the supplier by PIRSA Rural Solutions, of the composted grape marc used in the Langhorne Creek experiment. pH and electrical conductivity (EC) were analysed on a 1:5 marc:water extract. Nutritional elements are expressed on a dry weight basis.

$pH_{1:5}$	OC	$EC_{1:5}$	P	K	Ca	Na	Mg	S	Cu	Zn	Mn	Fe
	%	dS/m	---------- % ----------						---------- mg/kg ----------			
5.8	11.2	8.89	0.33	1.97	1.78	0.12	0.37	0.31	44	103	97	4820

Irrigation was applied uniformly to all treatments as per usual vineyard management. Irrigation water was source from Lake Alexandrina with variable water quality. Weather data was collected using the SILO patch point data drill (www.longpaddock.qld.gov.au/silo/) using station 24515 (Langhorne Creek).

For the 2009 vintage a separate experiment was conducted to determine whether the treatments imposed impacted on vine nutrition and wine properties. This experiment was setup using the existing treatment area but restricted to two localised areas of high and low apparent soil electrical conductivity. Apparent soil electrical conductivity data were collected prior to bud burst 2008 using an electromagnetic induction sensor (EM38, Geonics, Mississauga, Ontario, Canada). Spatial position and EM38 data in the vertical and horizontal dipoles were collected simultaneously. Two areas were identified as low and high EM and triplicate plots for each treatment established consisting of three panels each. The low EM area was located within soil 1 while the high EM area straddled soils 3 and 4.

Vine performance

Vine and grape properties were recorded for three seasons. This included vine yield and grape properties at harvest and pruning weight. Berry juice total soluble solids (TSS), pH and titratable acid (TA), and whole berry tannin, anthocyanin and, phenolic concentration were measured at harvest in all three years. Berry juice TSS (°Brix), pH, TA (g tartaric acid equivalents/l berry juice), total N (mg/l) and Cl (mg/l) were measured after crushing and centrifuging the fresh berry sample from harvest. TSS, pH and TA were measure following the methods of Iland *et al* (2004). Whole berries were homogenised and anthocyanins (mg malvidin-3-glucoside equivalents/g fresh berry weight), phenolics (au/g fresh berry weight) and tannins (mg catechin equivalents/g fresh berry weight) were determined by spectrophotometry following the methods of Iland *et al* (2004). Total N was determined by high temperature catalytic combustion and chemiluminescence detection (Formacs^{TN}, Skalar Analytical Ltd., Breda, Netherlands). Total chloride was determined by an automated colorimetric method (APHA, 2005 – method 4500-Cl^- E) using an automated segmented flow analyser (Alpkem Flow Solution 3, OI Analytical, Texas, USA).

Basal petioles were also collected at flowering during the 2009 vintage to assess differences in plant nutrition. Samples were analysed for NO_3-N, P, K, Ca, Mg, Na, Cl, Zn, Mn, Fe, Cu, B, and S. Samples were analysed by ACML Analytical Services, Loxton. Nitrate N (%) was determined by ion specific electrode. P (%), K (%), Ca (%), Mg (%), Na (%), S (mg/kg), B (mg/kg), Cu (mg/kg), Fe (mg/kg), Mn (mg/kg), and Zn (mg/kg) were determined by inductively coupled plasma optical emission spectroscopy (SPECTRO ARCOS, SPECTRO Analytical Instruments, Kleve, Germany). Cl (%) was determined by colorimetric method (APHA, 2005 – method 4500-Cl^- E).

Aerial imagery was also collected at veraison during the 2006, 2007 and 2008 vintage years using a digital multi-spectral camera (High Resolution Airborne Multispectral System, SpecTerra Services Pty Ltd, Perth, WA, Australia) at a spatial resolution of 0.5 m. Data pre-processing, (band-to-band registration, radiometric correction for removal of vignetting, bi-directional reflectance distribution effects, and geo-referencing), was carried out by SpecTerra services using in-house software (Frank Honey, Pers. Comm.). The pre-processed data were used to create a surface of normalised difference vegetation index (NDVI) calculated as (NIR-Red)/(NIR+Red). Image processing and data extraction was conducted using ArcView software (ESRI, 1996).

Soil properties

Soil profile cores were collected in the mid row at the locations indicated in Figure 5. At each location, two steel cores (5 cm in diameter) were driven into the ground using a jackhammer; the two cores

were located within 50 cm of each other. The cores were extracted and the soil removed. For each location, the depth to the subsoil, determined by a significant change in soil texture, was recorded as the average of the two cores. The extracted soil was sectioned into 0-10, 15-25 and 35-45 cm depth increments, air-dried and sieved (< 2mm) prior to analysis. Using standard methodologies (Rayment and Higginson, 1992) all samples were analysed, in a 1:5 soil:water extract, for pH, electrical conductivity (EC) and chloride (Cl), and a subset of samples from the 15-25 and 35-45 cm depth increments were also analysed for exchangeable cations. Mid infrared (MIR) predictions (Janik *et al*., 1998) were carried out on all samples for physical properties (% sand, silt and clay; water holding properties).

Based on the MIR analysis 30 intact soil cores representing the full range of soil textures across the experimental site were collected from the topsoil (5-10 cm) and the subsoil (varied between 25 to 50 cm). The intact cores were analysed for volumetric water content at matric suctions of 10 and 60 kPa using standard methods (Romano *et al.,* 2002); MIR analysis was also performed on the intact soil cores. These data were then used to correct for any bias in the MIR predictions of soil hydraulic properties in the larger sample set.

Apparent soil electrical conductivity data was collected in Spring 2008 using an electromagnetic induction sensor (EM38, Geonics, Mississauga, Ontario, Canada). Spatial position and EM38 data in the vertical and horizontal dipoles were collected simultaneously. These data were used to determine the position of high and low EM zones for a replicated experiment during the 2009 vintage.

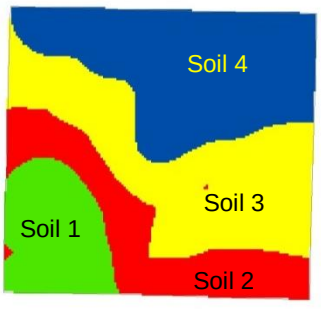
Wine properties

Wines were made from 50 kg of fruit collected from each replicate and treatment of the high and low EM zones. Grapes were put through primary fermentation only following a standard procedure outlined in appendix 5 (Provisor http://www.provisor.com.au/). Wines were analysed for alcohol, pH, colour, hue, phenolics and chloride. Wine alcohol (%), pH, hue, anthocyanins (mg malvidin-3-glucoside equivalents/g fresh berry weight) and phenolics (au/g fresh berry weight) were determined by spectrophotometry following the methods of Iland *et al* (2004). Cl (mg/l) was determined by colorimetric method on diluted samples (APHA, 2005 – method 4500-Cl^- E).

Treatments underwent sensory difference testing within each EM zone while the control treatments were tested for difference between EM zones.

Statistical analysis

The vineyard block was divided into four zones based on the soil profile analysis of particle size analysis and depth to B horizon. Zones were determined by k-means standardised clustering (SAS 2002) and are shown in Figure 6 along with the zonal summary statistics. Treatment effects on vine, grape and soil parameters were analysed using an unbalanced general ANOVA (Genstat 2008) using each measurement within each zone as replicates. The 2009 vintage experiment was analysed using a general ANOVA (Genstat 2008).



	% Clay 0-10 cm	% Clay 15-25 cm	% Clay 35-45 cm	Depth to B cm
Soil 1	7.2	10.1	25.2	35.5
Soil 2	13.7	24.6	35.7	30.2
Soil 3	18.6	32.8	41.6	26.4
Soil 4	22.9	41.2	45.1	21.3

Figure 6: Resultant zones after clustering profile soil texture and depth to B horizon using standardised k-means clustering. Included is the mean % clay content of each zone and the mean depth to the B horizon.

Results and Discussion

Full soil profile modification

Each growing season experienced different weather conditions (Table 3). The 2008 and 2009 vintages were marked by unusually dry conditions between veraison and harvest while the 2007 vintage received good rainfall. During the course of the experimental period conditions leading up to bud burst became increasingly wetter while the period to leaf fall became increasingly drier. Temperature conditions for each phenological period and vintage year were generally within 1 ^{o}C. Periods that were contrary to this were a near 4 ^{o}C drop in average maximum temperature experience between flowering and veraison during the 2009 vintage and a near 3 ^{o}C drop in average maximum temperature experience between veraison and harvest during the 2008 vintage. Evapotranspiration was also close to 8% lower during the 2009 vintage.

Table 3: Climate indices for each phenological interval and vintage year. Weather is derived from SILO patch point data station 23773 (Nuriootpa viticulture). Values highlighted in red and blue are 5% hotter or colder and 10% lower and higher than the period average, respectively.

	Av. T_{max} (^{o}C)			Av. T_{min} (^{o}C)			Rain (mm)			Irrigation (mm)			ET_0 (mm)		
	07	08	09	07	08	09	07	08	09	07	08	09	07	08	09
LF-BB	14.5	14.2	13.3	**3.3**	**4.4**	**4.6**	**79**	**101**	**164**	0	0	0	134	134	116
BB-F	22.1	22.1	21.9	**7.1**	**8.7**	7.8	**44**	**76**	55	0	0	0	313	307	303
F-V	29.8	29.7	**25.8**	13.4	13.2	**11.7**	**28**	**32**	**90**	37	18	6	378	380	**307**
V-H	30.3	**28.0**	**32.2**	15.2	**14.0**	15.1	**59**	**4**	**3**	24	24	40	239	235	**278**
H-LF	22.5	22.9	21.3	**10.8**	9.5	9.6	**182**	**121**	**104**	9	6	21	268	286	249
Total							392	**334**	416	70	48	67	1332	1341	1252

Vine, yield and berry quality parameters

The action of ripping the entire mid-row soil profile had a pronounced effect on vine performance in the initial year after ripping (Table 4). However, these effects disappeared by the third year. Yield was reduced by 60% in the first year due to ripping (Figure 7). The reduction in yield can be mainly attributed to a drop in the number of bunches and berries per bunch (data not shown). Whilst berry weight was not significantly affected by ripping at harvest (P=0.05) Figure 8 suggests that ripping reduced berry weight during early berry development and these differences diminished closer to harvest.

Table 4: Summary of main effects on vine and grape properties over three vintages as related to ripping (with and without) and traffic (with and without). Probability levels P>0.05, P≤ 0.05, P≤ 0.01, P≤ 0.001 are notated as o, x, xx, xxx, respectively. **xxx** and **xxx** represent an increase or decrease respectively of the applied treatment (ripping or traffic). NDVI refers to normalised difference vegetation index, TSS refers to total soluble solids, and TA refers to titratable acid.

Main Effect	Ripping			Traffic		
Variable	2007	2008	2009	2007	2008	2009
Yield	**xxx**	**xxx**	o	O	o	o
Berry weight	o	o	o	O	o	o
No. of Bunches	**xxx**	**xx**	**xx**	O	o	o
Pruning weight	**xxx**	-	-	O	-	-
NDVI	**xxx**	**xxx**	o	O	o	o
TSS	**xxx**	**xx**	o	O	**xxx**	o
pH	**x**	o	o	**Xxx**	o	o
TA	o	o	o	**Xxx**	o	o
Anthocyanins	o	**x**	o	O	**x**	o
Phenolics	o	o	o	O	**x**	o
Tannin	o	o	o	O	o	o

'-' data not available

Like yield, pruning weights and NDVI were significantly reduced in the first two years after ripping. Shoot growth rates, measured between flowering and veraison during the 2008 vintage, showed that the TNR treatment had a significantly higher growth rate than the NTR treatment (P=0.034). By the third year, however, no difference was observed between ripping treatments apart from a significant reduction in the number of bunches per vine. Canopy porosity measurements, which were taken at veraison during the 2009 vintage season, showed no significant difference between ripping treatments (P=0.111).

The impact of ripping on canopy size and fruit load also had an impact on fruit maturity although these impacts differed between years. Total soluble solids of berries of the ripped treatment was reduced in the first year after ripping (Figure 8) but in the second year showed an increase in soluble solids accumulation in the berries during berry development. Whilst this might suggest an improvement in maintaining vine photosynthetic function this response was not observed in the third vintage and thus it is difficult to draw a conclusion. Further it is also difficult to draw a conclusion for the significantly lower pH and higher anthocyanins due to ripping due to the inconsistent response between years.

Whilst the intent of ripping the mid-row was to improve root access to the mid-row, initial observations of the vineyard prior to ripping showed that root growth already extended into the mid-row. Hence, ripping of the mid-row severed roots that were accessing stored soil moisture and nutrients in the mid-row. Hence, the reduction of vine performance can be attributed to the value of roots being able to access the mid-row. Although this was not the original intent of the experiment it does highlight the value of root systems that extend into the mid-row.

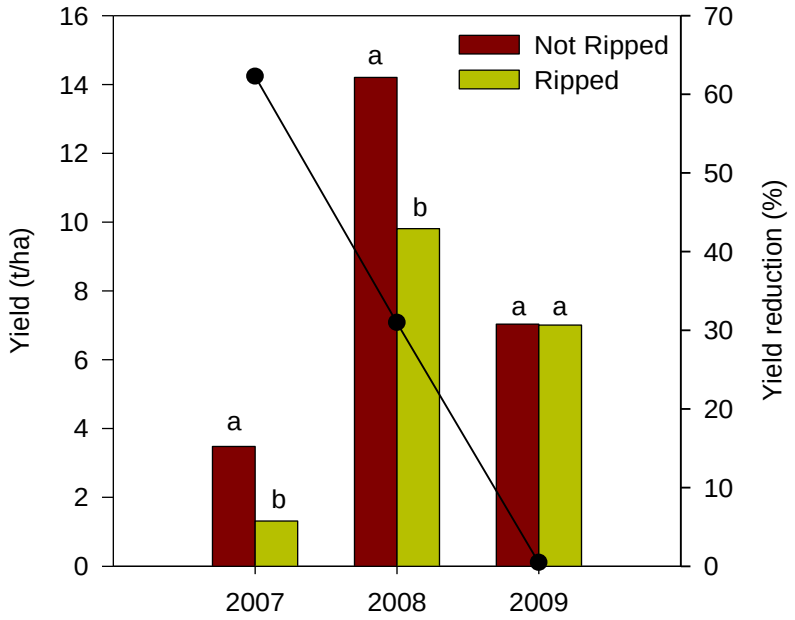


Figure 7: Variation in yield due to ripping over three seasons. Bars followed by the same letter within the same vintage year are not significantly different (P=0.05)

In contrast to the ripping treatments the removal of heavy traffic from the vineyard had no consistent effect on vine performance (Table 4). It was expected that the use of heavy machinery on the ripped treatment would have a pronounced effect on root growth establishment and vine recovery compared to traffic on the non-ripped treatments. However, there was no difference, or interaction, between trafficking ripped and non-ripped treatments on vine yield parameters. This indicates that natural slumping could have occurred during the winter and spring period prior to the first season to an extent that any further traffic did not cause any further densification of the soil profile. Canopy porosity measurements however, which were taken at veraison during the 2009 vintage season, showed a significantly greater porosity in the trafficked treatments (P<0.001) compared to the non-trafficked. However, this was not supported by the NDVI measurements. This conflict could be due to the nature of the measurement whereby NDVI measurements are derived from images captured vertically while

the canopy porosity measurements are captured horizontally. Further, some berry quality parameters showed significant effects due to traffic. These effects however were not consistent from year to year. Traffic increased pH and decreased TA significantly in the first year only while TSS, anthocyanins and phenolics were decreased in the second year only.

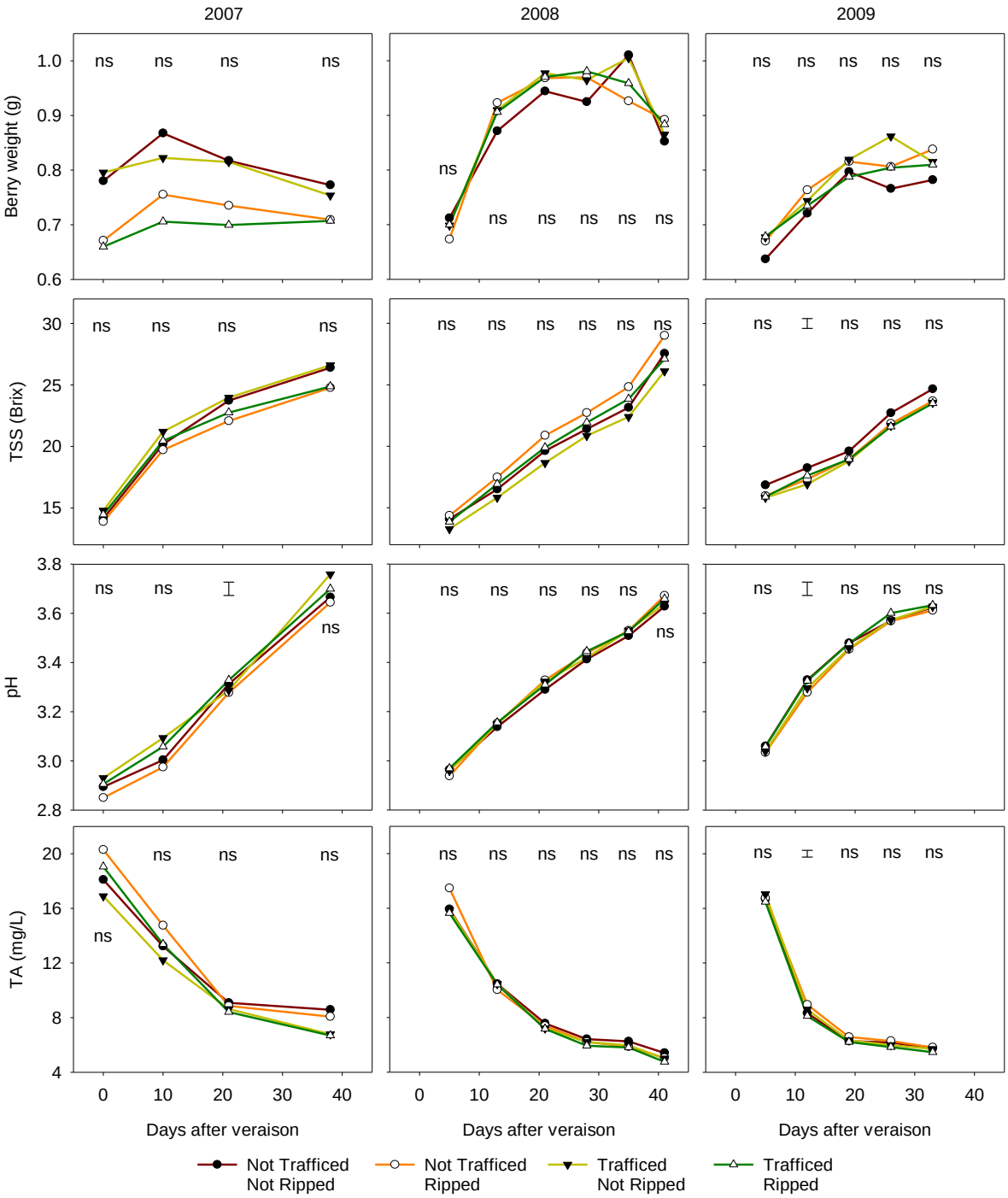


Figure 8: The effect of ripping and traffic on berry development over three vintages. LSD's for comparison of individual treatments are included (P=0.05) when significant, otherwise they are notated with 'ns'.

Vine nutrition

In general, most vine nutrient concentrations fell in the adequate range according to Robinson *et al* (1997) with some minor nutrients tending to develop marginal or deficient levels (Table 5). Chloride and sodium levels indicated no salt problems (< 1.5% and < 0.5%, respectively) (Robinson *et al* 1997). The high level of Cu could be associated with contamination from foliar sprays. For instance, according to Robinson et al (1997) petiole Cu values above 15 mg/kg are considered contaminated by foliar sprays and should not be considered for nutritional assessment purposes. Whilst copper was significantly affected by traffic, this effect most likely reflects the different processes employed during spray application, that being normal spray application on trafficked rows versus hand spray application on non-trafficked rows. This effect may also be applicable to S since sprays that contained S were used throughout this experiment. Other fungicide spray applications included Legend®, Dithane® and Flint®.

Vine nutrition was expected to be affected by traffic and ripping via their effects on root access to the mid-row and changes in nutrient leaching due to changes in soil physical properties. Of all the measurements made in this experiment, vine nutrition seemed the most affected by the imposed treatments (Table 5). One consideration that may affect the interpretation of these results is the impact of the clonal trial on which the experiments were implemented. Although the experimental setup was tested for any significant impacts using historical data from the clonal trial these tests were limited to yield and basic grape quality parameters. Arguably, vine nutrition may have provided a better insight into the effect of the clonal trial on the given experimental setup whereby the historical nutritional levels could have been used as a covariate with any statistical analysis of treatment effects. This should be kept in mind when interpreting these results particularly when little differences were found in soil chemistry (Table 6), although this is not an exhaustive list of soil nutritional properties and are more related to the potential for soil physical changes.

Petiole nutrient levels were most affected by sampling time (phenological stage) (Table 5). This was expected given that vine nutrients are transported to different plant organs depending on the phenological stage of the vine (Porro *et al* 1995; Schreiner *et al,* 2006). Some nutrients however accumulate while others are more dynamic. This is demonstrated in Figure 9 where chloride continued to accumulate in the petiole tissue while nitrate nitrogen dropped considerably during the ripening phase of berry development. The effect of phenological stage on vine nutrition was consistent between experiments (see Figure 17 in section *Relative impacts of ripping and surface mulch*).

Table 5: Summary of main effects on petiole nutrient status as related to traffic, ripping and phenological stage. Probability levels P>0.05, P≤ 0.05, P≤ 0.01, P≤ 0.001 are notated as o, x, xx, xxx, respectively. Nutritional values are assessed against guidelines defined by Robinson et al (1997). Where nutritional guidelines only report an adequate range the nutritional level is reported high or marginal if it is above or below the adequate range, respectively. **xxx** and **xxx** represent an increase or decrease respectively of the applied treatment (ripping or traffic) when significant at P<0.05.

		Ripping		Traffic		Phenology		Grand Mean#	
Nutrient		2008	2009	2008	2009	2008	2009	2008	2009
NO_3–N	(mg/kg)	o	o	**xxx**	o	xxx	xxx	968	967
P	(%)	**xxx**	**x**	**xxx**	o	xxx	xxx	0.33	0.15
K	(%)	**xx**	**xxx**	o	o	xxx	xxx	2.45	3.64
Ca	(%)	**xxx**	o	o	o	xxx	xxx	1.25	1.26
Mg	(%)	**xxx**	o	o	**x**	xxx	xxx	0.44	0.53
Na	(%)	o	**xx**	o	o	xxx	xxx	0.30	0.32
Cl	(%)	**xx**	o	o	**x**	xxx	xxx	0.82	0.90
Zn	(mg/kg)	o	o	**x**	**xx**	xxx	xxx	18.2	19.7
Mn	(mg/kg)	o	o	o	**xxx**	xxx	xx	14.4	26.0
Fe	(mg/kg)	**xx**	o	o	o	xxx	o	40.0	20.2
Cu	(mg/kg)	o	o	**xxx**	**xxx**	xxx	xxx	57.7	26.0
B	(mg/kg)	o	o	o	o	xxx	o	29.5	56.0
S	(%)	o	**x**	**x**	**x**	xxx	xxx	0.17	0.13

high/toxic adequate marginal deficient

grand mean at flowering

Of the macro nutrients, only petiole nitrate nitrogen (NO_3-N) was not affected by ripping. Petiole phosphorus (P) and magnesium (Mg) were decreased and potassium (K) and calcium (Ca) where increased as a result of ripping. P and K were the only two elements to show consistent directional response in both 2008 and 2009 vintages. In contrast, sodium and chloride showed alternate responses to ripping in different vintage years. It is difficult to explain these responses in vine nutrition to the ripping treatment particularly when petiole sodium and potassium responses do not reflect the relative changes in soil chemistry between the vine row and mid-row (data not shown). Further, elevated petiole K has been associated with an increase in juice pH (Ruhl 1989). This association was not found in this experiment where a significant decrease in juice pH was observed in the 2007 vintage (Figure 8).

It could be argued, however, that the petiole P response reflects the vines access to soil P. Removing root access to the mid-row by ripping can reduce the root systems capacity to access available P in the soil. Further, the higher soil carbon in the mid-row (data not shown) may also give rise to root mycorrhizal infection (Hršelová *et al,* 1999), known to increase P uptake in plants (Smith *et al,* 2004), as a result of improved soil health. However, mycorrhizal infection has also been shown to enhance zinc (Zn) uptake (eg. Possingham and Groot Obbink, 1971), which was not observed.

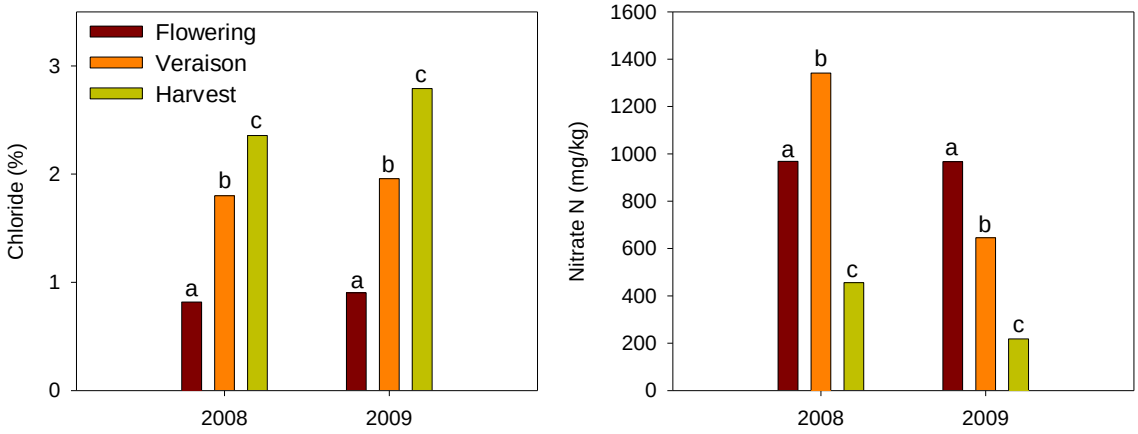


Figure 9: Variation in petiole Chloride and Nitrate Nitrogen levels as a function of phenological stage. Bars followed by the same letter within the same vintage year are not significantly different (P=0.05)

The effect of traffic on petiole nutrient levels was somewhat different to that of ripping. Of the macro nutrients, traffic was associated with a NO_3-N increase and a P decrease in the 2008 vintage and a Mg decrease in the 2009 vintage. Of the minor elements, Zinc (Zn) and Manganese (Mn) were increased as a result of traffic but only Zn increased in both 2008 and 2009 vintages. Whether these results reflect a change in available nutrients in the soil remains unclear, particularly if the effects are not consistent from year to year.

Soil properties

The soil samples taken at the conclusion of the experiment represent the treatment effect on a set of standard soil properties over a three year period. As shown in Table 6, the location and depth at which the soil samples were taken had a significant effect on the measured soil property. Soil carbon was highest in the mid-row which reflects the organic input from the use of winter cover crops whilst the vine row had the lowest soil carbon. The application of irrigation water had a significant impact on the exchangeable cation balance (Figure 10) with the vine row having a significant increase in the exchangeable sodium percentage. The electrical conductivity (EC) in the vine row also increased with depth compared to other sampling locations (Figure 11). Calculation of the electrochemical stability index (ESI) (Hulugalle and Finlay, 2003) shows that whilst the surface soil in the vine row is not as sodic as the deeper soil layers it is less stable due to lower EC (Figure 11) leading to poor soil structure.

The application of traffic had little effect on the measured soil properties (Table 6). Further, both electromagnetic induction (EM) and penetration resistance (PR) were not significantly different

(P=0.565 and P=0.990, respectively) (data not shown). Surprisingly, total nitrogen was significantly increased due to traffic (Table 6). Soil compaction, often as a result of traffic, has been shown to be associated with a reduction in net nitrogen balance in the soil (De Neve and Hofman 2000). Given that the experimental setup used a restricted randomized deign, it is probable that the higher total nitrogen percentage was a result of spatial variation rather than the applied treatment. Without soil data prior to treatment establishment it is not possible to correct for spatial variation in soil properties.

Table 6: Summary of main effects on soil chemical properties due to traffic, ripping, location (vine row, wheel track or mid-row) and soil depth (0-10, 10-20, 30-40 and 50-60 cm). Probability levels P>0.05, P≤ 0.05, P≤ 0.01, P≤0.001 are notated as o, x, xx, xxx, respectively. **xxx** and **xxx** represent an increase or decrease respectively of the applied treatment (ripping or traffic) when significant at P=0.05.

Property		Ripping	Traffic	Location	Depth	Grand Mean
Total C	(%)	**xx**	o	xxx	-	1.10
Total N	(%)	**x**	**x**	o	-	0.10
C:N ratio		**xx**	**x**	o	-	12.3
pH_{CaCl2}		o	o	xxx	xxx	6.53
$EC_{1:5}$	(dS/m)	o	o	xxx	xxx	0.15
Cl	(mg/kg)	o	o	xxx	xxx	94.8
exch. Ca	(%)	**x**	o	xxx	xxx	62.5
exch. Mg	(%)	o	o	xxx	xxx	22.9
exch. K	(%)	**xx**	o	xxx	xxx	9.0
exch. Na	(%)	o	o	xxx	xxx	5.6

'-' 0 – 10 cm soil samples taken only

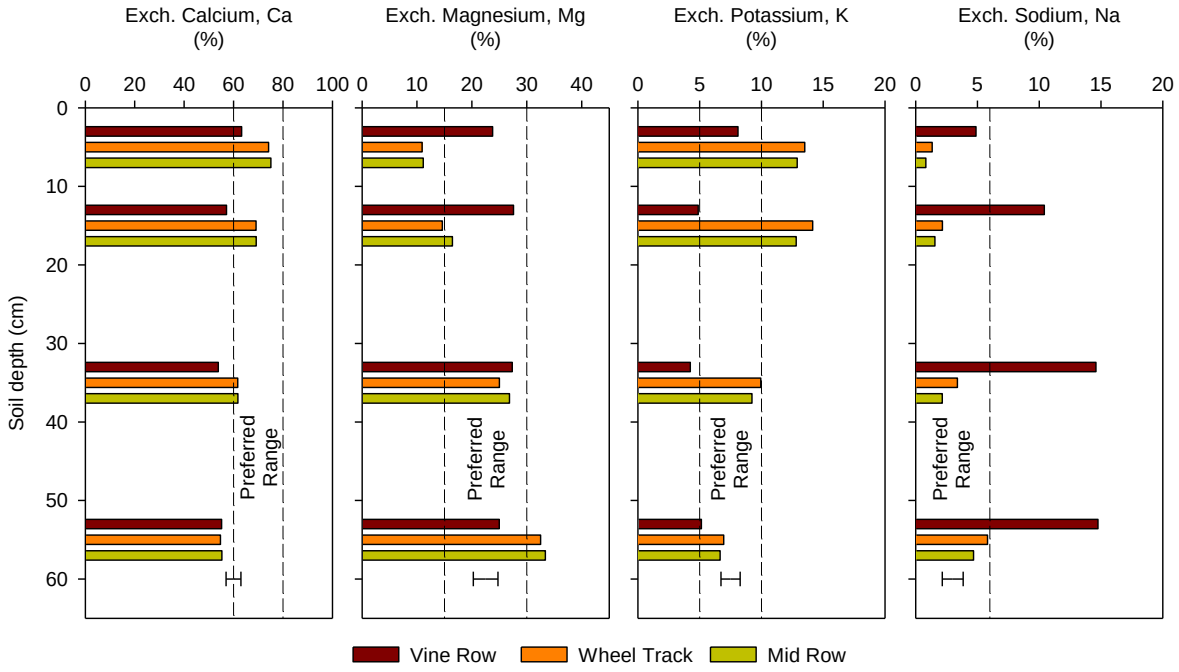


Figure 10: Variation in exchangeable cation percentage as a function of soil depth and sampling location. LSD's are included for each cation at P=0.05

The effect of ripping of the entire mid-row area on reducing soil strength was still evident after three vintages. Penetrometer readings of the ripped treatments were significantly lower (P = 0.002) than the non-ripped treatments. The significantly higher soil carbon (Table 6), which is particularly higher in the mid-row, (data not shown), could have contributed to the maintenance of low soil strength (Cockroft and Olsson, 2000). The higher soil carbon of the mid row can be attributed to the amount of biomass produced from the winter cover crop. The ripped treatment showed a pronounced increase in the amount of biomass created compared to the non-ripped treatment (Plate 4).

Despite the better soil physical conditions of the ripped treatments, and presumably better infiltration and leaching from winter rainfall, EC and chloride (Cl) were not significantly affected (Table 6). Similarly to the EC results, there was no significant effect of ripping (P=0.408) on EM readings. However, there were significant changes in exchangeable cations associated with the ripping, notably a decrease in exchangeable calcium and an increase in exchangeable potassium. Whilst the ripping treatment also included the injection of Gypflo the addition of calcium would only result in a theoretical increase of 0.03% in exchangeable calcium, which can be considered negligible. As shown in Figure 12 the magnitude of the drop in exchangeable Ca as a result of ripping increased as a function of soil depth whereas the opposite is true for exchangeable K. It is difficult to attribute these responses to increase water penetration and movement or cations, hence, as before it is probable that these significant effects are a result of spatial variation rather than the applied treatment.

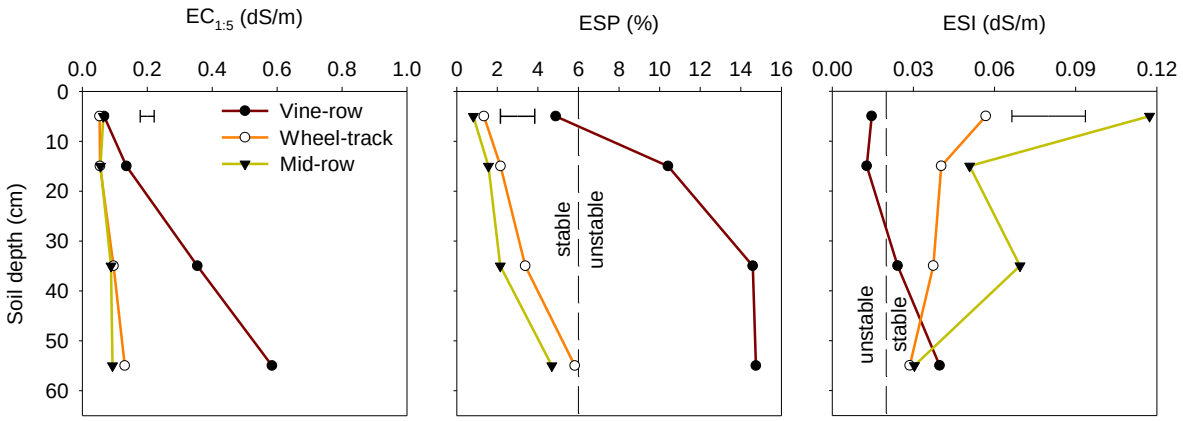


Figure 11: Variation in soil electrical conductivity ($EC_{1:5}$), exchangeable sodium percentage (ESP) and electrochemical stability index (ESI) as a function of soil depth and sampling location. LSD's are included at P=0.05.



Plate 4: Comparison of surface biomass on ripped and non-ripped plots after slashing of the winter cover crop.

Whilst the effect of traffic on vine performance and soil properties in this experiment appear to be negligible the effect of ripping on vine yield is pronounced. Similarly, berry quality and soil properties indicated some changes due to ripping. The interest now, however, lies in how the vines will perform beyond this experimental period. Although the vines have recovered from their initial root pruning the question is whether the vines will continue to improve and utilize the resources of the mid-row. If so, vines will have access to more stored water and nutrients in the growing season which may result in a reduced demand on irrigation water. Further, this experiment demonstrates the value of roots that have access to the mid-row and the time it takes the root system to recover from severe root pruning.

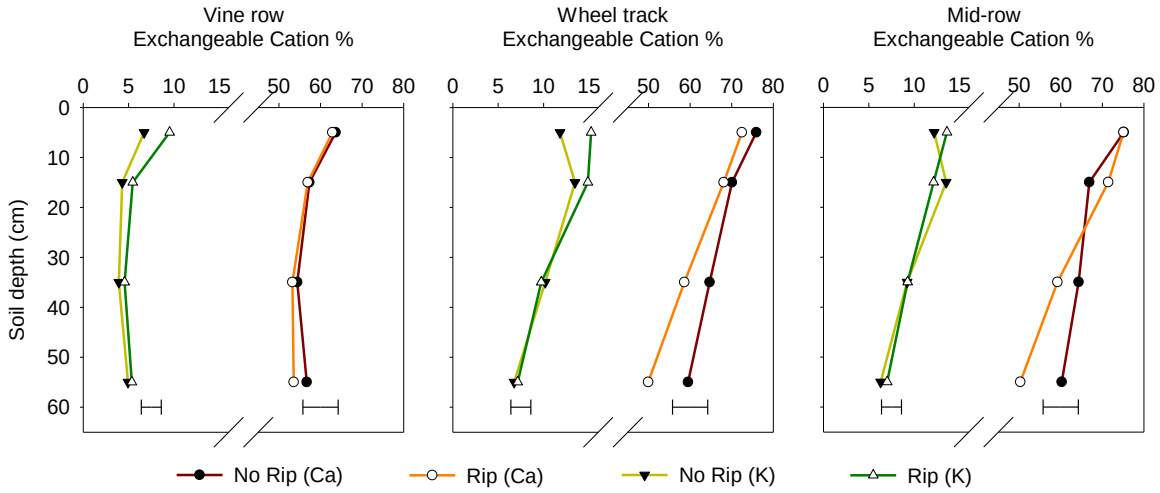


Figure 12: Variation in soil exchangeable cations %, calcium (Ca) and potassium (K), as a function of soil depth and sampling location. LSD's are included at P=0.05.

Relative impacts of ripping and surface mulch

Each growing season experienced different weather conditions (Table 7). The 2008 and 2009 vintages were marked by unusually dry conditions between veraison and harvest while the 2007 vintage received good rainfall. During the course of the experimental period conditions leading up to bud burst became increasingly wetter while the period to leaf fall became increasingly drier. Temperature conditions for each phenological period and vintage year were generally within 1 ^{o}C. Periods that were contrary to this were a near 4 ^{o}C drop in average maximum temperature experienced between flowering and veraison during the 2009 vintage and a near 3 ^{o}C drop in average maximum temperature experienced between veraison and harvest during the 2008 vintage. Evapotranspiration was similar in all seasons.

Table 7: Climate indices for each phenological interval and vintage year. Weather is derived from SILO patch point data from station 23729 (McLaren Vale). Values highlighted in red and blue are 5% hotter or colder and 10% lower and higher than the period average, respectively.

	Av. T_{max} (^{o}C)			Av. T_{min} (^{o}C)			Rain (mm)			Irrigation (mm)			ET_0 (mm)		
	07	08	09	07	08	09	07	08	09	07	08	09#	07	08	09
LF-BB	15.6	15.4	14.9	7.4	7.8	8.0	**87**	139	**160**	0	0	0	148	144	140
BB-F	21.3	21.5	21.7	10.2	11.1	10.9	**43**	**82**	**23**	28	29	29	288	281	288
F-V	27.8	27.6	**24.3**	15.1	15.1	14.1	**25**	36	**38**	94	69	69	358	354	**301**
V-H	28.2	**25.9**	**30.1**	17.2	15.2	17.2	**43**	**12**	**0**	58	72	72	226	223	**266**
H-LF	22.8	23.3	**21.3**	14.0	13.0	12.5	**163**	**96**	143	0	54	53	268	292	249
Total							361	366	364	180	225	224	1288	1294	1244

- total water applied was measured but assumed the same seasonal distribution as previous season

Yield and berry quality parameters

Unlike the previous experiment, ripping of the mid-row soil profile had little effect on vine yield and berry quality parameters in the first two vintages (Table 13). The yield in the third vintage was

significantly higher than the control (Figure 13) and was consistent for all soil profiles. Similarly, the application of surface mulch had little effect on vine yield and berry quality parameters in the first two vintages (Table 13) but the yield was significantly higher in the third vintage (Figure 13). The increased yield from the ripping and mulch treatments was mainly due to an increase in the number of berries per bunch (data not shown). In addition, vine porosity measurements were taken during the 2009 vintage prior to vine trimming[2]. These results show a significant decrease in vine porosity (P=0.005) due to the application of mulch compare to the control were as ripping had no effect. Again, these observations were consistent across all soil types.

Table 8: Summary of main effects on vine and berry properties over three vintages compared to treatment (control vs mulch, control vs ripping) and soil (soil profiles 1-4). Probability levels P>0.05, P≤0.05, P≤0.01, P≤0.001 are notated as o, x, xx, xxx, respectively. **x** and **x** represent an increase or decrease of the vine and grape properties respectively due to the application of mulch or ripping compared to the control when significant at P=0.05. TSS refers to total soluble solids and TA refers to titratable acid.

Main Effect	Mulch			Ripping			Soil		
Variable	2007	2008	2009	2007	2008	2009	2007	2008	2009
Yield	o	o	**x**	o	o	**x**	xx	x	x
Berry weight	o	o	o	o	o	o	xxx	xxx	xxx
No. of Bunches	o	o	o	o	o	o	o	xx	o
TSS	o	o	o	o	o	o	x	o	xxx
pH	o	o	o	o	o	o	xxx	xxx	xx
TA	o	o	o	o	o	o	xxx	xxx	o
Anthocyanins	o	o	o	o	**x**	o	xxx	x	o
Phenolics	o	o	o	o	o	o	o	x	o
Tannin	o	o	o	o	o	o	o	o	x

The effect of ripping and surface mulch application on berry growth and development (Figure 14) shows the same results as the data taken at harvest. In nearly all cases, grape growth and development was not affected by the application of surface mulch or ripping of the mid-row. However, in the 2009 vintage both ripping and mulch treatments show a significant reduction in total soluble solids (TSS) concentration (Figure 14) during berry growth but not at harvest. Surprisingly, this was not accompanied with a significant increase in berry weight, often linked to lower TSS concentration (eg. Goodwin 2009). More likely the lower TSS concentration reflected the greater number of berries per bunch changing the balance between crop demand (sink) and vine size (source) (Coombe 1989).

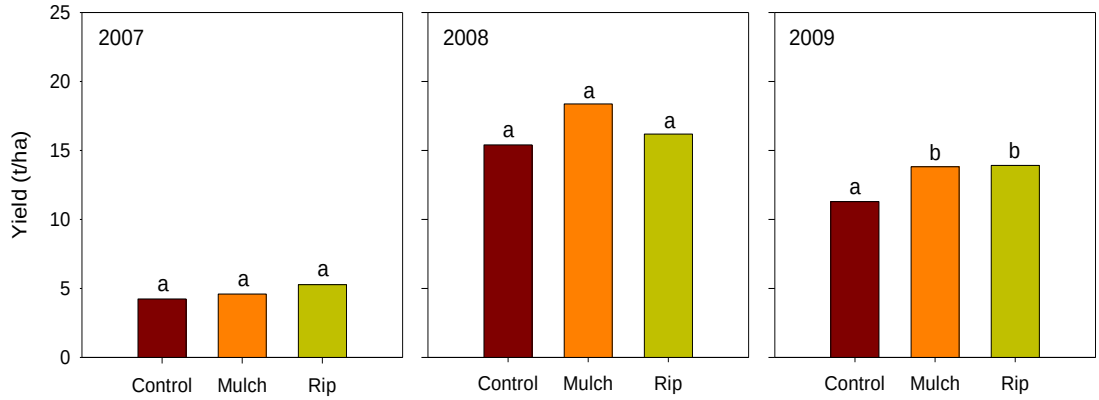


Figure 13: Variation in yield as a function of applied treatments over three vintages. Bars followed by the same letter within the same vintage year are not significantly different (P=0.05).

[2] Pruning weights were not recorded in this experiment as the vines were trimmed around veraison

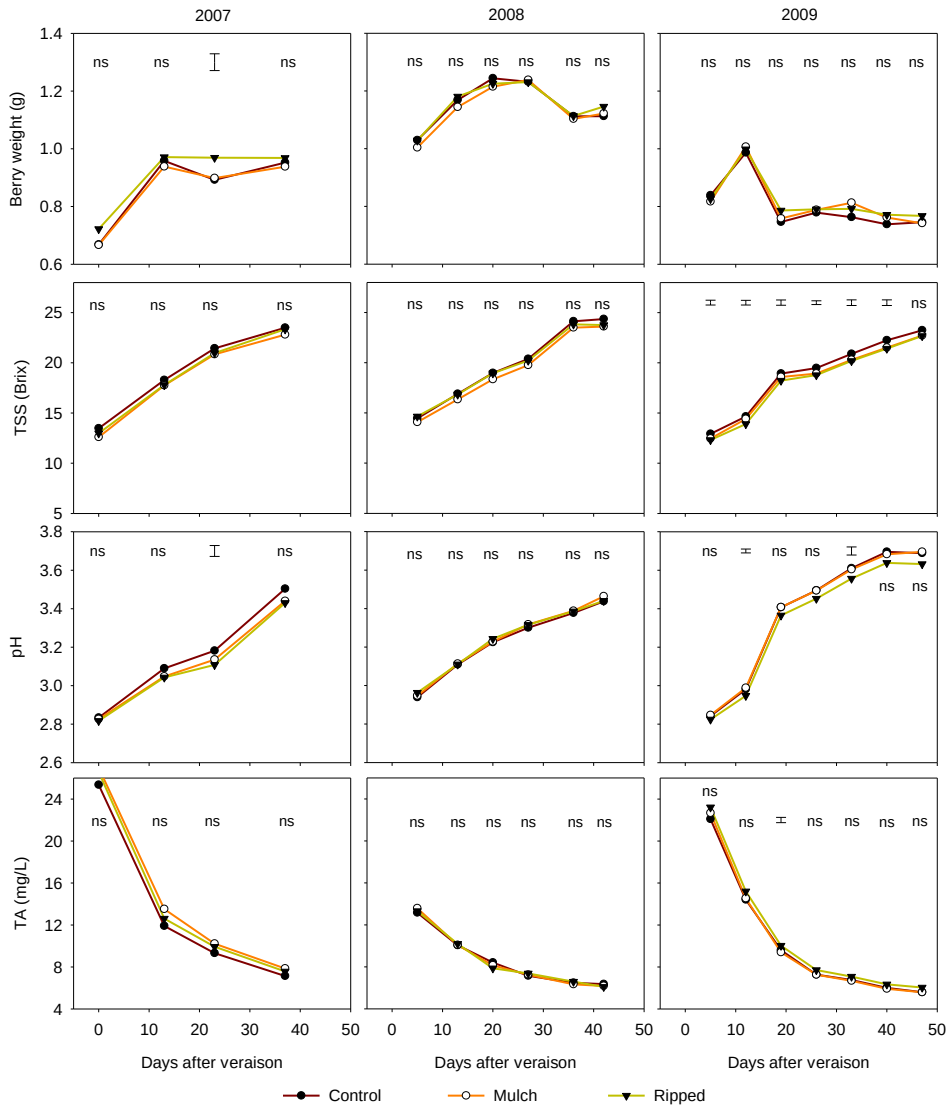


Figure 14: The effect of different treatments on berry development over three vintages. LSD's of treatments are included (P=0.05) when significant, otherwise they are notated with 'ns'.

The lack of yield and grape composition response to the application of ripping and mulch does reflect the general responses found by others (eg. Lanyon and Bramley 2004; Buckerfield and Webster 1999, 2002). Lanyon *et al* (2004) showed that ripping of the mid-row and the application of surface mulch had an immediate impact on vine growth and yield, although it was not the same for all soil types. On an experiment over two vintages they found that the application of mulch increased yields the most on the lightest soil. This was attributed to a confined root system and shallow sandy soils resulting in a low water holding capacity for water storage and use by the vine. In this experiment, however, the readily available water is much higher and the root system not restricted in the sandy soil profile. Lanyon and Bramley (2004) also found little vine response when mulch was applied to heavier soils and attributed this to potential aeration problems and the effect of a larger root system in the mid-row offsetting the potential soil water retention benefits of mulch application. In this experiment however, root access to the mid-row is minimal given that the ripping treatment did not adversely affect vine growth and yield. Hence, the gradual response of the vine to mulch is more likely to reflect a gradual change in soil properties along the vine row, particularly with respect to water infiltration and soil salinity.

Whilst ripping took three vintages to establish a significant increase in yield, presumably due to increased root access to stored soil moisture in the mid-row, the rate of response was slower than results reported by Lanyon and Bramley (2004). The ripping treatment was effective in removing the

compacted traffic lines as shown in Figure 4. However, for roots to grow through the ripped soil the soil conditions need to suit root growth, ie the soil still needs to be sufficiently moist. Arguably, the drier winter and spring conditions during the first two vintages did not adequately wet the mid-row resulting in a reduction in opportunity time for roots to grow into the ripped mid-row. Some evidence of increased root growth into the mid-row is presented (see section *Root distribution*).

Given the large variation in soil profile characteristics (see Figure 3) it is not surprising to see that soil profile affected yield and grape properties significantly (Table 8). However, these effects were not consistent from vintage to vintage. As shown in Figure 15 the distribution of yield as a function of soil profile indicates that the light deep soil profile (soil 4) had the highest yield for the 2007 and 2008 vintages. This changed for the 2009 vintage where soil 4 had the lowest yield despite each of the soil profiles receiving the same amount of irrigation water. This yield variation is reflected in the variation in berry weight (Figure 16) whereby soil 4 resulted in significantly higher berry weights for the 2007 and 2008 vintages. Whilst the berry weight of soil 4 continued to be higher initially in the 2009 vintage it failed to maintain this difference compared to the other soil profiles. Similarly, the comparison of berry TSS, pH and TA of soil 4 to other soil profiles shows a progressive inversion from the 2007 to 2009 vintages. For example, the rise in berry pH of soil 4 during development was consistently below the other soil profiles during the 2007 vintage. By the 2009 vintage this trend was reversed with the rise in berry pH of soil 4 during development consistently above the other soil profiles. There are two factors that could be the cause of this reversal. Firstly, this experiment was conducted during a drought that continued for the entire experimental period and water storage from rainfall was far less than normal. The larger fruit loads from soil 4 have been a result of greater readily available water (see Figure 3) which, presumably, was not able to be replenished adequately as a result of lower winter and spring rainfalls. This could have caused a progressive drawdown of vine reserves leading to a change in fruit and canopy balance. Secondly, the veraison date is taken from the block as a whole rather than from individual areas within a block. It was noted that the fruit from soil 4 was phenologically behind the other soil profiles during the 2007 vintage. By the 2009 vintage phenological differences between soil profiles were not evident. The inconsistent nature of the influence of soil characteristics on yield and grape properties makes the development of relationships problematic unless other drivers, such as climate variation, can help explain the vintage variations.

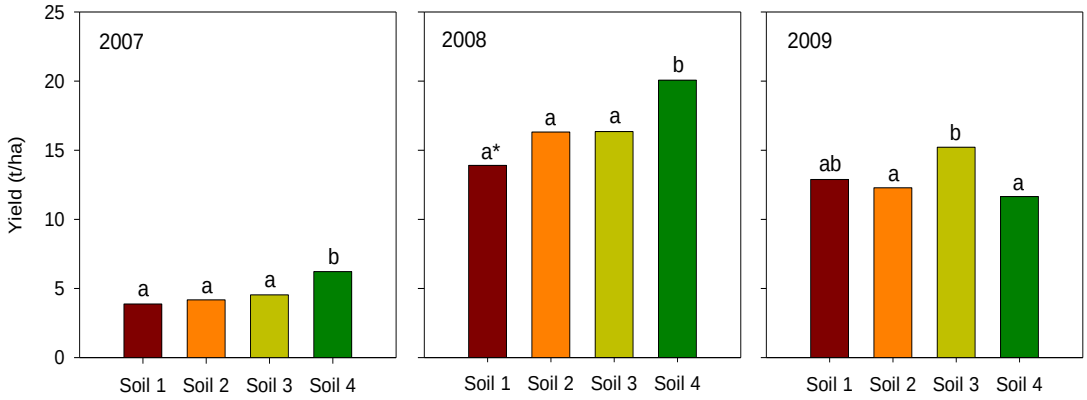


Figure 15: Variation in yield as a function of different soil profiles over three vintages. Bars followed by the same letter within the same vintage year are not significantly different (P=0.05). * denotes a different pruning method was used that year compared to other soil profile sites.

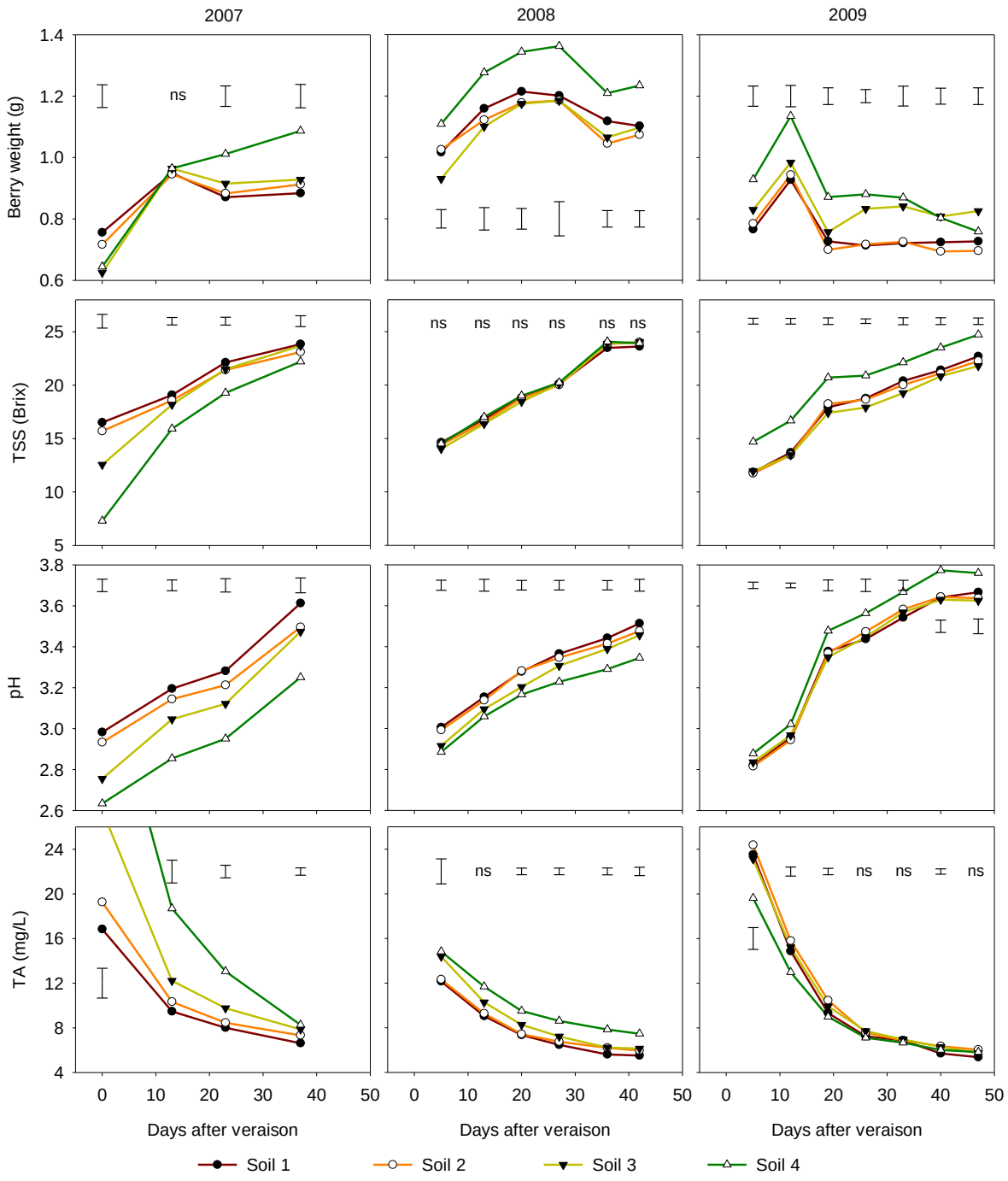


Figure 16: The effect of different soil profiles on berry development over three vintages. LSD's for treatments are included (P=0.05) when significant, otherwise they are notated with 'ns'.

Vine nutrition

In general, most vine nutrient properties fell in the adequate range according to Robinson et al (1997) with some minor nutrient properties tending to develop marginal or deficient levels (Table 9). Chloride and sodium levels indicate no salt problems (< 1.5% and < 0.5%, respectively) (Robinson et al 1997). The high level of Cu could be associated with contamination from foliar sprays. According to Robinson et al (1997) petiole Cu values above 15 mg/kg are considered contaminated by foliar sprays and should not be considered for nutritional assessment purposes.

Petiole nutrient levels were most affected by sampling time (phenological stage) and between soil profiles (Soil) (Table 9). The effect of sampling time on petiole nutrition was expected given that vine

nutrients are transported to different plant organs depending on the phonological stage of the vine (Porro *et al* 1995; Schreiner *et al,* 2006). Some nutrients however accumulate while others are more dynamic. This is demonstrated in Figure 17 where chloride continues to accumulate in the petiole tissue while nitrate nitrogen drops considerably during the ripening phase of berry growth and development. The effect of phenological stage on vine nutrition was consistent between experiments (see Figure 9 in section *Full soil profile modification*). The effect of different soil profiles on petiole nutrition was also expected given the differences in nutrient availability associated with different soil textures, as notionally indicated in Table 10.

Table 9: Summary of main effects on petiole nutrient status over two vintages as related to soil (soil profiles 1-4), treatment (control vs mulch, control vs ripping) and phenological stage (flowering, veraison and harvest). Probability levels P>0.05, P≤ 0.05, P≤ 0.01, P≤ 0.001 are notated as o, x, xx, xxx, respectively. Nutritional values are assessed against guidelines defined by Robinson et al (1997). Where nutritional guidelines only report an adequate range the nutritional level is reported high or marginal if it is above or below the adequate range, respectively. **x** and **x** represent an increase or decrease of the nutrient respectively due to the application of mulch or ripping compared to the control when significant at P=0.05.

		Soil		Mulch		Ripping		Phenology		Grand Mean#	
Nutrient		2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
NO_3–N	(mg/kg)	o	xxx	o	x	o	o	xxx	xxx	507	322
P	(%)	xxx	xxx	x	o	x	x	xxx	o	0.62	0.46
K	(%)	xxx	xxx	x	x	x	o	xxx	xxx	3.92	4.19
Ca	(%)	xxx	xxx	o	x	o	o	xxx	xxx	1.62	1.95
Mg	(%)	xxx	xxx	x	x	o	x	xxx	xxx	0.26	0.28
Na	(%)	xxx	xxx	x	o	x	o	xxx	xxx	0.18	0.06
Cl	(%)	xxx	xxx	o	o	x	o	xxx	xxx	0.87	0.61
Zn	(mg/kg)	xxx	xxx	x	x	x	o	xxx	xxx	32.5	42.9
Mn	(mg/kg)	xxx	xxx	o	x	o	x	xxx	xxx	18.5	33.0
Fe	(mg/kg)	o	xxx	o	o	o	x	o	xxx	40.6	24.7
Cu	(mg/kg)	xxx	xxx	o	x	x	x	xxx	xxx	40.4	10.1
B	(mg/kg)	xxx	xxx	o	o	x	x	xxx	xxx	31.8	45.4
S	(%)	xxx	xxx	x	o	x	o	xxx	xxx	0.12	0.14

High adequate marginal deficient

grand mean at flowering

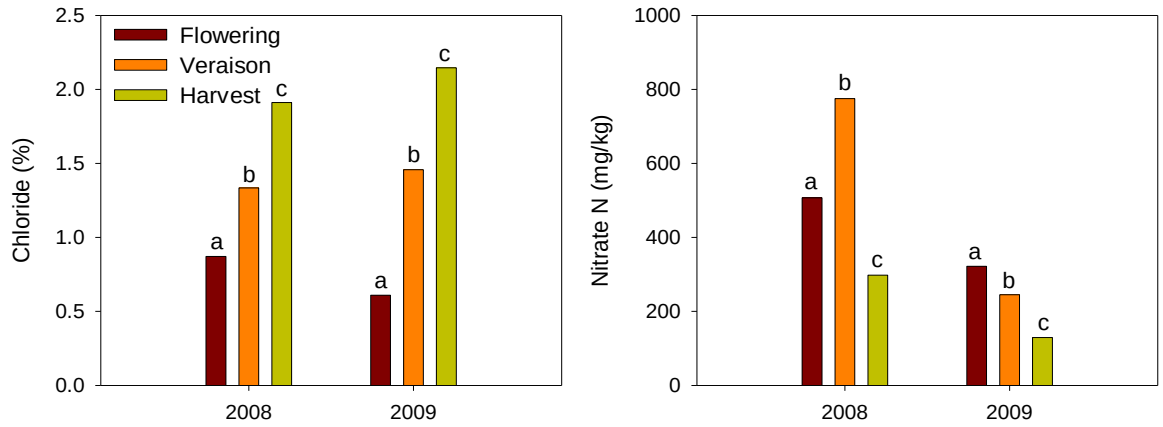


Figure 17: Variation in petiole Chloride and Nitrate Nitrogen levels as a function of phenological stage over two vintages. Bars followed by the same letter within the same vintage year are not significantly different (P=0.05).

All macro and micro nutrients were significantly affected by either ripping or mulch during the experimental period. It is difficult to explain the cause of many of the petiole nutritional responses, particularly the inconsistent effects between seasons; however there are some nutrients that display a consistent response to the applied treatments. For example, ripping consistently increased petiole phosphorus (P). Whilst this is a different observation than the previous experiment where petiole phosphorus levels decreased with ripping, the two experimental conditions are considerably different. The previous experiment (Nuriootpa) had considerable root growth into the mid-row while the McLaren Vale site reported here was lacking root growth into the mid-row. Ripping of the mid-row removed roots from the mid-row in the previous experiment reducing petiole P whilst ripping in this experiment could enhance root exploration in the mid-row increasing petiole P. Additional soil P data of the vine row and mid-row area would be needed to help confirm this link. Another petiole nutritional element that responded consistently to ripping was boron (B). Initial soil surveys of the vineyard site suggested high B levels in the subsoil and attempts were made to avoid these areas during experimental establishment. The suggestion was that ripping could cause the mixing of the subsoil with the surface soil resulting in a potential boron problem. However, these results indicate that ripping decreased the level of boron uptake by the vine. Without any significant mixing of soil layers a possible cause for this response could be that the vines were less reliant on water extraction from the subsoil due to an increase water extraction from the mid-row from new root growth after ripping. However, it would be expected that a greater yield response would also accompany better utilization of the mid-row resources which was not observed (Table 8).

The effect of mulch on petiole nutrition showed a consistent increase in potassium (K) and a decrease in magnesium (Mg) across all vintages (Figure 18). The increase in petiole K was greatest in the first vintage after mulch application and was also greatest on the lightest soil profile (Soil 4 – data not shown). Whilst the level of K in the forest mulch (Table 1) is not high compared to the composted grape marc (Table 2) K is the dominate cation. The petiole K observations are also reflected in the soil exchangeable K values for each soil profile (Figure 20), particularly in the surface soil under the applied mulch (data not shown). This response is also observed for zinc (Zn) whereby the relatively high Zn levels in the forest mulch (Table 1) reflect the petiole Zn response in Table 9.

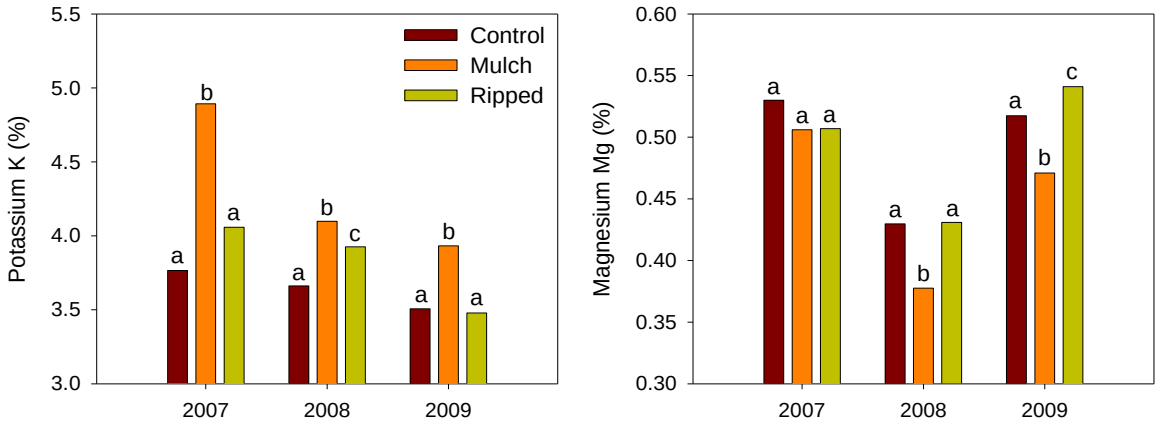


Figure 18: Variation in petiole Potassium (%) and Magnesium (%) levels as a function of applied soil treatment over three vintages. Bars followed by the same letter within the same vintage year are not significantly different (P=0.05).

Soil properties

The location (vine row or wheel track), soil profile (Soils 1 - 4) and soil depth all had a significant effect on the standard soil properties measured at the conclusion of the experiment (Table 10). Soil carbon was highest in the wheel track which reflects the organic input from the use of winter cover crops whilst the vine row had the lowest soil carbon. The application of irrigation water had a significant impact on the exchangeable cation balance (Figure 19) with the vine row having a significant increase in the exchangeable sodium percentage. The electrical conductivity (EC) in the vine row also increased with depth compared to other sampling locations (Figure 19) and was moderately saline for wine grape production (Cass *et al*. 1995). Calculation of the electrochemical stability index (ESI) (Hulugalle and Finlay, 2003) suggested that whilst the vine row soil profile is sodic and susceptible to soil structural problems the high EC values aid in maintaining soil structural stability (Figure 19).

These samples, however, were taken after a full year of irrigation and would not reflect the soil salinity conditions experience during dormancy after significant rainfall leaching.

Table 10: Summary of main effects on soil chemical properties as related to soil (soil profiles 1-4), treatment (control vs mulch, control vs ripping), location (vine row or wheel track) and soil depth (0-10, 10-20, 30-40 and 50-60 cm). Probability levels P>0.05, P≤ 0.05, P≤ 0.01, P≤ 0.001 are notated as o, x, xx, xxx, respectively. **x** and **x** represent an increase or decrease of the property respectively due to the application of mulch or ripping compared to the control when significant at P=0.05.

Property		Soil	Mulch	Ripping	Location	Depth	Grand Mean
Total C	(%)	xxx	**x**	**x**	x	-	1.69
Total N	(%)	xxx	**x**	o	o	-	0.12
C:N ratio		xxx	**x**	**x**	x	-	14.2
pH_{CaCl2}		xxx	o	o	x	x	7.62
$EC_{1:5}$	(dS/m)	xxx	o	o	xxx	xxx	0.40
Cl	(mg/kg)	xxx	o	o	xxx	xxx	253
exch. Ca	(%)	o	o	o	xxx	xx	75.6
exch. Mg	(%)	xxx	o	o	o	xxx	13.4
exch. K	(%)	xxx	**x**	o	o	xxx	4.7
exch. Na	(%)	xxx	o	o	xxx	xxx	6.3

'-' 0 – 10 cm soil samples taken only

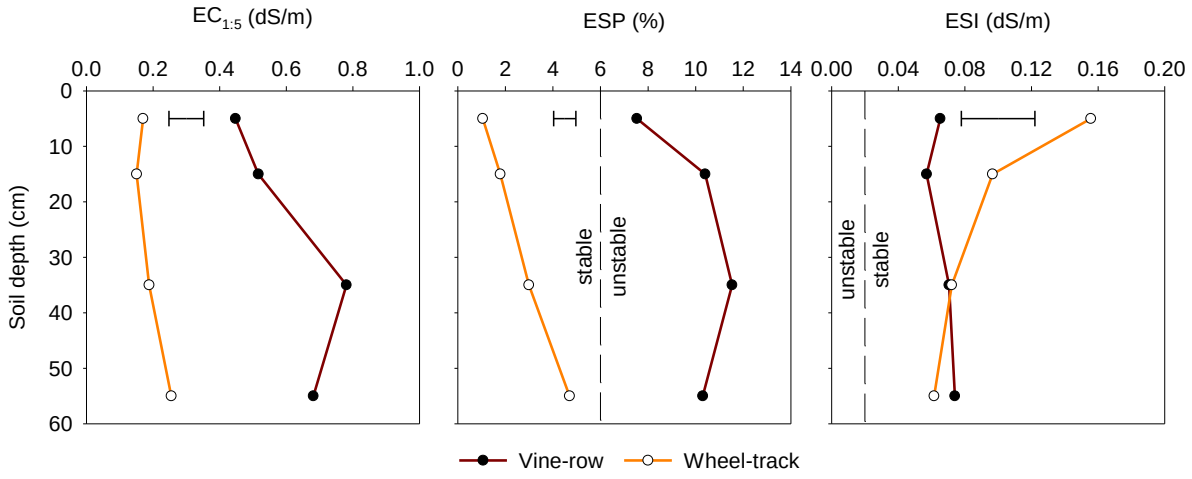


Figure 19: Variation in electrical conductivity ($EC_{1:5}$), exchangeable sodium percentage (ESP) and electrochemical stability index (ESI) as a function of sampling location (vine row and wheel track and soil depth. LSD's at P=0.05 is also shown

Few measured soil properties were affected by the application of mulch and ripping treatments (Table 10). Compared to the control, total carbon and nitrogen were significantly increased with the application of mulch but were significant decreased by ripping (P<0.001). Whilst there was a significant difference in the penetrometer resistance for each soil type (P<0.001) there was no effect of the applied treatments (P=0.449). Penetration resistance decreased as the soil became lighter which is caused by the variation in soil adhesion due to soil texture. The same outcome was also observed for EM measurements, ie no effect of treatments but significant differences between soil profiles.

Despite the expectation that the application of mulch would increase the leaching effectiveness of rainfall and applied water through a reduction of soil water evaporation, the use of mulch had no significant effect on soil salinity. However, was the exchangeable cation balance in the soil was affected. As mentioned previously, exchangeable potassium (K) was significantly increased due to the

application of the mulch with the largest increase occurring on the lightest soil (Soil 4) (Figure 20). To a lesser extent this was reflected in the petiole analysis.

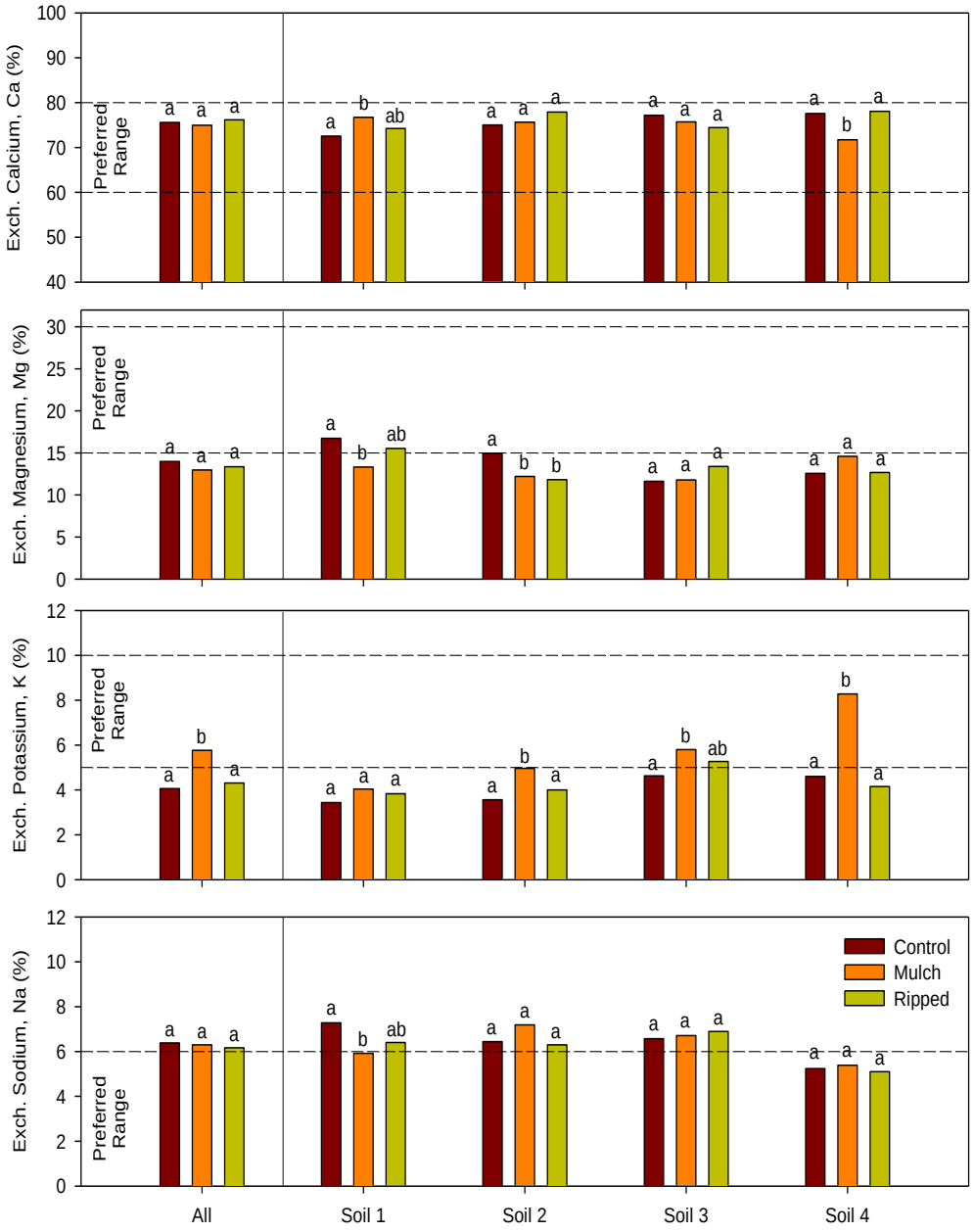


Figure 20: Variation in exchangeable cations (Ca, Mg, K and Na) as a function of soil profile (Soils 1-4) and applied soil treatment (control, mulch and ripped). Main effect of applied soil treatment (All) is also shown. Bars followed by the same letter within the same soil profile are not significantly different (P=0.05).

Root distribution

Given the large time commitment required to quantify root distribution, only one soil profile (Soil 3) was selected to assess if there was any observable change in root distribution as a result of ripping of the mid-row. Following the procedure of van Huyssteen (1988), roots of different size classes were counted within a 100 mm square grid on an exposed soil face one metre deep traversing from vine row to vine row (Plate 5). Of these soil pits, however, one was disturbed presumably from the soil survey pits that were excavated prior to vineyard establishment and another was atypical to all other

soil profiles. Nevertheless, the results do indicated that there may have been more roots growing into the mid-row as a result of ripping compared to the control and mulch treatments, particularly at depth (Figure 21). It also indicated that there were roots growing into the mid-row. Whether they are vine roots remains unclear, particularly when cover crops are used. If vine roots are present in the mid-row their contribution to vine performance must be minimal given the lack of vine response to ripping in this experiment compared to the previous experiment.



Plate 5: Example cross-section of a soil profile between vine rows and the process of counting roots on the exposed soil face using a 100 x 100 mm mesh.

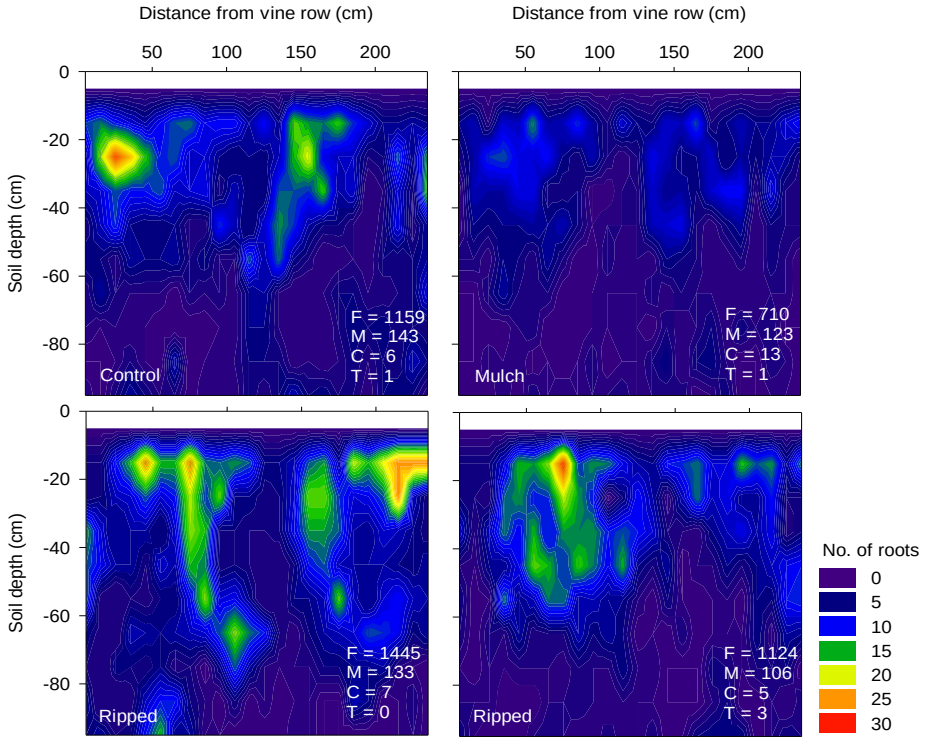


Figure 21: Root distributions of selected soil pits taken at the soil profile location #3 (Soil 3). The total number of roots counted for each size class (F<2mm, M=2-5mm, C=5-10mm, T>10mm) is also provided.

Longevity of ripping and surface mulch

Similar to the previous two experiments each growing season experienced different weather conditions (Table 11 and 12). Vintages 2004, 08 and 09 were marked by unusually dry conditions between veraison and harvest while vintages 2003 and 05 received good rainfall during this period. Vintages 2004, 05, 06 and 09 experienced good winter and spring rainfalls while the 2007 vintage was the driest season. Average maximum and minimum temperatures fluctuated considerably throughout the experimental period with the key differences highlighted in Table 11. Evapotranspiration could be broken into two periods of low and high ET. Low ET was experienced in vintages 2003, 04 and 06 while high ET was experienced in 2007-09.

A further variation throughout the experimental period was the sudden increase in water salinity used for irrigation in the latter vintages. The salinity of the irrigation water was typically between 1 and 1.5 dS/m (Figure 22). However, with the continued drought and reduced water flows through the lower Murray River system, the salinity of the irrigation water supply increased to as high as 4 dS/m. This is well above the 3 dS/m severe salinity threshold for irrigated agricultural production (Ayers and Westcot 1985). Hence, interpretation of the results from this experiment will need to consider the possible impacts due to the use of highly saline irrigation water.

Table 11: Average minimum and maximum temperature for each phenological interval and vintage year. Weather is derived from SILO patch point data station 24515 (Langhorne Creek). Temperatures highlighted in red and blue are 5% hotter and cooler than the period average, respectively.

	Av. T_{max} (°C)							Av. T_{min} (°C)						
	2003	2004	2005	2006	2007	2008	2009	2003	2004	2005	2006	2007	2008	2009
LF-BB	17.0	15.7	16.4	17.0	16.6	16.5	15.6	6.6	6.9	**7.7**	**7.3**	**5.3**	**6.2**	6.8
BB-F	21.3	**19.1**	21.4	21.0	22.4	22.0	**22.5**	8.8	**8.0**	8.7	**10.0**	**8.3**	9.1	8.8
F-V	26.5	27.0	27.6	26.8	28.4	28.3	**25.6**	13.3	13.7	13.8	13.3	13.2	13.8	13.0
V-H	27.5	26.6	26.8	27.6	28.7	**26.3**	**30.8**	14.8	14.5	14.2	15.4	**15.9**	**13.6**	15.3
H-LF	22.0	22.6	23.7	**21.6**	23.8	**24.3**	22.3	**10.1**	**10.2**	10.7	10.6	**12.1**	10.6	10.9

Table 12: Rainfall and reference evapotranspiration (ET_o) for each phenological stage and vintage year. Weather is derived from SILO patch point data station 24515 (Langhorne Creek). Rainfall and ET_o highlighted in red and blue are 10% lower and higher than the period average, respectively.

	Rainfall (mm)							ET_o (mm)						
	2003	2004	2005	2006	2007	2008	2009	2003	2004	2005	2006	2007	2008	2009
LF-BB	**92**	**172**	**146**	**205**	**57**	**86**	**158**	145	130	139	147	150	150	136
BB-F	**41**	**100**	**83**	**150**	**31**	77	**33**	240	**215**	237	220	**271**	253	260
F-V	**35**	41	**68**	46	**30**	**35**	45	339	345	349	347	382	383	332
V-H	**55**	**12**	**46**	**19**	23	**13**	**1**	217	222	207	217	223	218	**258**
H-LF	73	**28**	**26**	**108**	**99**	74	70	237	255	274	248	271	285	247
Total	**297**	352	370	**528**	**240**	**284**	308	1177	1167	1207	1178	1298	1290	1234

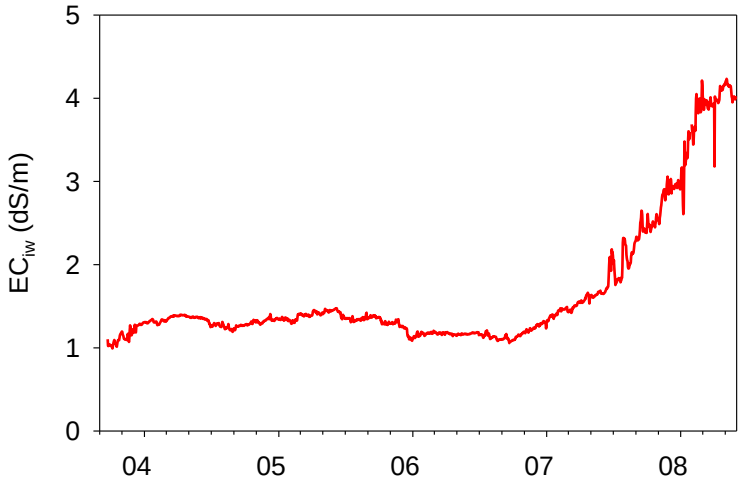


Figure 22: Variation in the electrical conductivity of the irrigation water (EC_{iw}) used at the Langhorne Creek experimental site as a function of time.

Vine, yield and berry quality parameters

The identification of four soil zones within a 7 ha vineyard block of Shiraz was to separate the relative effects of the imposed treatments (ripping and mulch) on vine performance in response to the underlying soil properties. This type of analysis was previously presented by Lanyon and Bramley (2004) but for only two seasons. This was extended over several seasons in this study. As previously noted in the methods the soil is characterized by a variation in surface soil texture overlying a light to medium sodic clay (see Figure 6). The soils are notated from Soils 1 – 4 referring to the lightest surface texture to the heaviest, respectively.

Whilst the differences in vine performance between zones were significant (Table 13), the relative variation between zones was not consistent (Figures 23 and 24). Further, the vintage averages for vine and grape properties also tended to fluctuate. Generally, these fluctuations reflect the changes in season rainfall and the impact of using highly saline water. This is highlighted by the gradual decrease in berry weight with each vintage and the reduced pruning weights in the last two vintages (Figure 23). Pruning weights tended to reflect the early season conditions with greater pruning weights recorded for vintages with above average rainfall prior to veraison (2004, 2006) and lower pruning weights recorded for vintages with below average rainfall prior to veraison (2003, 2007-08). The lower pruning weights in the 2007 vintage, as well as the lowest NDVI, correspond with high titratable acid (Figure 24). This contradicts the relationship that has been noted in other studies (eg Cortell et al, 2007; Bergqvist et. al. 2001; Smart et. al. 1988) where high TA levels have been associated with high vigour zones, albeit within one vintage.

Table 13: Summary of soil zone effects (Soil 1 – 4) on vine and grape properties over five seasons. Probability levels P>0.05, P≤ 0.05, P≤ 0.01, P≤ 0.001 are notated as o, x, xx, xxx, respectively. NDVI refers to normalised difference vegetation index, TSS refers to total soluble solids, and TA refers to titratable acid.

	Vintage				
Variable	2003	2004	2006	2007	2008
Yield	x	xxx	x	x	o
Berry weight	o	o	xxx	x	xxx
No. of Bunches	o	xx	o	x	x
Pruning weight	xxx	o	xx	o	o
NDVI	-	-	xxx	xxx	xxx
TSS	x	xxx	xxx	o	xxx
pH	xx	xx	o	o	o
TA	xxx	xxx	xx	xxx	xxx

'-' no data available

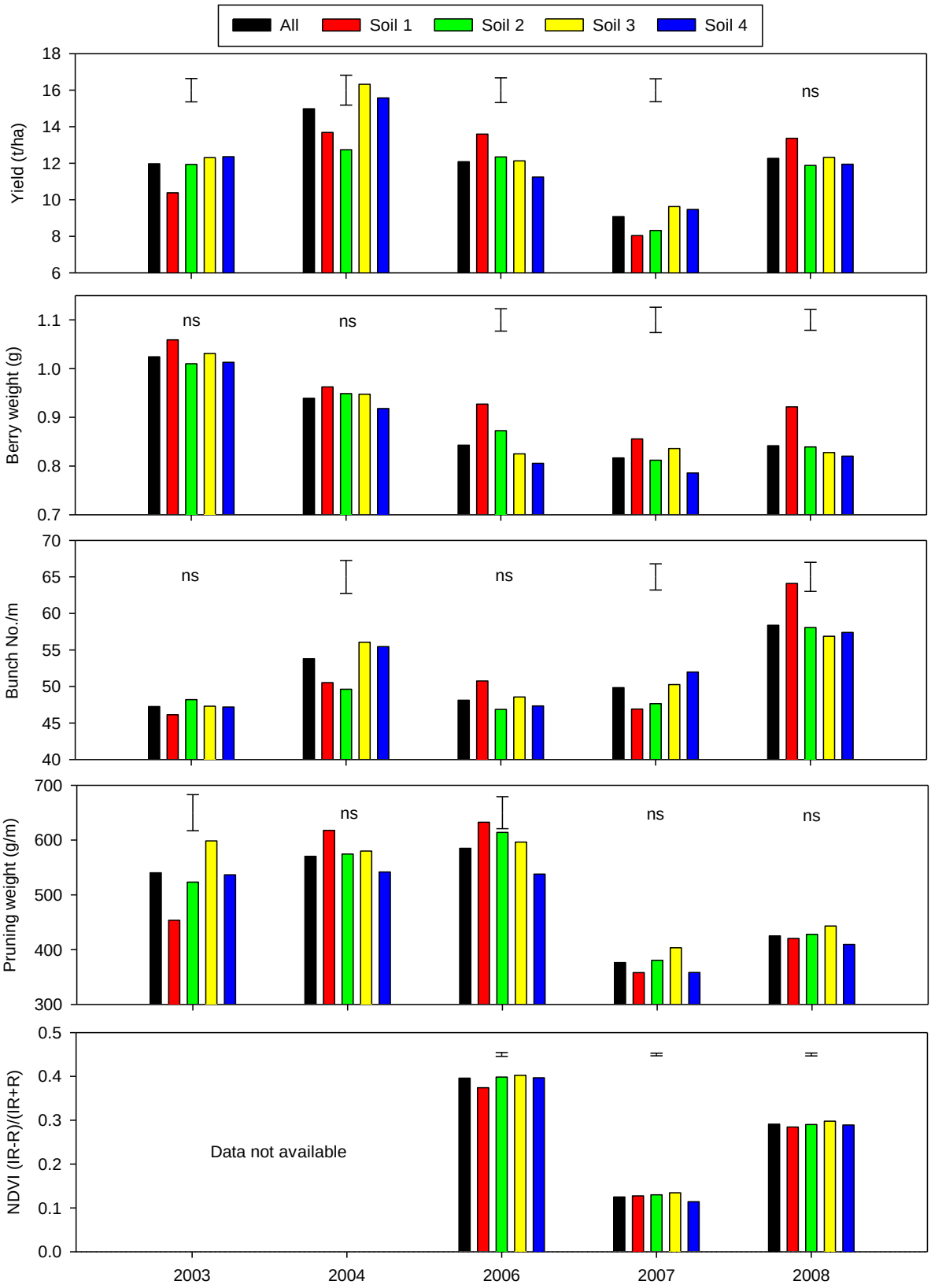


Figure 23: Variation in selected vine and grape attributes as a function of soil zone (Soil 1-4) over five seasons. LSD's for each vintage are included (P=0.05) when significant, otherwise they are notated with 'ns'. NDVI refers to normalised difference vegetation index.

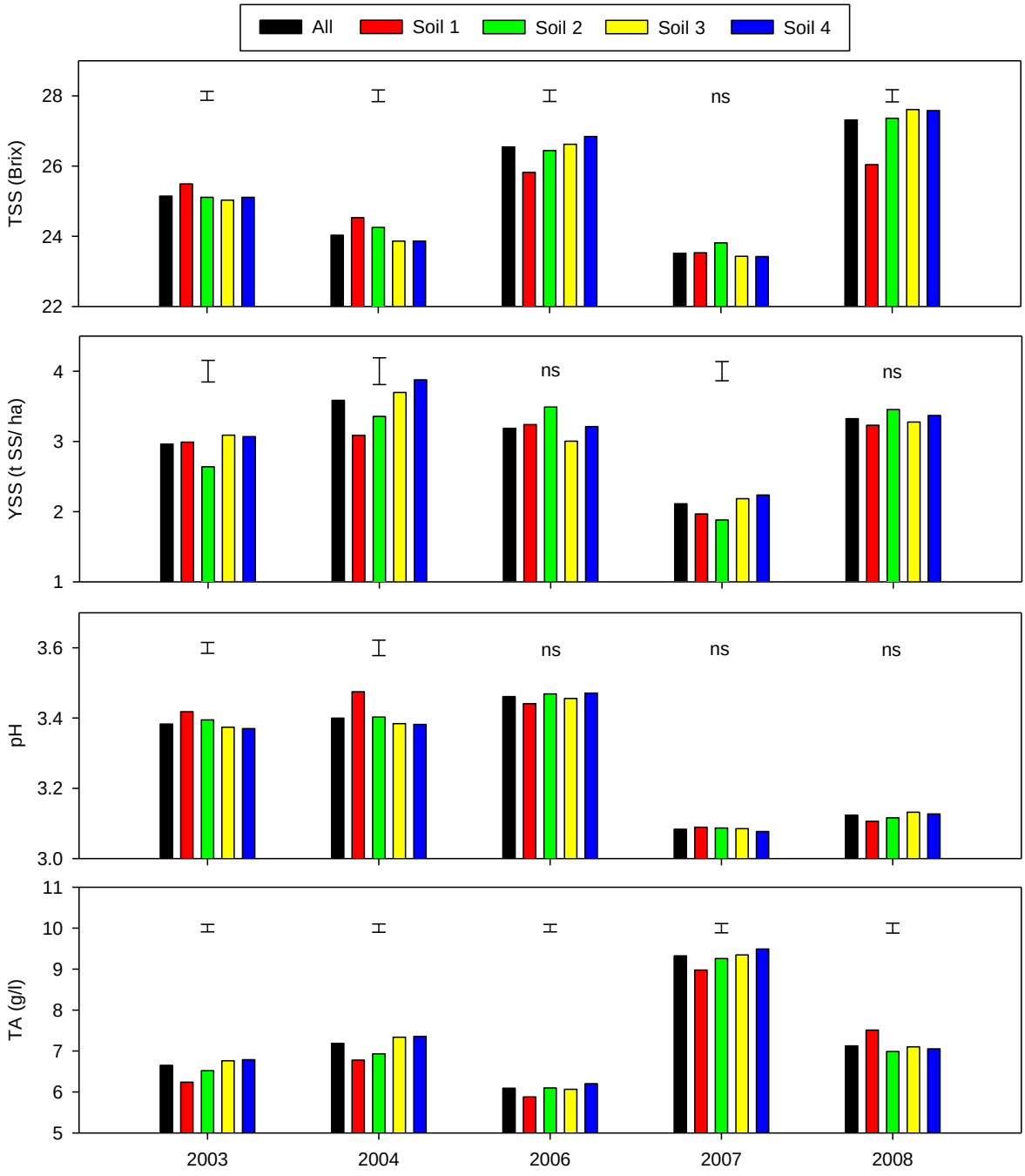


Figure 24: Variation in selected grape attributes as a function of soil zone (Soil 1-4) over five vintages. LSD's for each vintage are included (P=0.05) when significant, otherwise they are notated with 'ns'. TSS refers to total soluble solids, YSS refers to yield of soluble solids, and TA refers to titratable acid.

For three vintages (2003, 2004 and 2007) yield tended to be lowest on the lightest soil and increased as the soil became heavier. However, this was reversed in the 2006 vintage with the lightest soil yield the most and the heaviest soil the least. Presumably this was due to the relatively high rainfall experienced during that season reducing the onset of vine stress in the lighter soils. This variation between soil zones was not observed with berry weight where berry weight was always greatest on the light soils and smallest on the heaviest soils. The difference in pruning weight between soil zones was only significant on two vintages (2003 and 2006). The trend in these two vintages was opposite and mimicked yield variation (Figure 23). In contrast, NDVI did not reflect the pruning weight variation between zones in the 2006 vintage but broadly reflect the variation for the 2007 and 2008 vintages.

Whilst significant differences in NDVI were observed between soil zones for all recorded vintages the relationship between pruning weights and NDVI values is not direct whereby NDVI accounts for canopy size in the horizontal plane only. Difficulty in relating NDVI to pruning weights have also been experienced by others (eg Goodwin 2009).

Grape properties were also affected by soil zone. The variation in total soluble solids between soil zones tended to be opposite to that of yield. That is, higher the yield the lower the soluble solids and vice versa. Combining yield and soluble solids to calculate the yield of soluble solids and relating it to soil zone shows that, generally, the heaviest soil yields more soluble solids than the light soils, which is particularly demonstrated in the 2004 vintage (Figure 24). Grape juice pH was significantly affected by soil zone in vintages 2003 and 2004 only. pH tended to be higher on the lightest soil compared to the heaviest soils. Similarly, grape juice titratable acid (TA) tended to be lowest on the lightest soils and highest on the heaviest soils. The only vintage that this was not true was the final vintage in 2008 when the TA on the lightest soil was significantly greater than the other soil zones. Apart from using the total soluble solids as a covariate in the analysis to correct for variation in grape sugar maturity, which only accounted for between 1 and 16% of the variation, changes in weather conditions seem to have a greater influence on grape quality parameters through its influence on canopy development than the soil zones identified in this study.

The application of composted grape marc to the under vine area and the ripping of the wheel tracks had a significant effect on vine and grape properties (Table 14). The applied treatments showed significant effects to more vine and grape properties the greater time was after initial application. Whilst there were apparent effects of the treatment on vine performance in the initial years they were not significance due to the variation between target vine measurements. The effects shown in Table 14 relates to the average vine response to treatments and does not take into account any variation in response that might be related to changes in soils properties across the vineyard block. The real interest in this study was whether relationships exist between the response of the vine to the applied treatment (ripping or mulch) and the soil zone it was applied to. These interactions between treatment and soil zone are summarized in Figures 25 to 31.

Table 14: Summary of treatment effects (control, mulch and ripping) on vine and grape properties over five vintages. Probability levels P>0.05, P≤ 0.05, P≤ 0.01, P≤ 0.001 are notated as o, x, xx, xxx, respectively.

	Vintage				
Variable	2003	2004	2006	2007	2008
Yield	o	o	xxx	o	xxx
Berry weight	o	o	o	o	o
No. of Bunches	x	o	o	x	o
Pruning weight	o	xxx	xxx	xxx	o
NDVI	-	-	xxx	xxx	xxx
TSS	o	x	xxx	o	xxx
YSS	o	o	xxx	o	xxx
pH	xx	xxx	xx	xxx	o
TA	o	o	xxx	o	xxx

'-' no data available

Unlike the previous experiment at McLaren Vale which did not show an immediate vine response to mulching and ripping, the application of ripping and mulch at the Langhorne Creek vineyard had an immediate effect. In the first two vintages there seemed to be a clear relationship between vine response to the applied treatment and soil zone. The application of mulch had the greatest impact on yield, berry weight and pruning weight on the lightest soil and diminished to no effect on the heaviest soil (Figures 25 to 27). The vine response to ripping seemed to follow a similar relationship, however the vine response was smaller with a larger response tending toward the medium textured soils. The effects also seemed to diminish after the initial vintage. A similar vine response was noted by Lanyon and Bramley (2004). The expectation was that the response to the applied treatments would diminish as the soil conditions reverted back to the control condition. For vintages 2006 and 2008, however, the effect of the applied treatments on vine properties continued to be significant and increase in

some soil zones. Yield response can be difficult to interpret given that it can be markedly affected by weather conditions during flowering and inflorescence development and changes in management practices, such as pruning, between vintages. Nonetheless, yield showed a significant increase due to mulch across all soil zones for the 2006 and 2008 vintages (Figure 25). The response to ripping was somewhat less but all yield responses were positive. Berry weight on the other hand showed very few significant responses to the applied treatments for all soil zones (Figure 26).

The purpose of the applied treatments was to increase the vines access to stored soil moisture. The most direct way to measure the impact of the applied treatments on access to stored soil moisture is the measurement of biomass production, which is inexplicitly linked to crop water use (Sinclair *et al.* 1984). As a result, the measurement of pruning weights gave a more consistent relationship between the effects of the applied treatments on different soil zones (Figure 27). The application of mulch had an immediate effect on the growth of the vine with the largest impact occurring on the lightest soils. This continued for the four vintages with a peak increase in vine growth on the lightest soils around 2-3 vintages post application. On the heaviest soils, however, vine growth continued to increase as a result of mulch application such that by 4-5 vintages post mulch application the effects on vine growth were similar across all soil zones. Whilst not reaching the same level of vine growth response as that observed on the lightest soil zones, the effect of mulch application on the heavier soil zones seem to have a longer lasting effect on vine growth albeit at a slower response rate. Even after 6 vintages from the single application of surface mulch the effects on soil condition and soil moisture retention were still evident and detectable by aerial imagery (Figure 27, Table 14). With respect to the reapplication of surface mulch it could be argued from these results that reapplication should occur every 5 vintages for light textured soils whereas every 7 vintages for heavy textured soils. Both are considerable longer than current industry practice which can be as often as every third year.

The effect of ripping on vine growth did not have the same magnitude and systematic response compared to the application of mulch. The vine growth did not show any significant response in the first two vintages after initially ripping the tractor wheel line (Figure 27). By the 4th and 5th vintage the ripping treatment had increased vine growth significantly on the lightest and heavier soil zones. However, by the final vintage these effects had reduced and were not significant. The variation in the response of vine growth to ripping was attributed by Lanyon and Bramley (2004) to the amount of root growth into the mid-row. Whilst this may be true it does not account for the general observations observed over several vintages. Other factors that also need to considered such as the rate of re-compaction of the soil by natural and induced means and the effectiveness of ripping in alleviating restrictive barriers to root growth, if any. The net effect of these results on vine growth indicate that whilst there is an overall positive response to ripping there is no further information that can be put forward about specific vine response to ripping in different textured soils.

Basic berry quality parameters were also affected by the application of mulch and ripping (Figures 28 to 31). Only small changes in total soluble solids (TSS) were observed in the first two vintages despite some of the large variations in berry weight and yield in some of the soil zones. TSS was most affected by the applied treatments in the 2006 and 2008 vintages (Figure 28). Mulch tended to decrease TSS across all soil zones whereas ripping had no definite structure to the TSS response. The response of TSS to the treatments reflected the variation in yield response suggesting that the accumulation of TSS in the berries were sink limited rather than source limited (Goodwin 2009). This is confirmed by the response of the soluble solids yield (YSS) to the applied treatments (Figure 29) which reflect the yield response rather than the pruning weight response, or canopy area.

Of all the basic grape quality parameters, grape pH showed the most sequential response to the applied treatments. Almost universally, pH was increased the most by both mulch and ripping on the lightest soil zone, particularly in the first two vintages. Whilst the effects of the applied treatments on grape pH generally persisted they became more uniform across each soil zone and smaller in magnitude. By the 2008 vintage the response of grape pH was insignificant, six seasons after the initial application (Figure 30). In contrast, the response of titratable acid (TA) to the applied treatments persisted equally from the first vintage to the last (Figure 31). There was only one vintage that showed an overall significant decrease in TA and a uniform decrease across all soil zones. The general response of TA to both treatments, however, showed a decrease in TA on the light soil zones gradually moving to an increase in TA on the heaviest soil zone. Again, the TA response does not follow the normal response associated with higher vigour as stated earlier, particularly on the light soil zone. Hence, this study suggests that the soil properties and current vine balance may play an important part in determining the TA response to changes in vine vigour.

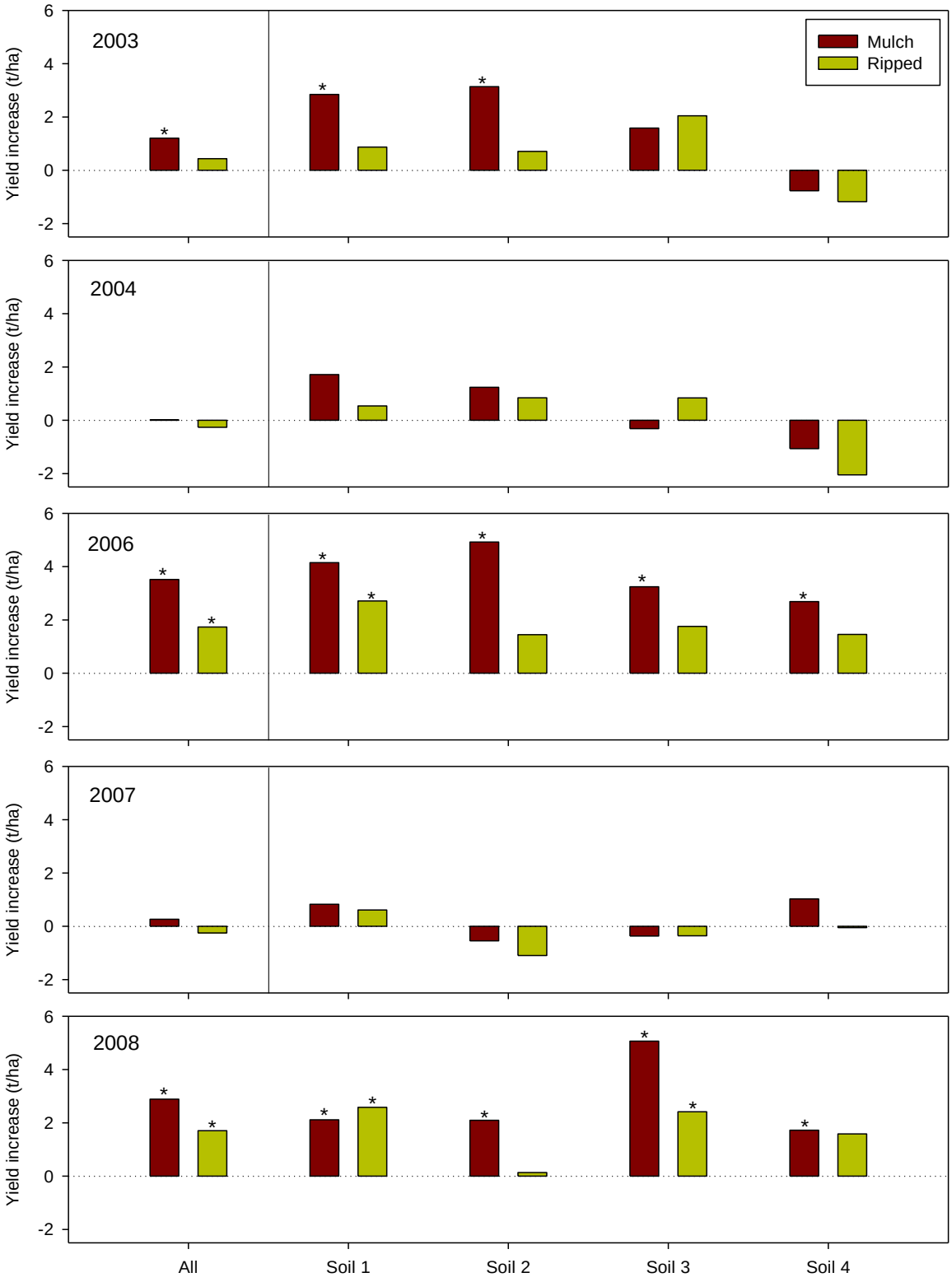


Figure 25: Change in yield as a function of soil treatment (mulch or ripped) compared to the control over five vintages. Bars marked with an asterisk (*) are significantly different to the control (P=0.05).

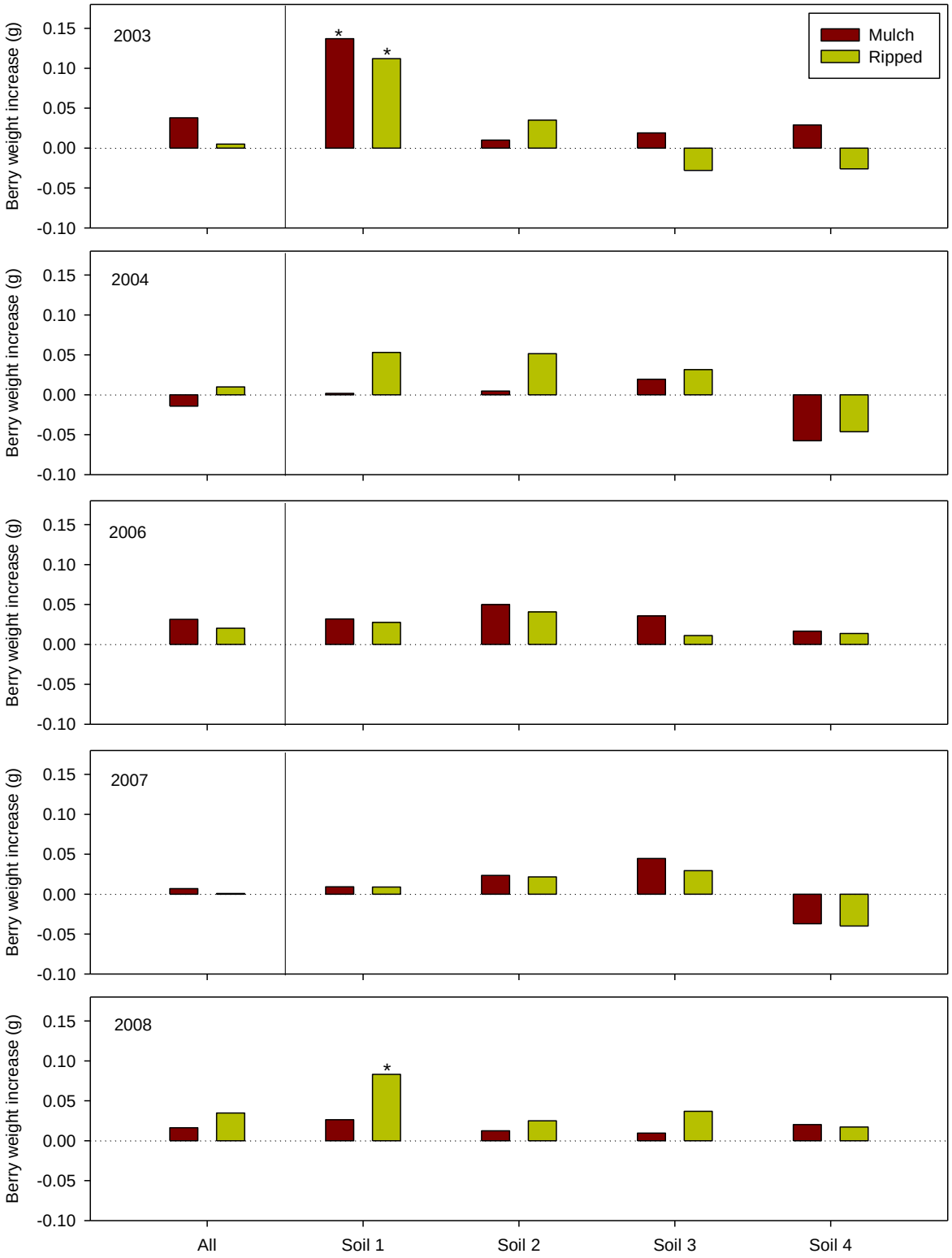


Figure 26: Berry weight change as a function of soil treatment (mulch or ripped) compared to the control over five vintages. Bars marked with an asterisk (*) are significantly different to the control (P=0.05).

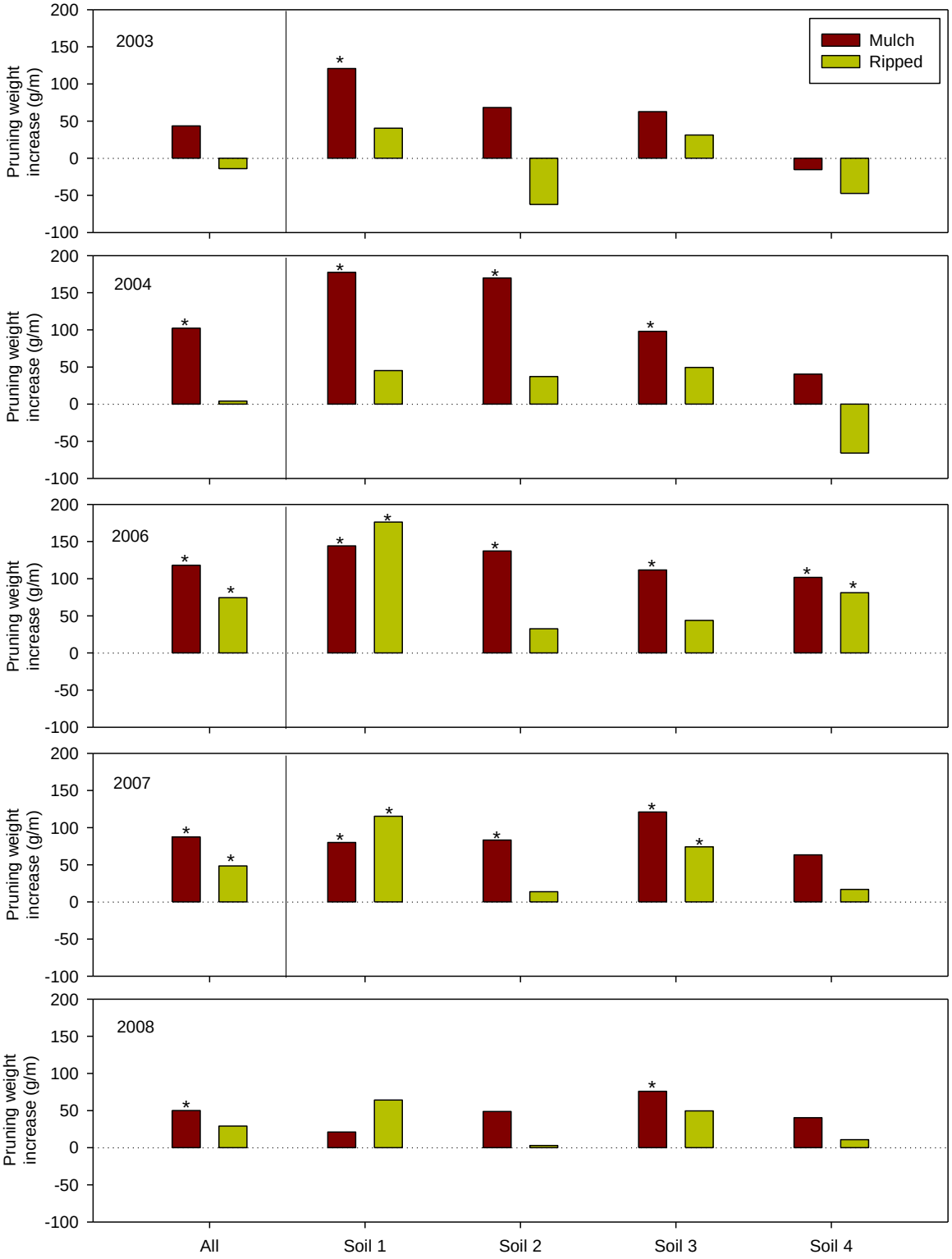


Figure 27: Change in pruning weight increase as a function of soil treatment (mulch or ripped) compared to the control over five vintages. Bars marked with an asterisk (*) are significantly different to the control (P=0.05).

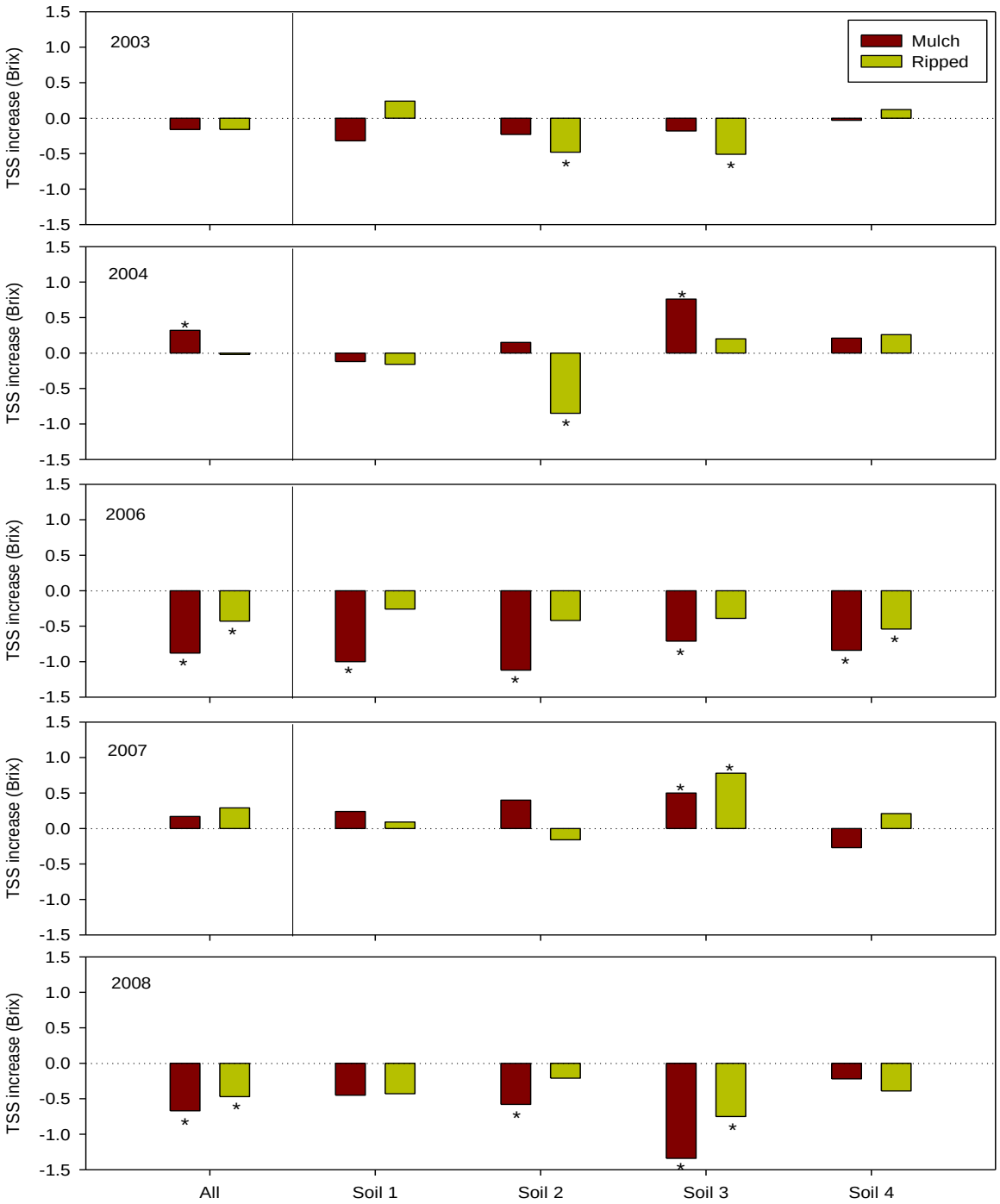


Figure 28: Total soluble solids (TSS) change as a function of soil treatment (mulch or ripped) compared to the control over five vintages. Bars marked with an asterisk (*) are significantly different to the control (P=0.05).

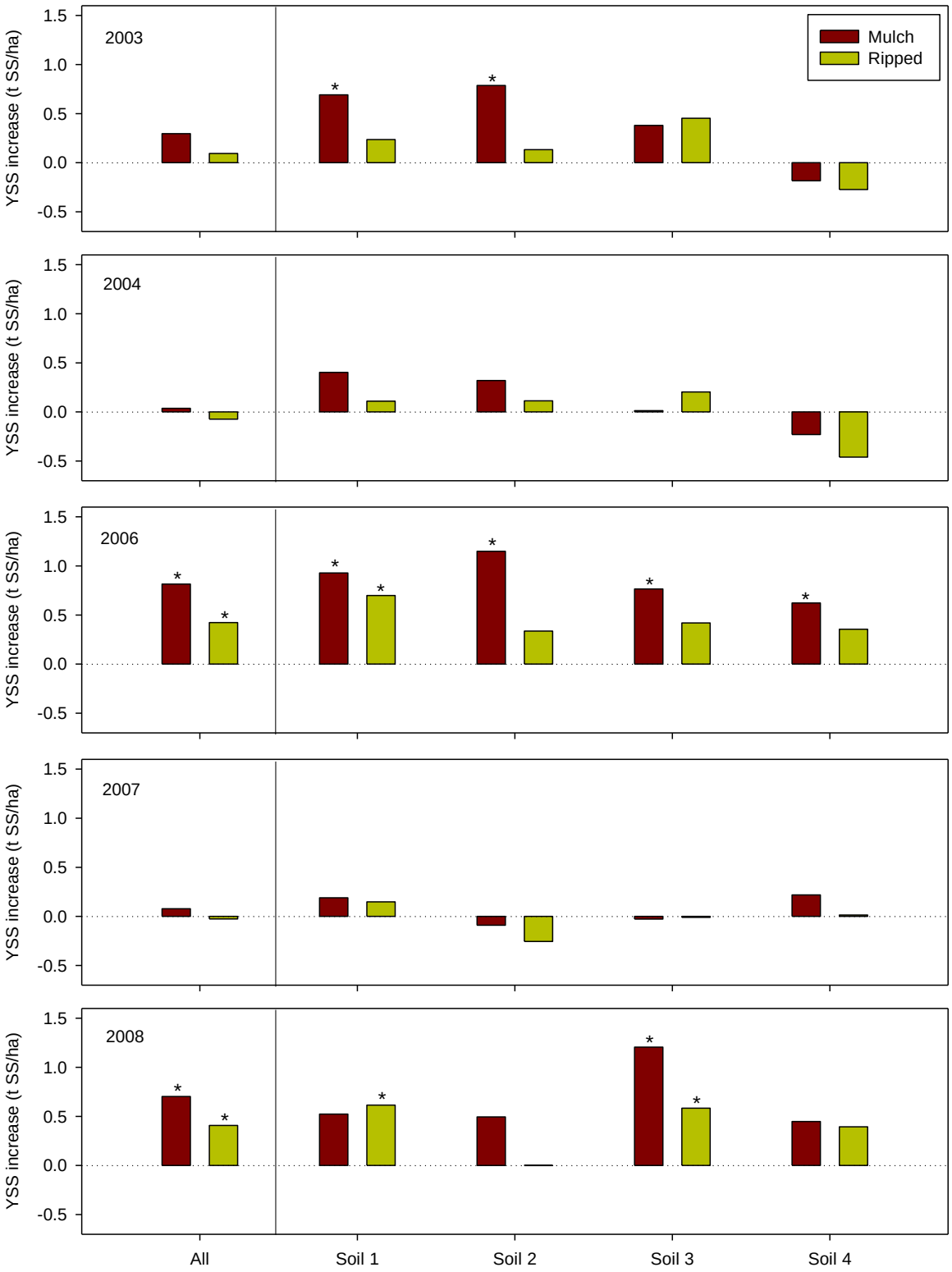


Figure 29: Change in yield of soluble solids (YSS) as a function of soil treatment (mulch or ripped) compared to the control over five vintages. Bars marked with an asterisk (*) are significantly different to the control (P=0.05).

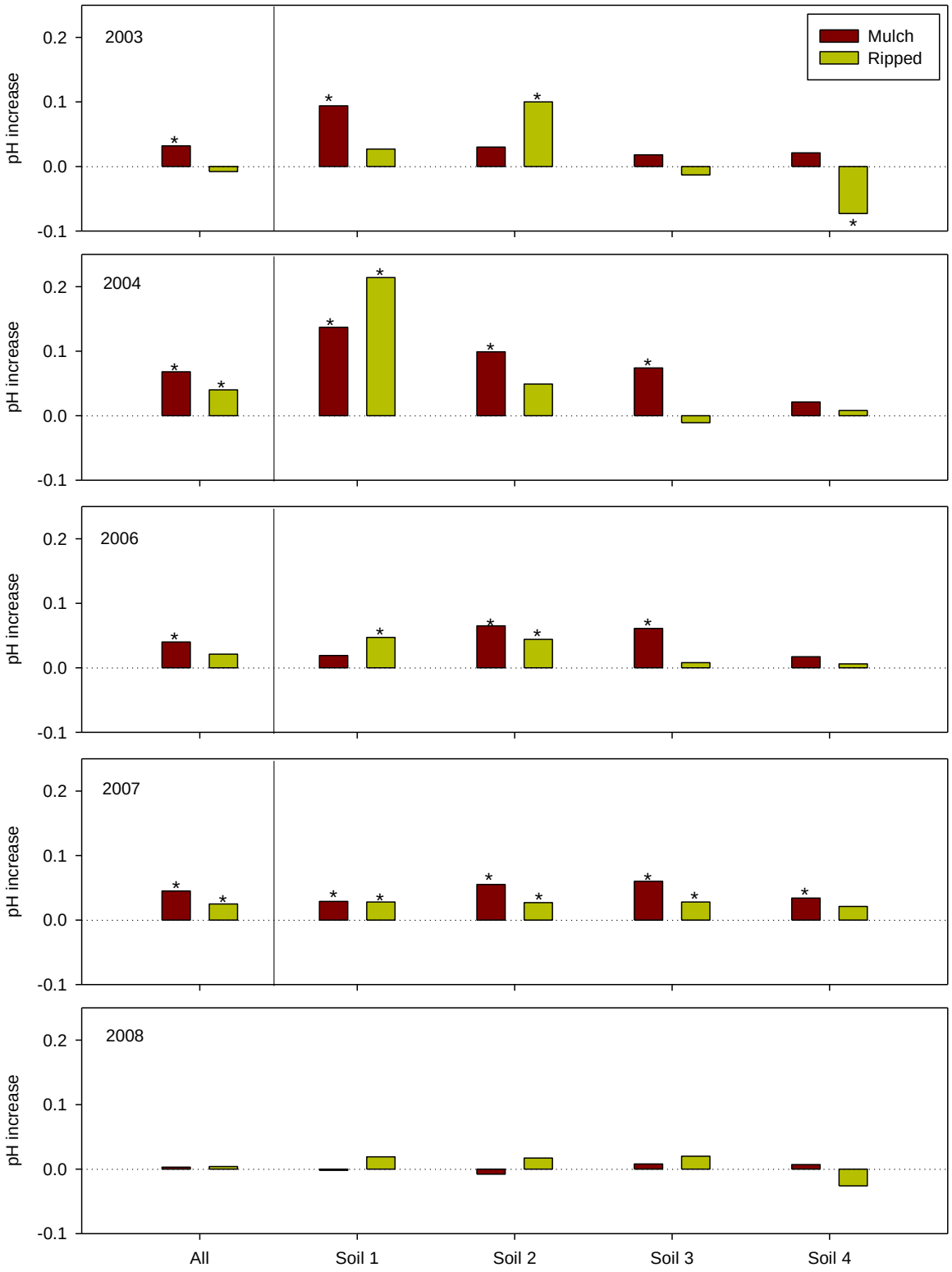


Figure 30: Change in grape pH as a function of soil treatment (mulch or ripped) compared to the control over five vintages. Bars marked with an asterisk (*) are significantly different to the control (P=0.05).

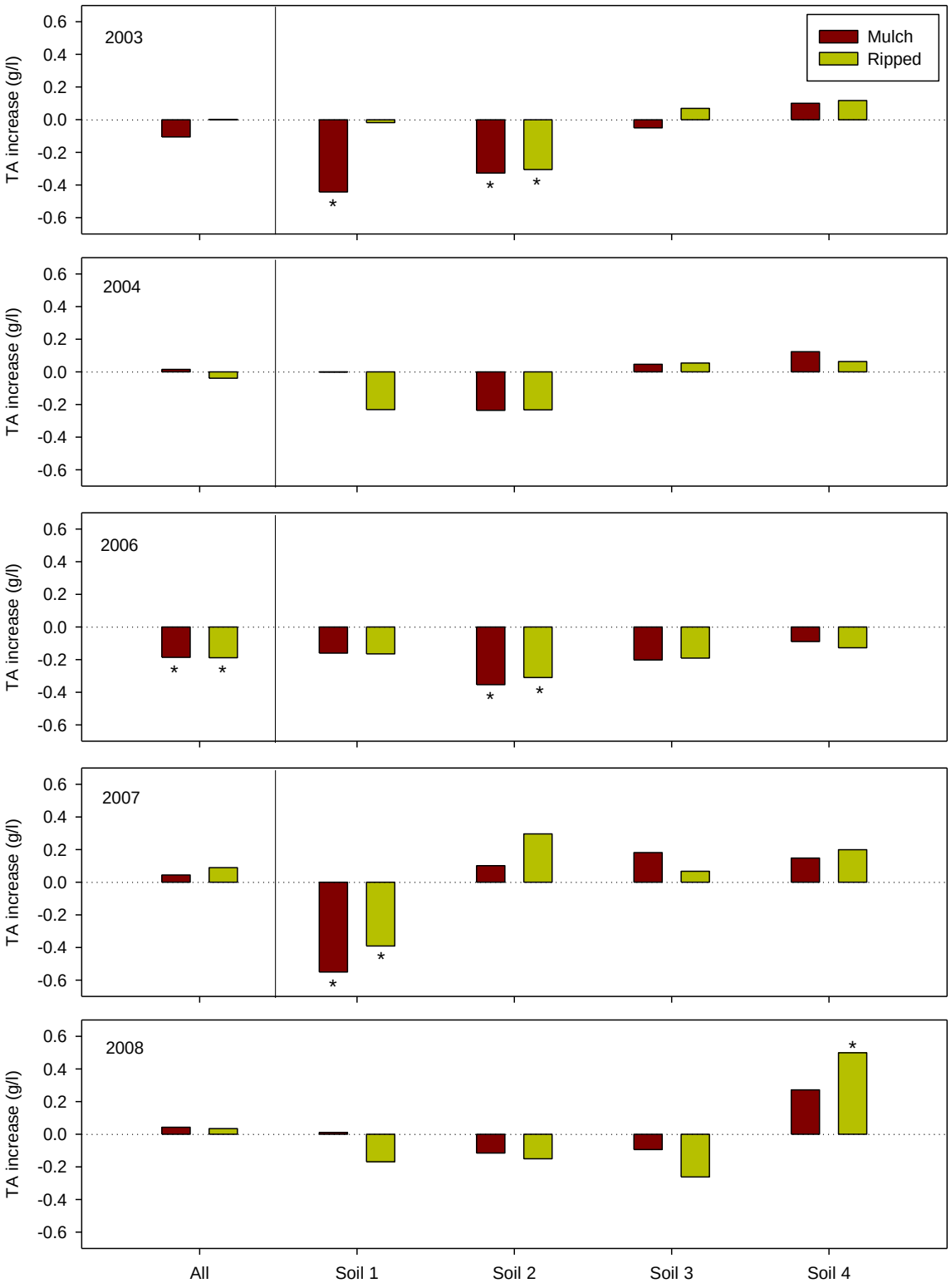


Figure 31: Change in grape titratable acid (TA) increase as a function of soil treatment (mulch or ripped) compared to the control over five vintages. Bars marked with an asterisk (*) are significantly different to the control (P=0.05).

Since the treatments were still having an effect on vine performance six seasons after the initial application, data was collected from a seventh year to determine whether the effects of the treatments on vine nutrition and grape properties had any impact on the resultant wine spectral and sensory properties. Further, experimental areas were established in high and low EM zones in order to measure any differences in vine response to the imposed treatments under different soils conditions. In this particular vineyard, the apparent electrical conductivity was associated with variation in soil salinity (Goodwin 2009).

Both the applied treatments and EM zones had a significant effect on vine yield and grape properties (Table 15). The application of mulch had the greatest influence on grape properties of the two treatments. Yield was significantly increased, particularly in the high EM zone, which could be attributed to an increase in the number of bunches per vine and berries per bunch (data not shown). Despite the higher yield, which was previously associated with lower TSS in the previous vintages, the mulch treatment had significantly higher TSS. This outcome was primarily due to the impact that mulch had on TSS development within the high EM soil zone (Figure 32). One of the potential reasons for this response in the high EM zone could be that the vines were able to continue to photosynthesize for a longer period, aiding sugar accumulation, due to better soil conditions. The effect of poorer soil conditions in the high EM zone was reflected in the significantly lower yield and berry weight (Table 15). The lower berry weights were mostly likely the reason for the significantly higher colour and phenolics observed in the high EM zone (Table 15).

Table 15: Summary of main treatment effects on vine and grape properties for the 2009 vintage. Values followed by the same letter within the main effects are not significantly different (P=0.05).

	Yield t/ha	Bunches per metre	Berry W. g	TSS Brix	pH#	TA# g/l	Anthocyanins au	Phenolics au
Control	8.3[a]	64.1[a]	0.82[a]	23.1[a]	3.54[a]	4.3[a]	1.92[a]	1.90[ab]
Mulch	11.9[b]	71.8[b]	0.87[a]	23.6[b]	3.61[b]	4.0[b]	1.87[a]	1.83[a]
Ripped	8.4[a]	67.3[ab]	0.79[a]	23.1[a]	3.52[a]	4.3[a]	1.97[a]	1.96[b]
Low EM	11.6[a]	71.2[a]	0.91[a]	23.3[a]	3.61[a]	3.9[a]	1.87[a]	1.79[a]
High EM	7.4[b]	64.3[b]	0.74[b]	23.2[a]	3.50[b]	4.5[b]	1.97[b]	2.00[b]

pH and TA were determined from juice collected after de-stemming, sulphur stabilisation and overnight storage in a cool room.

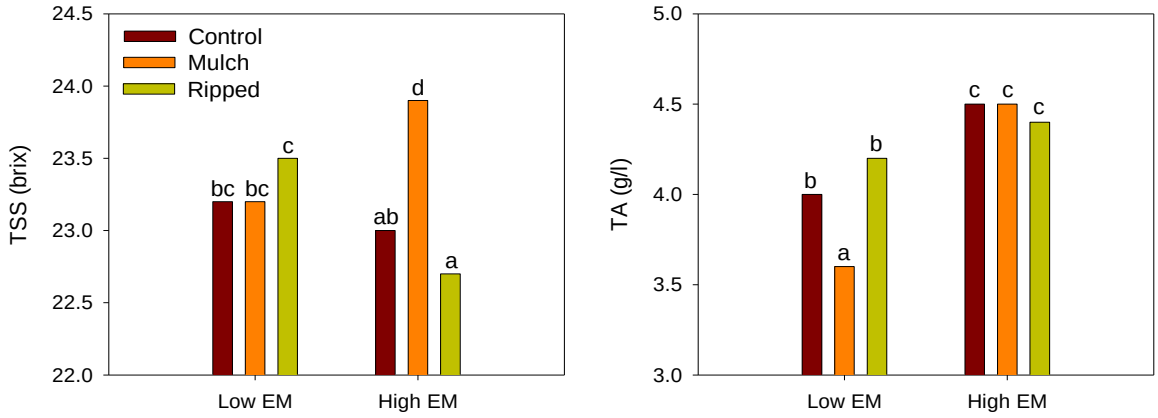


Figure 32: Variation in total soluble solids (TSS) and titratable acid (TA) as a function of soil treatment (control, mulch or ripped) and apparent electrical conductivity (Low EM or High EM). Bars followed by the same letter are not significantly different (P=0.05).

Vine nutrition

In general there was little effect of the applied treatments on petiole nutrient concentrations (Table 16). One exception, however, was that petiole nitrate nitrogen levels were significantly higher in the mulch treatment. Soil conditions under mulch have been associated with increased levels of soil biological activity, through increased organic carbon levels, which can lead to increases in nitrogen availability (Biala 2000) but the addition of straw mulch, with a high carbon:nitrogen ratio, has been also associated with nitrogen tie up (Biala 2000).

Whilst the impact of mulch and ripping on petiole chloride (Cl) and sodium (Na) was not significant, there was a significant interaction between treatments and EM zones (Figure 33). The effect of mulch in the low EM zone was to increase Na and Cl levels whereas the high EM zone mulch decreased Na and Cl levels compared to the control and ripped treatments. The hypothesis was that petiole Na and Cl levels would be decreased in both high and low EM zones due to better leaching of salts over the life of the experiment. What this did not take into account was the potential difference in vine size and transpiration differences between treatments. Hence, it is difficult to interpret these observations with a clear causal mechanism.. Nevertheless, in the high EM zone, where salt accumulation is evident in the vines, the mulch application tended decrease petiole Na and Cl. The petiole Cl observations in 2009 did not translate into significant differences in grape juice Cl concentration between treatments measured in the 2008 season. The analysis of the entire experimental area did not show a significant effect of the applied treatments on chloride concentration ($P<0.05$). Whilst the Cl concentration in grape juice from the mulch treatment area was 10% lower compared to the control it was not significant. One of the reasons for this is due to the degree of variability between sampling locations. Using a larger sampling area at targeted zones, such as this experiment during the 2009 season, would help reduce the variations between replicated areas.

Table 16: Summary of main treatment effects on petiole nutrient status at flowering 2008. Values followed by the same letter within the main effects are not significantly different (P=0.05). Nutritional values are assessed against guidelines defined by Robinson et al (1997). Where nutritional guidelines only report an adequate range the nutritional level is reported high or marginal if it is above or below the adequate range, respectively.

	NO_3-N mg/kg	P %	K %	Ca %	Mg %	Na %	Cl %	Zn mg/kg	Mn mg/kg	Fe mg/kg	Cu mg/kg	B mg/kg	S mg/kg
Control	222^{a}	0.25^{a}	2.90^{a}	1.68^{a}	0.58^{a}	1.05^{a}	2.94^{a}	45.9^{a}	55.3^{ab}	16.8^{a}	51.5^{a}	44.0^{a}	0.18^{a}
Mulch	268^{b}	0.29^{a}	3.00^{ab}	1.74^{a}	0.60^{a}	1.11^{a}	2.87^{a}	45.0^{a}	52.4^{a}	17.3^{a}	48.9^{a}	41.9^{a}	0.16^{a}
Ripped	232^{a}	0.31^{a}	3.06^{b}	1.74^{a}	0.55^{a}	1.01^{a}	2.96^{a}	44.4^{a}	63.7^{b}	17.8^{a}	50.6^{a}	41.6^{a}	0.18^{a}
Low EM	214^{a}	0.33^{a}	2.96^{a}	1.53^{a}	0.57^{a}	0.87^{a}	2.17^{a}	39.1^{a}	55.4^{a}	15.6^{a}	46.5^{a}	44.8^{a}	0.16^{a}
High EM	267^{b}	0.24^{b}	3.02^{a}	1.91^{b}	0.58^{a}	1.25^{b}	3.67^{b}	51.2^{b}	58.9^{a}	19.0^{b}	54.2^{b}	40.2^{b}	0.19^{b}

high/toxic adequate marginal deficient

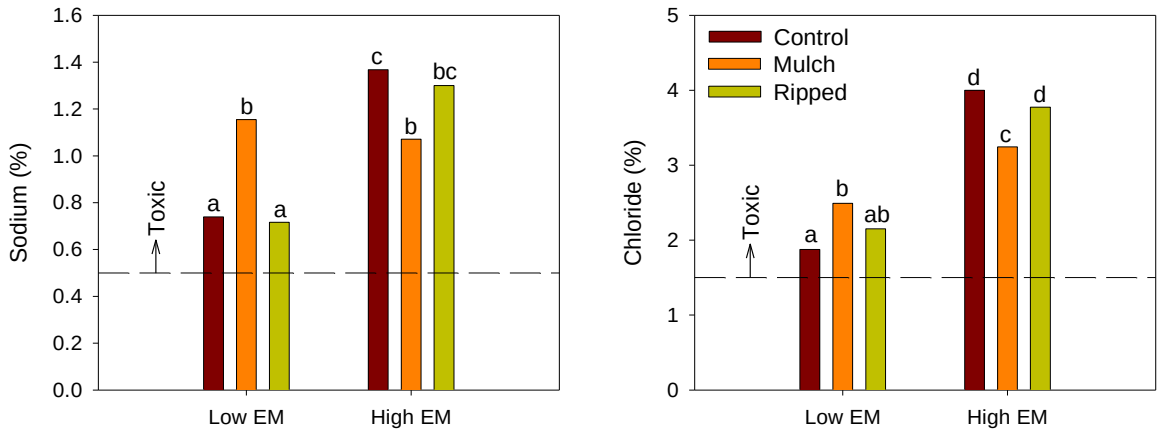


Figure 33: Variation in petiole Sodium (%) and Chloride (%) at flowering as a function of soil treatment (control, mulch or ripped) and apparent electrical conductivity (Low EM or High EM). Bars followed by the same letter are not significantly different (P=0.05).

Wine properties

The wines made from the grapes harvested in the 2009 vintage were above the international export threshold of 607 mg/l for Chloride (Cl). The difference in petiole Cl measured at flowering between the two EM zones was also observed in the wine (Table 17). Further, the concentrations measured in the petiole were also considered toxic and some toxicity symptoms in the vine were observed, particularly in the high EM zone. This is also reflected in the wine Cl concentrations between the EM zones (Table 17). Other wine properties were also affected by the EM zone. Phenolics and anthocyanins were higher in the high EM zone most likely reflecting the smaller berry size in that zone. Further, the alcohol was lower in the high EM zone despite there being no difference in total soluble solids between the EM zones (Table 15). Although DAP was added during the fermentation process (see appendix 1), the differences in alcohol could reflect differences in yeast assimilable nitrogen (YAN) between the high and low EM zones.

The effect of the treatments on wine properties was significant with the mulch treatment having the most influence whilst the ripping having the least. Of note, is the significant reduction in Cl in the wine as a result of the use of mulch six seasons earlier (Table 17). This confirms earlier observations during the 2008 vintage. The reduction in Cl concentration mostly occurred in the high EM zone (Figure 34) reflecting the substantial increase in yield. Whilst the wine Cl concentration was lower in the mulch treatment the amount of Cl removed at harvest was greater, in both EM zones, due to the significantly higher yield. This could simply reflect the increased capacity of the vines to continue transpiring under mulched soil conditions compared to both the control and ripped treatments. This was also noted in relation to the increased pruning weights of the mulch treatment compared to the other treatments. Apart from the effect of mulch on Cl, it also significantly reduced phenolics and anthocyanins in the wine. Both these reductions were more pronounced in the low EM zone (Figure 34). The increased size of the vine in the high EM zones may not have been sufficient to induce a reduction in phenolic and anthocyanin development through shading (Price et al 1995). However, in the low EM zone, with higher vigour, the increased size of the vine could have been sufficient to induce a reduction in phenolic and anthocyanin development through shading.

Table 17: Summary of main treatment effects on wine properties for the 2009 vintage. Values followed by the same letter within the main effects are not significantly different (P=0.05).

Treatment	Alcohol %	Hue	Phenolics au	Anthocyanins mg/L	Chloride mg/L
Control	14.2[a]	0.37[a]	59.6[a]	720[ab]	1235[a]
Mulch	14.2[a]	0.37[a]	53.5[b]	698[b]	1117[b]
Ripped	14.2[a]	0.36[a]	63.1[c]	736[a]	1228[a]
Low EM	14.4[a]	0.39[a]	54.0[a]	698[a]	1009[a]
High EM	13.9[b]	0.34[b]	63.4[b]	738[b]	1378[b]

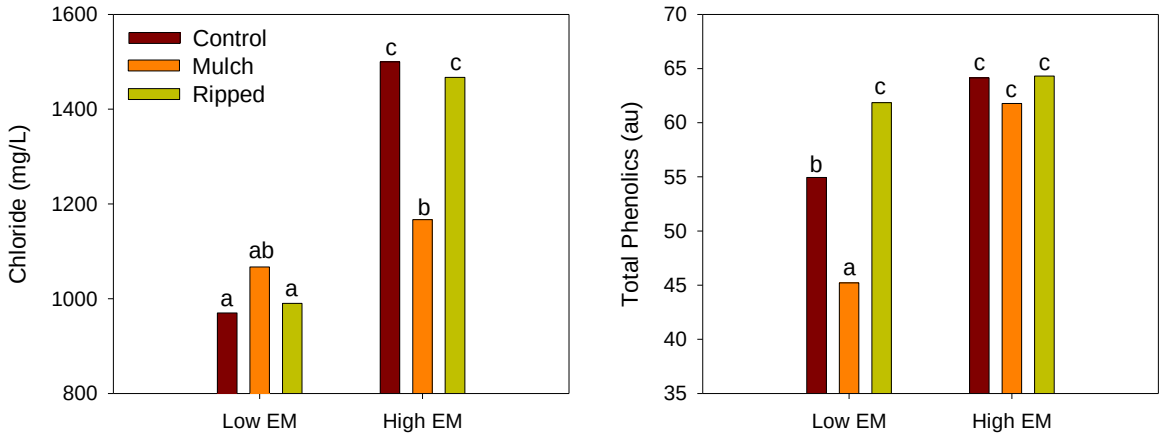


Figure 34: 2009 wine chloride and total phenolics as a function of soil treatment (control, mulch or ripped), and apparent electrical conductivity (Low EM or High EM). Bars followed by the same letter are not significantly different (P=0.05).

Despite the significant differences between wines made from each of the treatments, the ability to detect organoleptic differences was not consistent (Table 18) and did not align with the differences found by spectral and analytical means. These results suggest that even the mulch produced higher yield it did not result in a different wine compared to both ripping and control treatments.

Table 18: Summary of sensory difference testing between 2009 wines. Probability levels P>0.05 and P≤0.05 are notated as o and x, respectively.

Within Site	C vs M	C vs R	M vs R	Between Sites	C	M	R
Low EM	o	o	o	Low EM vs High EM	X	o	o
High EM	o	o	x				

Outcomes and Conclusions

The variation in yield and berry quality parameters is not controlled by any one variable but rather a number of variables that change concurrently within and between seasons. The three studies examining the effect of soil profile modification and soil surface management on vine performance have demonstrated that the influence of seasonal weather variation and soil properties play a significant role in determining vine performance. With limited seasons, usually three, this makes it difficult to gain clear outcomes on the response of the vine to soil profile modification and soil surface management. Nevertheless, the studies have demonstrated some clear directions with respect to ripping, or the value to mid-row root systems, and the application of mulch in more saline environments and their impacts on vine performance.

The full profile modification experiment showed that the presence of roots in the mid-row contributes significantly to vine performance. This was demonstrated by the dramatic reduction in vine yield and canopy size after ripping of the mid-row soil profile which severed the active root system in the mid-row. Where significant roots were not present in the mid-row, ripping of the mid-row soil profile had little effect on vine performance initially. In both cases, whether roots were present or not in the mid-row, the yield and canopy growth of the vine increased after the first vintage although the amount of increase could not be attributed to any underlying soil condition. Where roots were pruned by ripping the vine recovered to its original performance within three vintages. Evidence from the experiment conducted over seven vintages suggests a continued increase in yield and canopy growth. Despite any increase or decrease in yield and canopy growth due to ripping of the mid-row the berry quality parameters were not consistent. Whilst there were some significant impacts on berry quality within the experimental area the variability in response both within and between vintages suggests that, in general, ripping does not affect berry quality. The effectiveness of ripping the mid-row in increasing vine access to the mid-row resources does depend on season rainfall conditions. Post ripping irrigation of the mid-row area may provide a more suitable soil moisture environment so that vine roots can actively grow into the ripped soil profile before reconsolidating. Alternatively, minimising evapotranspirational losses from the mid-row by not planting a cover-crop may encourage increased root exploration into the ripped zone.

The application of mulch on the vine row soil surface can have a considerable effect on soil moisture retention, potential nutrient availability and vine growth. Whilst it is assumed that mulch universally increased vine access to stored soil water, data reported here does not support this. This was first reported by Lanyon and Bramley (2004) where they suggested that on heavier soil types the use of surface mulch had little effect on vine growth and yield. Results presented here generally supported this over the short term (two vintages). However, evidence from two experiments using mulch suggests that the addition of mulch on heavy soils will take more than two vintage to show any effect on vine growth and yield. The effect on vine growth and yield then peaks in the fourth to fifth vintage with some residual effects still evident in the seventh vintage. In contrast, the response in vine growth and yield on light soils is immediate, with a peak in the second vintage which then dissipates by the seventh vintage. Unlike ripping, mulch does affect berry quality. The addition of mulch had the greatest effect on both total soluble solids and grape pH. Soluble solids were generally reduced by the addition of mulch although this could be offset by delayed harvesting. Grape pH was increased after the application of surface much with the greatest impact occurring on the lightest soils. The increase in pH diminished with each vintage until the effect was negligible by the seventh vintage.

Whilst the effect of the mulch on berry quality was measured as minimal by the eighth vintage, differences in wine spectral and chemical attributes were still evident. These differences, however, were not strong enough to be detected organoleptically.

The selection of either ripping or adding mulch to the under vine soil surface primarily depends on the expected response of the vine to the applied treatment and the cost of implementing. The expectation is that if roots are growing in the mid-row there will be a negative response to ripping that will dissipate by the third year. The difficulty in ripping areas that are void of root activity is that there is no clear expectation about how the vine will respond. Generally, vine growth and yield increase after the second vintage but this cannot be associated with soil texture or soil conditions. More research is required before a more reliable prediction of vine response to ripping can be made. These studies would need to that take into account the different soil profile conditions as well as the soil moisture dynamics and weather conditions that can influence root access to the mid-row. The response of the vine to the application of mulch is more predictable. From this report and others, the vine response to mulch on a light soil is larger and more immediate compared to a heavy textured soil but the effects will dissipate quicker. Hence, the reapplication of mulch on light soils should occur every six years whereas on heavy soils reapplication should occur every eight years. From the results in this report and those presented by Lanyon and Bramley (2004) it can be argued that the magnitude of the vines response to mulch application increases in more saline environments. The effect of salinity on vine performance is partly alleviated by the single application of mulch, much more than ripping, however, the effect of multiple application of mulch has not been tested. The expectation would be that the impact of successive mulch applications on reducing the effects of soil salinity on vine yield would progressively become less pronounced. Soil salinity would still remain but the soil conditions and reliance on irrigation would be reduced.

Cover crops, water use and vine performance

Colin McDonald, Vivek Bhat, Rob Hetherington

Methods

The trial on the effect of width of cover crop on vine vigour was undertaken at Powder bark Ridge Vineyard, Frankland WA on a seven year old medium to vigorous Shiraz block commencing in 2006-07. The experiment was designed in randomised blocks with the following four cover crop width treatments randomly applied within each of the four replicated gradually sloping vineyard blocks:

1) 0.0 metre (bare)
2) 0.8 metre wide cover crop
3)1.6 metre wide cover crop
4) 2.4 metre wide cover crop (Full width crop)

Within each replicate there were six experimental vines per treatment from which data were collected giving a total of 24 vines per treatment. Several buffer vines were used to separate replicates. The cover crop was a volunteer sward principally of rye grass (annual & perennial). The different treatment widths were obtained by use of herbicide spray.

During 2007-08 the bare mid-row and the full width cover crop treatments were replicated eight times leaving the other two treatments replicated four times to nullify the high degree of variation observed among the vines within the replicates. Thus there were 48 vines in the first and the fourth treatment while, the middle two narrow cover crop width treatments had 24 vines per treatment The treatments were applied for three consecutive years. The data were subjected to simple ANOVA with a total of 20 degrees of freedom (df) and the linear (1df) and deviations (2 df) components as added sources of variation.

The following data were collected as indicated:

Shoot length at fortnightly interval

Pruning weight per vine in 2007

Ripening profiles: ^{0}Brix, pH

Harvest ^{0}Brix, pH and TA

Harvest yield, bunch number and berry weight- were recorded only for the first two seasons due to the reasons beyond the control of the researchers.

Gypsum blocks were used to indicate soil moisture levels. These were placed under vines in each replicate at 30, 60 and 90cm depths with extra gypsum blocks in the mid rows at 60 and 90cm depths. Under-vine blocks were monitored continually with G bugs while, those in the mid-rows were monitored weekly with hand loggers. An automatic weather station was also installed at the site.

Results and Discussion

2006-07

The season was very dry with a total of only 306mm compared with the 600mm long term average. There was negligible rain until early August and the cover crop grew to only 2.21 tonne/ha by the end of September when it was slashed and gradually senesced over the subsequent few weeks.

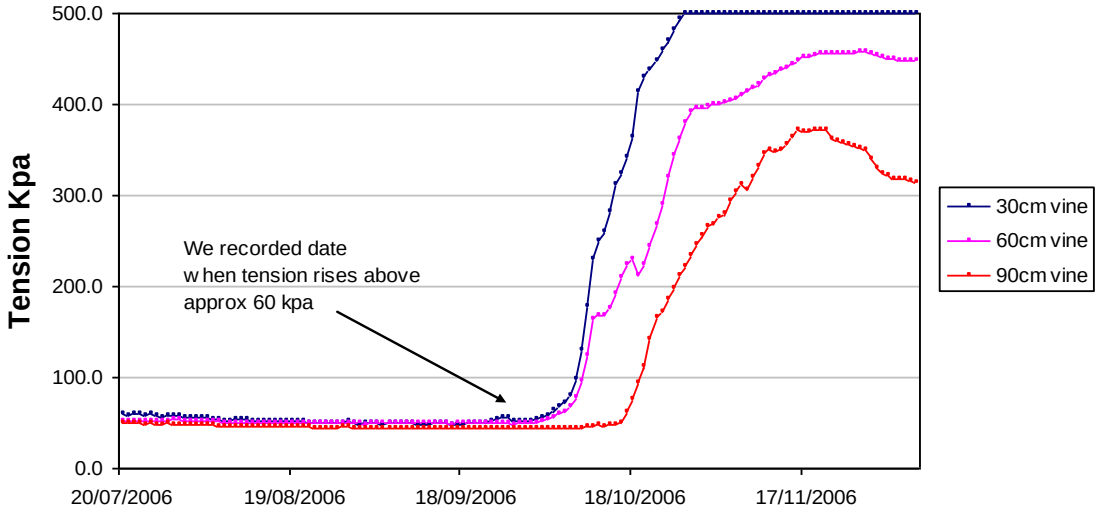


Figure 35: Example of the transient change in soil water tension measured with gypsum blocks at three depths

The change in soil water tension from July to November is presented in Figure 35. For a number of weeks the soil water tension was about 60 kPa which suggests water was readily available to the vines for all treatments. Different treatments then rose above the 60 kPa as they dried out at various times in late spring. The number of days taken from bud bursting for soil drying above 60 kPa for each replicate was counted and the data were analysed and graphed in Figure 36.

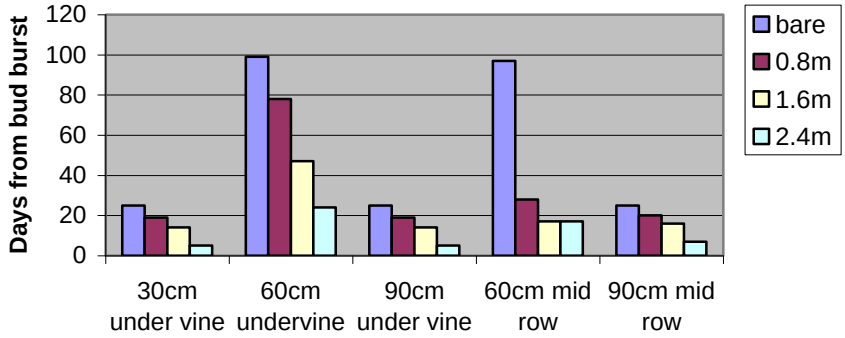


Figure 36: Effect of cover crop width on the number of days from budburst for gypsum blocks to reach 60 kPa soil water tension at different depths, locations and treatments for the 2007 vintage

60cm under the vines with the bare treatment, the soil stayed moist for nearly 100 days, but dried out progressively faster with increased width of cover crop. The full width cover crop treatment dried the soil about 20 days after bud burst- or five times faster in reducing the soil water under vine than bare soil. There was a similar trend for gypsum blocks at 30cm depth; however the soil was drier for all width cover crops than at 60cm depth, probably as a result of increased surface evaporation. Surprisingly the 90cm deep blocks dried as rapidly as those at 30cm with the wider cover crop plots drying more rapidly than the bare soil plots.

A similar pattern was apparent for the mid-row data, with the 60cm deep gypsum block in the bare treatment taking nearly five times longer to dry compared to other treatments. The soil moisture pattern was comparable at 90 cm deep both under the vines and at the mid row suggesting that the much below average rainfall was insufficient to refill the profile. The results showed a clear trend of wider cover crops drying the soil quicker even in this dry year.

There was an inverse relation between the shoot length and the width of cover crop (Figure 37). Shoots from the vines treated with wider cover crops (full width and 1.6m) were about 20cm or 20%

shorter than those from the vines with 0.8m and bare treatments. This is the reflection of the trends in soil water tension discussed above.

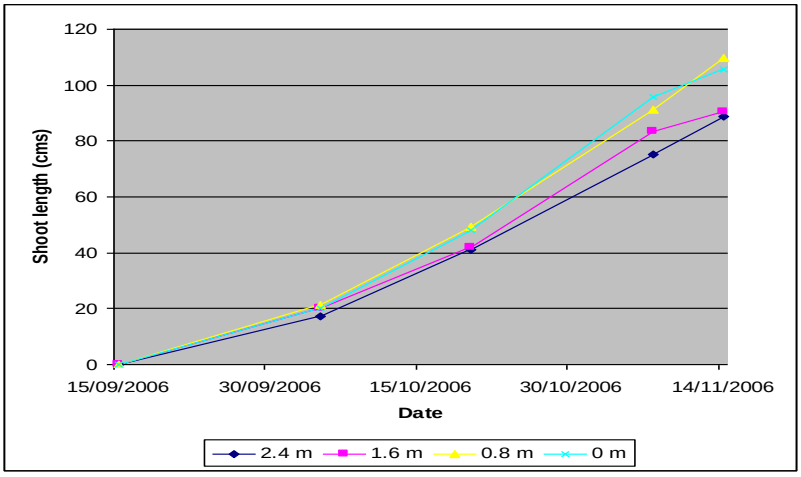


Figure 37: Effect of cover crop width on vine shoot growth during the 2007 vintage.

Despite the large and significant treatment effects on soil moisture and shoot length, there were no significant treatment differences in any of the harvest data. This could be attributed to the high degree of variation between the treatments within the replicates resulting in nullification of the treatment effects on the berry yield off the vines (Table 19).

Table 19: The effect of cover crop width on vine and grape properties for the 2007 season. Values followed by the same letter are not significantly different (P=0.05).

Cover crop width	Yield (t/ha)	Bunches /vine	TSS (ºBrix)	TA (g/l)	Berry weight (g)	pH
0.0 metres	14.4[a]	61.4[a]	22.8[a]	4.9[a]	1.43[a]	3.3[a]
0.8 metres	14.5[a]	64.1[a]	22.6[a]	4.9[a]	1.40[a]	3.3[a]
1.6 metres	13.6[a]	61.2[a]	22.8[a]	4.9[a]	1.28[a]	3.2[a]
2.4 metres	13.3[a]	55.6[a]	22.8[a]	5.1[a]	1.41[a]	3.2[a]

Yield per vine was about 7kg comprising 55-64 bunches per vine (Table 19), with an average berry weights of 1.3-1.4g. TSS in the berries ranged from 22.5 to 23 ^{0}Brix, pH between 3.3 and 3.4 and TA 5 to 5.5 g/L. It should be noted that the calculated yield/ha is higher than the surrounding vineyard as treatment vines were not crop thinned as is the regular practice.

2007-08

The season received 507 mm rainfall which was much higher than the previous year and although lower than the long-term average was well distributed through the winter and the spring. As a consequence the cover crop grew much faster and more vigorously producing 4.18 t/ha which was nearly double the amount of previous season. The wider cover crops dried the soil moisture in the mid-row in 35 days from the bud burst while it took almost 73 days in the bare soil treatment at 60 cm depth. This was a delay of 38 days (Figure 38). However, this was not the case under the vines where irrigation water counteracted the drying effect and maintained the moisture at a high level through the soil profile for up to nearly 80 days (Figure 39).



Figure 38: Effect of cover crop width on the number of days from budburst for the 60cm gypsum block in the mid-row to reach 60 kPa soil water tension during the 2008 season.

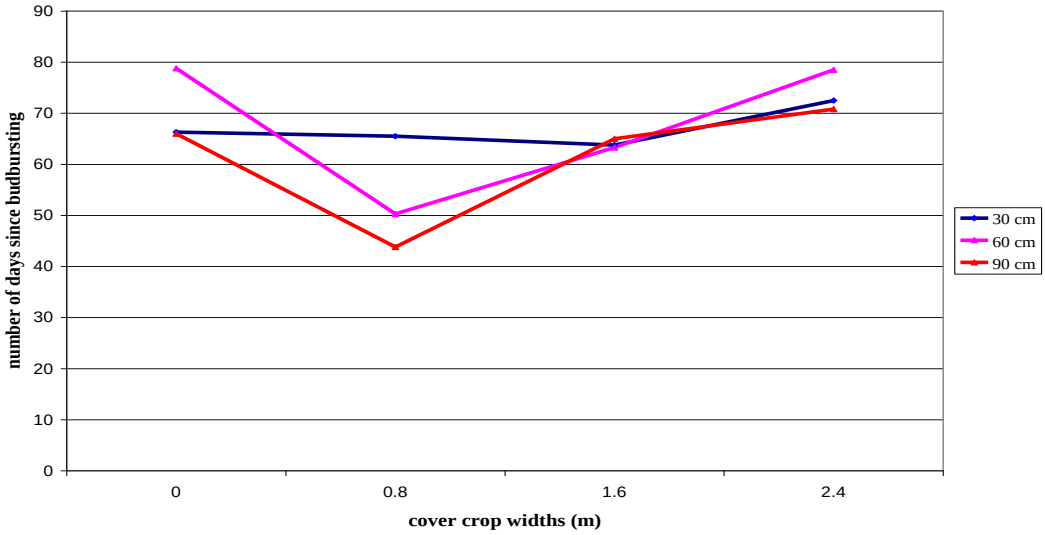


Figure 39: Effect of cover crop width on the number of days from budburst for gypsum blocks under the vine at various depths to reach 60 kPa soil water tension during the 2008 season.

The shoot lengths were impacted in a very similar way as in the previous year. With the exception of the initial first stage just after the bud burst there was a significant inverse linear correlation between shoot length and cover crop width (Table 20). The overall rate of growth (calculated from the initial and final lengths and expressed as a percentage was lowest for the vines surrounded by the full width cover crop. The growth rate was significantly less than the bare and the narrow cover crop treatment, however it was similar to the 1.8 m wide cover crop. The bare inter-row treatment stood out in producing significantly vigorous vine shoots..

The reduction in the vigour is very much reflected in the weights of the prunings collected in the second season during June 2007 (Figure 40). There were no significant differences in the weight of prunings between treatments in the first season and all were low as a result of the drought. In the second season there was a 150 percent (in the case of bare treatment) as a result of higher winter-spring rainfall. However, the full width cover crop checked this potential extra growth and vine vigour was about same as it was in the first season. Hence, there was a clear linear trend of reduced canopy volume with the wider cover crops.

Table 20: The effect of cover crop width on shoot growth for the 2008 season. Values followed by the same letter for the same sampling date are not significantly different (P=0.05).

Cover crop width	Shoot length (mm)					Overall growth (%)
	(5/10/07)	(26/10/07)	(9/11/07)	(23/11/07)	(1/12/07)	
0.0 metres	176[a]	500[a]	676[a]	881[a]	989[a]	466[b]
0.8 metres	130[b]	404[b]	558[b]	743[b]	788[b]	520[b]
1.6 metres	133[b]	382[b]	534[b]	645[b]	701[b]	431[ab]
2.4 metres	160[a]	422[b]	560[b]	674[b]	724[b]	356[a]

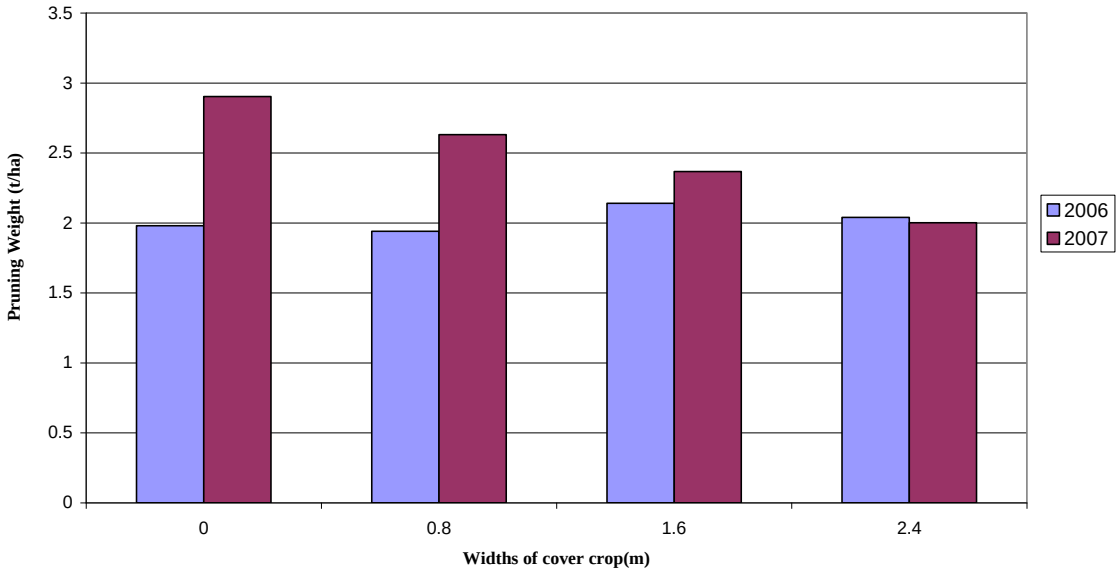


Figure 40: Effect of width of cover crop on pruning weight June 2006 & 2007

The number of bunches was decreased by increasing the width of the cover crops with the full width cover crop resulting in the lowest number of bunches per vine. There was a significant impact of cover crop on the fruit yield (Table 21) with about a 30% reduction in yield (from 9.79 kg/vine to 6.52 kg/vine) with full width cover crop compared with bare soil. This equates to a calculated yield reduction from 19.5 t/ha to 13 tons /ha in the block with full width cover crop. In sites prone to excessively high yield and vigour this result demonstrated the effectiveness of cover crop width in controlling this excessive vigour at relatively low cost. It was noteworthy that the berries from the vines surrounded by full cover crops had higher TSS compared to those from other vines (Table 21). None of the other berry maturity indices were affected by the cover crop treatments.

Table 21: The effect of cover crop width on calculated yield/ha, yield components and selected maturity indices for the 2008 vintage. Values followed by the same letter are not significantly different (P=0.05).

Cover crop width	Yield (t/ha)	# Bunches /vine	TSS (ºBrix)	TA (g/l)	Berry weight (g)	pH
0.0 metres	9.79[a]	83.[a]	21.7[a]	6.90[a]	1.36[a]	3.31[a]
0.8 metres	8.99[ab]	81[ab]	21.2[a]	6.73[a]	1.31[a]	3.30[a]
1.6 metres	7.74[bc]	78[ab]	22.1[ab]	6.68[a]	1.30[a]	3.30[a]
2.4 metres	6.52[c]	73[b]	22.7[b]	6.62[a]	1.28[a]	3.32[a]

2008-09

The 2008-09 season recorded higher rainfall (530mm) compared to the previous seasons although it was still less than the long-term average rainfall for the region it resulted in vigorous cover crop growth. The full width cover crop treatment hastened the drying of the soil profile at all the depths compared to the other treatments (Figure 41). Increasing the width of the cover crop resulted in a gain of around 14 days and 28 days at 60 cm and 90 cm depths respectively under vines. There was little advantage in the 0.8m wide cover crop over bare soil in terms of days to reach 60kpa and the 1.6m wide cover crop only advanced soil drying to 60kpa at 60 and 90cm by eight and 18days respectively. Full width cover crop resulted in drying out the top 30 cm soil profile under the vine within a month of bud burst which contributed to a significant reduction in vegetative growth. High transpiration of the full width cover crop may have reduced water movement through the profile during winter-spring thus reducing any potential contribution to saline water tables which otherwise could have risen into the rootzone

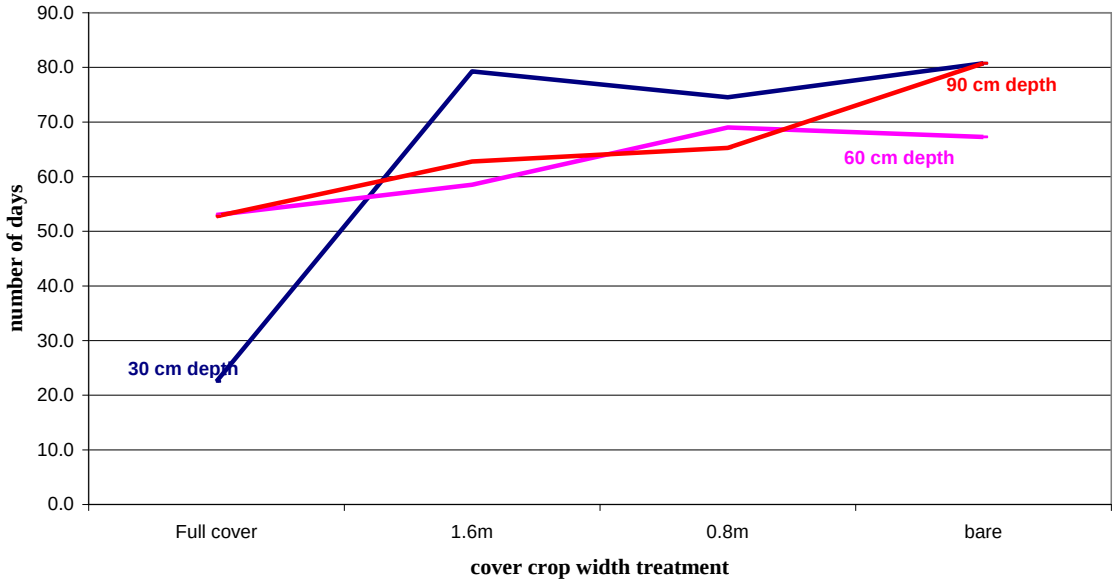


Figure 41: Effect of cover crop width on the number of days from budburst for gypsum blocks under the vine at various depths to dry to 60 kPa soil water tension during the 2009 season.

It is also apparent that the drying of soil profile under the vines by different cover crop widths was similar to the pattern in the mid-row (Figure 42). Full width or 1.6 m wide cover crops dried the mid rows much faster than not having any cover crop or a narrow (0.8m) cover crop. The latter combinations required many more days (80) to dry out the moisture from the middle profile at 60 cm depth than their counter parts under the vines (68 days) at the same depth of soil. The full width cover crop dried out the soil moisture in 25 days from the mid row and in 53 days under the vines; a difference of about 30 days.

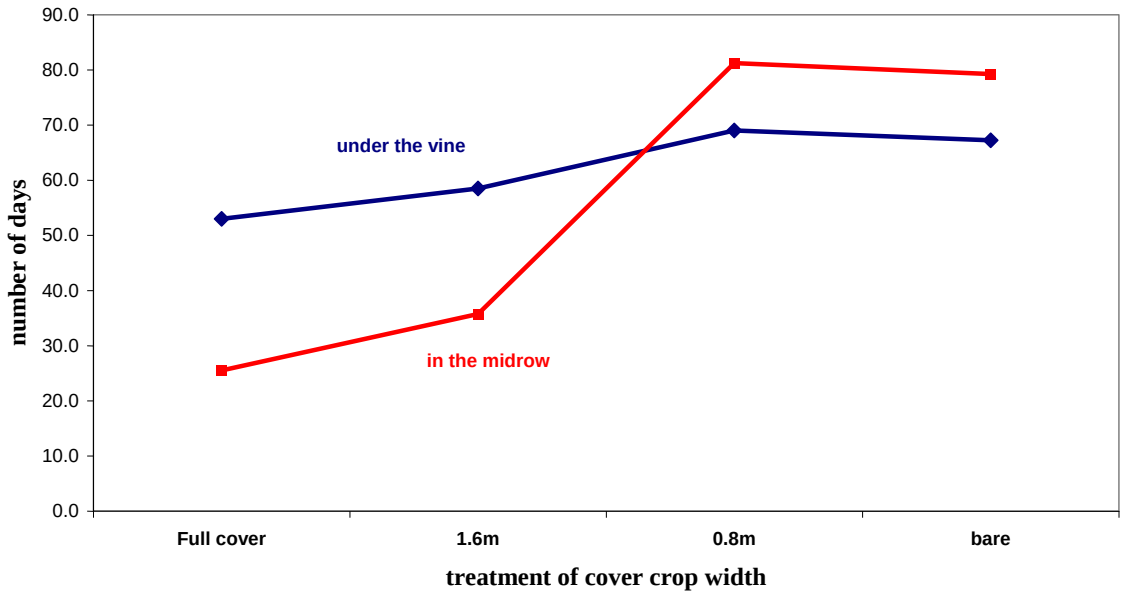


Figure 42: Effect of cover crop width on the number of days from budburst for 60 cm deep gypsum block to reach 60 kPa soil water tension during the 2009 season.

The linear negative relationship between cover crop width and shoot length observed in the previous year was repeated in this season as well with the widest cover crop resulting in a shortest shoot length (70.1 cm) recorded on 12/12/08 (Table 22). It was significantly shorter than those recorded on vines with no cover crop (81.8 cm), however it was similar to all other treatments. The overall rate of growth measured over the stages starting with the first stage to the fifth stage indicated a very significant difference among the treatments..

Table 22: The effect of cover crop width on shoot growth for the 2009 season. Values followed by the same letter at each sampling date are not significantly different (P=0.05).

Cover crop width	Shoot length (mm)					Overall growth (%)
	(21/10/08)	(3/11/08)	(18/11/08)	(28/11/08)	(12/12/08)	
0.0 metres	178^{a}	371^{a}	513^{a}	647^{a}	818^{a}	367^{a}
0.8 metres	173^{a}	360^{a}	513^{a}	640^{a}	790^{ab}	361^{a}
1.6 metres	164^{a}	344^{a}	470^{a}	602^{a}	738^{ab}	355^{a}
2.4 metres	187^{a}	348^{a}	453^{a}	565^{a}	701^{b}	278^{b}

Total sugar, titratable acid, and berry weight were not affected by the width of cover crop (Table 23). There was a slight but insignificant increment in the sugar level in the full cover crop width treatment. Interestingly the pH of the berry juice was significantly impacted by all the cover crop treatments except the bare mid-row. It was less acidic with the control (bare) cover crop than the other treatments. Cover crop width treatments did not impact the qualities of berries in spite of being able to reduce the vine vigour to a significant level through their quicker drying effect on the soil moisture in the mid-row.

Table 23: The effect of cover crop width on grape attributes for the 2009 vintage. Values followed by the same letter are not significantly different (P=0.05).

Cover crop width	TSS (ºBrix)	TA (g/l)	Berry weight (g)	pH
0.0 metres	24.1^{a}	6.05^{a}	1.26^{a}	3.39^{a}
0.8 metres	24.8^{a}	5.91^{a}	1.30^{a}	3.34^{b}
1.6 metres	24.3^{a}	6.06^{a}	1.26^{a}	3.34^{b}
2.4 metres	25.0^{a}	6.18^{a}	1.26^{a}	3.36^{ab}

In the first dry season of 2006-07 there was probably no loss of rainfall below the root zone and the soil stayed moist only in the bare mid-row block while, it got dried so rapidly in all other treatments that there was no affect of cover crop width.. This suggests that when the rainfall received is lower than the normal any width of the cover crop is equally effective at drying the soil moisture within a month of bud burst.

The next two seasons of 2007-08 & 2008-09, when rainfall was closer to average and more uniformly distributed the cover crops grew well enough to dry the profile under the 1.6 m and 2.4 m treatments. while the 0.8 m wide cover crop was not sufficient to dry the profile in time to control vegetative growth (Figure 43). There was a consistent pattern of their ability to dry out the soil moisture in the mid row at 60 cm depth by the wider cover crops indicating their importance in managing the ground water recharge and the possibility of a rise in saline ground water. It is also important from the view point of the canopy management of vigorous vines on high potential soil types.

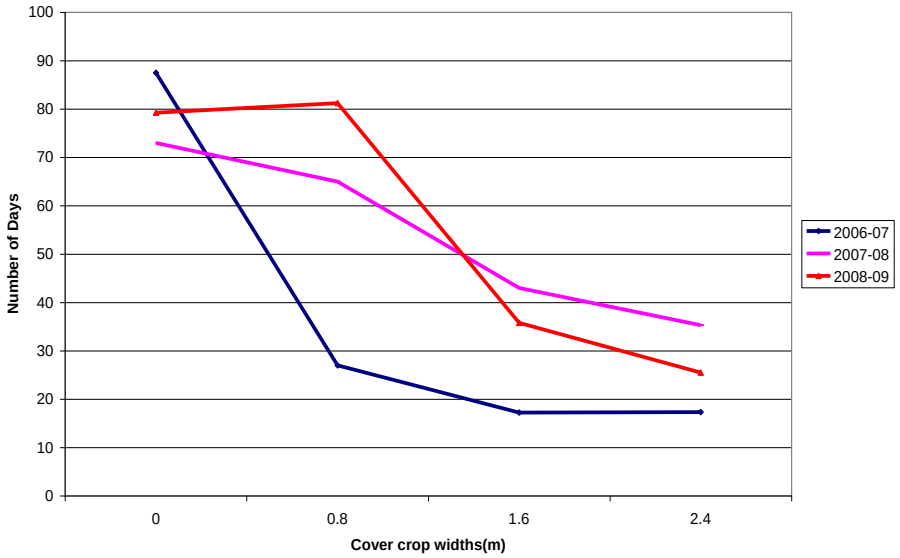


Figure 43: Comparative length of time taken for the mid-row soil at 60 cm depth to dry in different seasons

Outcomes and Conclusions

The current study has revealed a clear inverse correlation between the width of cover crops and vine vigour. The wider cover crops reduced the vine vigour by significantly reducing shoot length over the season and although inconsistent, improved the berry quality. More than all there was a greater reduction in the berry yield on a per hectare basis when the vines were surrounded by wider cover crops compared to their counter parts- the biggest gain that could be achieved to realise the marketability of the berries. The wider cover crops have enabled to slash down the crop by a third- a significant achievement.

The wider cover crops in a normal rainfall season could also help in achieving the following objectives along with the main objectives of reduced vine vigour and berry yield.

- Better and less expensive canopy management due to the lessened canopy over crowding
- Better air circulation inside the canopy
- Eventual reduction in the disease inoculums
- Improved exposure of berries to solar radiation and earlier ripening
- Easier harvesting
- Better soil ecology due to cover crops' root activities

Australian native cover crop species and vine performance

Chris Penfold

Methods

The outcomes from this project have the potential for adoption across all viticultural environments in south-eastern Australia. To determine the suitability of native species for cover crops, nine trial sites were established, across south-eastern Australia. At each site, an assessment of the most suitable species mix was made, using local knowledge of the native species known to grow and persist in that environment. These were then sown using machinery modified for the purpose, or in 2 cases where it was hand broadcast.

Seed Source: An important consideration in species selection was the availability of seed in sufficient quantities. The native grass seed was mostly purchased from a commercial seed producer in Victoria, while other smaller parcels were sourced from local producers. Saltbush seed was purchased from South Australian suppliers.

Seeding machinery: A major issue with planting native grasses is the nature of the seed, which often has long and sometimes barbed awns which support seed dispersal in the natural environment. For most species it is either physically impossible to remove these structures, or too expensive. It is therefore necessary to either adapt seeding machinery to handle the seed and/or modify the seed to enable passage through conventional equipment.

A New Zealand made vineyard seeder which used counter rotating sponge rollers for seed distribution at the base of the seed box, was modified to handle the range of seeds to be sown within this project. A new manifold with larger hoses, an electric/hydraulic lift mechanism and attachment to the 4 wheel ATV bike which towed the machine was all completed in the Roseworthy Campus workshops. An electric agitator was later added to the inside of the box to prevent seed from bridging, and press wheels were added to the rear of the machine. This unit was very mobile and manoeuvrable, and with disc soil openers suffered no blockages caused by prunings while sowing the vine mid-rows (Plate 6).



Plate 6: Modified Taege seeder towed by an ATV, used for sowing cover crops in the Yarra Valley, 2007.

In the case of wallaby grass, the seed was also coated to provide it with the ballistic properties for seed distribution and movement to the soil. This is a recent commercial innovation, which also allows the addition of insecticide and fungicide to the seed which assist in survival.

Setup and design of sites

The trial site locations were selected to provide the major grape growing regions of south-eastern Australia with access to information about the suitability of the cover cropping practice and associated

species to their environments. Vineyards were chosen based on the co-operators enthusiasm for the work, and the site suitability for conducting a trial. The trial sites ranged from 1 – 3 ha in size, as it was intended to conduct invertebrate population studies which required larger areas to provide relevant information. The trial design also varied, depending on the number of rows available for a trial, and the pre-existing treatments. At most sites, 4 replications of 3 or 4 treatments, with 3 rows per treatment were used. At Kingston-on-Murray where only 2 mid-rows of saltbush at 2 sites was available, the saltbush was removed from 4 panels down the row to provide plus and minus treatments. At Coonawarra, there were insufficient rows for full replication, so a side by side comparison was used instead. The initial seeding locations are listed in Table 24.

Table 24: Site locations and species sown at each site, their sowing date and the success of establishment.

Site	Species	Planting Date(s)	Success / Failure
Nuriootpa	Wallaby grass (*Austrodanthonia richardsonii)*	1-8-06	Success
	Windmill grass (*Chloris truncata)*		Success but later died
	Creeping saltbush (Atriplex semibacatta)	1-8-06	Success
Coonawarra	Wallaby grass	21-6-07;	Success
	Qld. Bluegrass	31-1-07 2-10-07 26-9-08	Failure
	Chloris	31-1-07 2-10-07 26-9-08	Failure
	Redgrass	26-9-08	Failure
Loxton	Creeping saltbush	13-7-06;	Success
Kingston-on-Murray	Ruby saltbush	Established prior to this trial	Success
Langhorne Creek	Creeping saltbush	15-8-05 16-11-06 29-8-08	Failure
Hunter Valley	Wallaby grass	30-10-06 8-8-07	Failure
	Windmill grass	30-10-06 8-8-07	Failure
	Qld. Bluegrass	30-10-06 8-8-07	Failure
	Kangaroo grass	30-10-06 8-8-07	Failure
	Weeping grass	30-10-06 8-8-07	Failure
Griffith	Creeping saltbush	11-7-06 19-6-07	Failure
	Wallaby grass	11-7-06 19-6-07 11-8-08	Failure
Yarra Valley	Wallaby, windmill, Qld. Bluegrass, kangaroo, weeping grass	5-10-06 4-10-07; 7-8-08	Failure
Swan Hill	Creeping saltbush	25-7-06 20-6-07	Success

As shown in Table 24, several sites failed to establish the sown cover crops. Unfortunately the sowing of these sites coincided with 3 years of drought throughout the south eastern region of Australia. Australian native plants have evolved to survive in environments of climatic extremes. Their perennial nature, with dormancy induced through water stress, is one such mechanism. Another is the dormancy mechanism of their seeds. In some saltbush species for example, high sodium levels in the seed coat need to be removed by significant rainfall events before germination will occur. With grasses, the size of the naked caryopsis is generally very small, meaning there are limited energy reserves in the seed to develop a coleoptile capable of emerging from greater than approximately 1 cm. The seeds therefore have to be sown very shallowly, meaning obtaining the desired moisture conditions to enable germination is not easy, particularly during periods of drought. It is also possible that the quality of the seed harvested during the drought was compromised. Despite germination testing in the lab prior to seeding each year, the performance of seed in the soil, especially during dry conditions, did not replicate the potential seed emergence. Native grasses are well known for their recalcitrant behaviour in establishment, and this remains a major impediment to their wider adoption.

Importantly, the main site at Nuriootpa established very successfully, and produced spectacular stands of each species. Again though, an unexpected response occurred with the windmill grass at Nuriootpa. When dormant during winter it is recognized as being tolerant of glyphosate herbicide. As a broad spectrum of weeds appeared during the winter period, it was decided to remove them using glyphosate with the addition of oxyflurofen (Striker®) for mallow control on the 10th of July, 2007. This mix was unfortunately lethal to the windmill grass, and disappointingly it did not regenerate from seed reserves. This treatment then became a regenerated sward consisting primarily of weed species (mallow *Malva parviflora*, geranium *Erodium* spp, wireweed *Polygonum aviculare*, and witchgrass *Panicum spp)* dominating during the summer period.

Site characteristics

Of the 8 sites sown, 4 established successfully, and with access to another site with sown saltbush from a previous CRCV trial, 5 sites were then used for evaluation. Their characteristics are shown in Table 25.

Table 25: Site characteristics of the five successful experimental plantings.

Site	Soil type	Rainfall (mm)	Irrigation method	Variety	Row spacing (m)	Vine spacing (m)
Nuriootpa	Brown grey loam / clay loam	525	Drip	Shiraz	3.0	2.25
Coonawarra	Brown / dark brown heavy clay	650	Dry grown	Shiraz	4.9	2.3
Loxton	Brown / red loam	250	Drip	Chardonnay	3.0	2.45
Kingston-on-Murray	Light brown loamy sand over limestone rubble	260	Drip	Semillon	3.0	2.0
Swan Hill	Brown / red heavy clay	350	Sub-surface drip	Shiraz	3.3	1.8

Trial assessment

Assessment of those sites which established successfully varied from basic yield and quality criteria to intense soil analysis and invertebrate population determination (Table 26).

Yield and quality determination

At each site, panels of vines for harvest were visually selected to ensure they were characteristic of that treatment, with no outliers exhibiting unusual growth characteristics. The number of bunches and yield per vine was recorded for two or three vines per panel. Harvested grapes were transported to Roseworthy Campus where they were sub-sampled for berry analysis (weight, pH, TA and ^{o}Brix). The wine making protocols of the Hickinbotham Roseworthy Wine Science Laboratory were followed

for both red and white wine, and small lots (5L) were successfully produced. A series of triangle and balanced reference duo-trio difference tests, were conducted to examine whether trained panellists could detect perceivable differences in flavour between three Barossa Shiraz wines and three Coonawarra Shiraz wines made from vines that had grown amongst different cover crops. Once difference was established, a trained sensory team at the AWRI then assessed the wine quality to determine what constituted the differences. The high cost of this assessment and the highly variable results meant this was only conducted on three Barossa wines.

Soil microbial biomass

Soil cores from the Nuriootpa site were sub-sampled at 0-10, 10-20, 20-30 and 30-50 cm increments. While the 30-50 cm depth is beyond the Australian Greenhouse Office requirement of 30cms, the extra analysis was undertaken to determine whether the root systems of the perennial plants were having a significant impact on organic matter accumulation at the greater depth. Soil microbial biomass was determined following the methods of Vance et al (1987).

Root length densities

To determine the capacity for the perennial species under investigation to improve soil characteristics via their root systems and associated biology, it was necessary initially to determine whether a more extensive root system was associated with the perennial species. At the Nuriootpa site, three soil cores per replicate, each 44mm in diameter were extracted from the top 50 cm and divided up into 0-10 cm, 10-30cm and 30-50cm sections. These were air dried at 40 ^{o}C, after which the samples were washed to separate the roots. These were scanned and total root lengths determined using the Win Rhizo® software.

Total Carbon and Nitrogen

This was undertaken to discriminate between the labile carbon as shown by the microbial biomass and the total carbon which may also include carbon as charcoal that is highly resistant to microbial degradation. Using soil from the above cores, soil was analysed for total carbon and nitrogen at the CSBP laboratories in Western Australia.

Soil mineral content determination

Soil from Nuriootpa, Coonawarra, Kingston-on-Murray, Loxton and Mystic Park was collected from 0-10cms, air dried and analysed for mineral content by CSBP.

Earthworm populations

Soil was collected from the Nuriootpa site twice in 2008 and once in 2009 from 0.1 m^2 quadrats to 10 cm deep. These were hand sorted, counted and weighed to determine earthworm populations and biomass.

Soil moisture

To measure the impact of the different cover crops on soil moisture in the mid-row and under the vine, gypsum blocks were installed (at Nuriootpa, Loxton and Banrock Station) at 4 depths to 1 metre down the soil profile, and attached to a GBug® data logger.

To compliment the in-field moisture determination, a glasshouse based lysimeter experiment was established in 2008 to determine the water use characteristics of the cover crop species that were under investigation. The glasshouse was covered with shade-cloth and evaporative coolers were set to restrict maximum temperatures to 25 ^{0}C. Sixteen PVC tubes 33 cm in diameter and 74 cm tall were filled with sandy loam topsoil removed from a Roseworthy paddock. In these tubes, 2 replicates of 5 native grass and 3 saltbush species were grown, along with a bare soil control. Once well established, the pots were filled with water and allowed to drain to field capacity, after which weights were taken weekly. As the plants senesced, DM samples were taken and oven dried. This experiment was conducted over 2 periods in October 2008 and February 2009.

Floor and canopy temperature

With the influence of climate change being displayed through higher temperatures, the potential for ground covers to subdue canopy temperatures was investigated at the Loxton site. Tiny Tag® temperature data loggers were placed on top of and below saltbush plants, on bare ground and in the canopy hanging from the cordon wire in plus and minus saltbush treatments.

Insect populations and abundance

In collaboration with Dr. Linda Thomson from CESAR (Centre for Environmental Stress and Adaptive Research) at the University of Melbourne, the Barossa, Coonawarra and Swan Hill sites were intensively sampled for invertebrate populations, to determine how they might change due to changes in habitat generated through the different cover cropping practices. Further detail on the methodology used is to be found in the paper provided in this report.

Weed management with native species

At all sites at appropriate phenological stages, crop and weed biomass were sampled from a 33cm square quadrat and dried to determine their relative dry matter production and quantify the capacity of the various cover crop species to suppress weed growth.

Table 26: Summary table of the assessments used to determine the value of native species as mid-row cover crops.

	Nuriootpa	Coonawarra	Loxton	Kingston-on-Murray	Swan Hill
Yield	√	√	√	√	√
Grape and Wine Quality	√	√	√	√	√
Pruning weights	√	√			
Cover Crop & Weed Biomass	√	√	√	√	√
Earthworms	√				
Invertebrates	√	√			√
Soil Biology	√				
Soil Chemistry	√	√	√	√	√
Soil Structure	√				
Water use	√		√	√	

Statistical analysis

Harvest data from all sites was analysed by Ray Correll (CSIRO). Other simple ANOVAs were performed by the chief investigator using Genstat.

Results and Discussion

Grape yield and quality

Nuriootpa

As noted earlier, the Nuriootpa site cover crops established well, but the chloris treatment became a regenerated sward following inadvertent herbicide damage. Due to the young vine age, when competitive effects would be greatest, this site provided a valuable insight into the compatibility of the native cover crops and vines in a water-limited environment. Yield components and selected maturity indices are presented in Table.27.

Table 27: Yield, its components and berry maturity indices, Nuriootpa, 2009

Variable	Control	Regen	Danthonia	Saltbush	SED	*P*
Yield (kg/vine)	7.9	6.8	5.6	4.3	0.7	<.001
Bunches per vine	139.2	119.5	119.9	120.1	12.4	0.364
Berry weight (g)	0.93	1.00	0.88	0.95	0.09	<.001
Berries per bunch	62.6	54.3	59.7	50.7	4.7	0.052
TSS (^{o}Brix)	24.8	24.5	24.7	24.0	0.4	0.085
TA (g/l)	9.97	9.60	9.71	9.58	0.21	0.273
pH	3.83	3.70	3.86	3.91	0.04	<.001

Yield loss compared to the control was significant where saltbush and wallaby grass cover crops were growing. The regenerating sward, which was mowed regularly also displayed a significant yield loss, which in all three treatments was found to be due mostly to loss in berry weight with a possible influence of more vine bunches on the control. These young vines were growing in a water-limiting environment and competing against plants in the mid-row that were well adapted to dry environments and were capable of soil water depletion well beyond 500 MPa tension. Their growth and productivity was therefore limited to the quantity of water provided via the drip system.

The results suggest the growth of these perennial cover crops as complete cover is not sustainable in the Barossa environment, particularly in a young vineyard. However, other benefits from their inclusion as cover crops would suggest they may still have a role within the vineyard, but at much lower densities than were explored in this project. For example, it may be possible to have saltbush only in every second row, or 2 seeding rows of wallaby grass with 2 rows of cereal either side, or growing alternate rows of wallaby grass and cereal, which would be quite compatible from a management perspective. In vineyards displaying excess vigour, the growth of wallaby grass or saltbush in the mid-row may be very effective at providing some competition to the vines, thereby improving vine balance and ultimately wine quality. Further research is therefore necessary to fine tune the inclusion of native perennials within the vineyard so their benefits can be realized in both high and low vigour sites.

Berry juice pH was higher in the saltbush plots and lower in the regenerated sward compared with control plots. This may be due to an enhanced level of potassium in the juice. As will be shown in a later section, the saltbush treatment did show elevated levels of exchangeable potassium and sodium in the top 10 cm of soil in the mid-row. Given the capacity for saltbush to dry the soil profile (see section 'Soil moisture'), it is surprising vine roots would be sufficiently functional in this zone to be taking up these minerals. However, as salts, these minerals would move readily down the soil profile after a rainfall event, possibly into a region of vine root activity and therefore uptake into the plant and berries. If this theory is correct, it provides further justification for not growing saltbush in areas such as the Barossa where vine root activity in the mid-row is expected, as higher pH juice, possibly due to potassium, and elevated sodium, is undesirable.

A tasting panel found distinct differences in wines produced from grapes grown using the different mid-row treatments (Table 28).

Table 28: Sensory analysis of Barossa Shiraz wines from the control, wallaby grass and saltbush treatments.

Wines	Bracket	N (number of panellists)	Number Correct	k	Significance
Wallaby grass v Salt Bush	25 Triangle	55	39	27	P<0.01
Wallaby grass v Cereal crop	26 Triangle	62	42	29	P<0.01
Salt Bush v Cereal crop	27 Triangle	62	27	29	ns

These analyses determined that wine produced from vines with wallaby grass as a cover crop either side was different to those with saltbush or cereal cover crops, but there was no difference between saltbush and cereal cover crops. While this was of interest, the trained sensory panel at AWRI were unable to reliably assess quality differences due to highly variable responses, and hence no meaningful insight into what the differences consisted of. In view of this such methodology was not pursued as an assessment procedure for any other sites.

Coonawarra

As shown in Figure 44, the grape yield was unaffected by the growth of wallaby grass in the wide mid-rows of the very old dry grown Shiraz vines at the Coonawarra site. This is probably due to the vineyard design, with 4.9 metre row spacings providing a large zone of mid-row soil for the old roots to access moisture, and the relatively low yield (in 2009) of the vines. Weather data for Coonawarra shows they had 648 mm rainfall in 2007 and below average 540 mm in 2008, which is most likely the reason for the reduced yield in 2009.

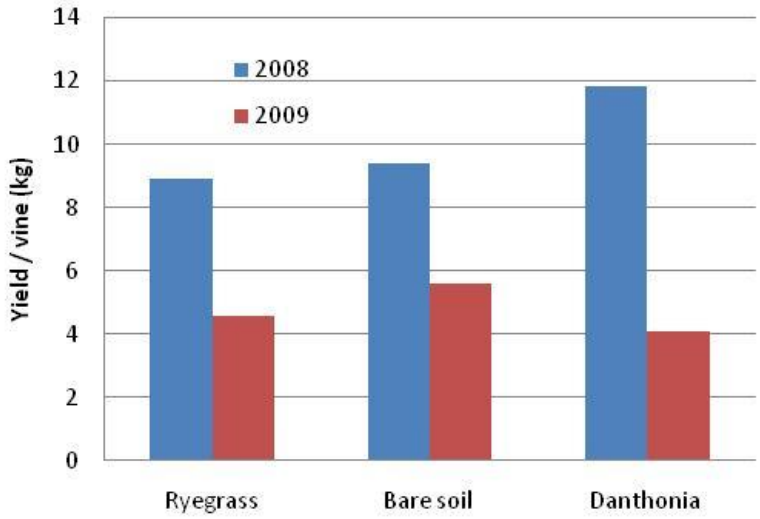


Figure 44: The effect of cover crop on the yield of dry grown vines in Coonawarra in 2008 and 2009.

The Coonawarra site was ideal in many ways being very visual (adjoining the Riddoch Highway), a 1 ha block and free of most grasses that could become weeds within the wallaby grass. It was however unusual being very old dry grown vines. The results obtained may therefore not be a true refelection of how wallaby grass will perform in irrigated vines on 3 metre row spacings. Given the enthusiasm by growers in this region for adoption of wallaby grass , a logical extension of this work would involve another cover crop planting with a broader range of species on a vineyard of conventional design.

Berry assessment showed no quality differences aside from a near (p=0.051) significant difference in ^{o}Brix, with the wallaby grass treatment being higher than the other 2 treatments. It is possible that this could be a more sensitive indicator than yield of havested grapes, as only minor reductions in water available to the berries may raise the ^{o}Brix without a significant yield difference being detectable.

There were treatment differences in small lot wines produced from the site in 2009 (Table 29).

Table 29: Sensory analysis of Coonawarra Shiraz wines from the bare soil, ryegrass and wallaby grass treatments.

Wines	Bracket	N (number of panellists)	Number Correct	k	Significance
Bare Soil v Wallaby grass	28 Duo Trio	54	51	36	P<0.01
Bare Soil v Rye grass	29 Duo Trio	60	50	39	P<0.01
Rye grass v Wallaby grass	30 Duo Trio	60	57	39	P<0.01

As with the Barossa wines, significant differences are apparent within wines resulting from the different cover crop treatments, but deficiencies in the next level of assessment preclude further conclusions being made.

Loxton

The site at Loxton Research Centre was a new planting at the start of the project, hence the 2009 harvest provided the first yield data. The trial was a simple replicated comparison between bare soil and a healthy stand of creeping saltbush. All yield and berry quality characteristics were virtually identical except for a significant reduction in juice pH of 0.15 units in the saltbush cover crop treatments. Should this be a repeatable outcome, it may be that if there is root intrusion from the saltbush into the vine row, they may be extracting cations from the vine row for deposition in leaf material in the mid row, away from the vine roots. In doing so, there would be less potassium and sodium in the undervine area available for uptake by the vine, leading to lower juice pH. Further investigations are needed at this site to support or reject this hypothesis however.

Despite the similar young age of vines at Loxton and Nuriootpa there was no impact on yield at the former site.. While this was only a short term comparison, it does suggest in the lower rainfall districts

such as the SA Riverland, that as a consequence of the vine water and nutirtion requirement being provided via drip irrigation along the vine, row roots are restricted to this zone and hence there is little interaction with the soil of the mid-row. This could infer that the management system of the mid-row is of little consequence to vine productivity.

Kingston-on-Murray

The cover crop at this site was planted to a mix of species in 2002, with the long lived ruby saltbush now being the dominant species. Two blocks were used in this trial, with one harvested in 2008 and two in 2009. There were no significant yield differences in either block 3 or 9 in either 2008 or 2009 where saltbush was or was not present as a cover crop (Table 30). There was however an overall trend towards yield reduction of about 2 t/ha where the saltbush was allowed to grow without any suppression. If this is a real effect then it may be quite significant for the growers. At the 2008 Semillon price of $300/t, approximately $600/ha was potentially lost in yield due to the saltbush cover crop. With depressed grape prices presently being experienced by Riverland growers lost income of any form may not be acceptable, despite the environmental benefits that could be attributed to having these perennial species in the vineyard.

Table 30: Effects of mid-row saltbush on vine yield (kg/vine) from the Kingston-on-Murray site.

Block	2008		2009	
	+ saltbush	- saltbush	+ saltbush	- saltbush
3	13	14.3	15.3	17.5
9	nh	nh	14.2	16.7

nh – not harvested

Berry assessment showed no differences between treatments.

This site is the oldest known stand of sown saltbush cover crop in an Australian vineyard. As such, it is a valuable resource for continued assessment of the integration of a long lived perennial with well established vines. Concerns by management of competition for water and subsequent yield reduction have not been supported conclusively by monitoring to date. It is however recomended that yield monitoring continue on this site, with the inclusion of a single sided cover crop treatment to determine whether alternative rows would allay concerns of competition while still confering the benefits of increased biodiversity realized from the saltbush cover crop. It is also recommended that a prostrate, very low maintenance form of ruby saltbush, for which seed is now available, also be sown on this site as a comparison, and to determine whether it provides a higher degree of utility within the vineyard than the existing Atriplex spp.

Swan Hill

Drought conditions in this region of Victoria prevented the establishment of the saltbush until 2008, so only one harvest of this site was conducted. No difference in yield or berry quality was found between plus and minus saltbush treatments. Despite this vineyard having been planted in 2006, the vines are very advanced, due in part to the use of a sub-surface irrigation system. Compared with the Kingston-on-Murray site, the soil quality is higher, with limited restriction in root growth, enabling improved vertical growth in the profile to access soil moisture. The vines therefore appear to be acquiring adequate water for their needs via the irrigation system without competition from the saltbush.

Berry assessment following harvest showed no differences in the common quality parameters.

This site is now very valuable in that it is the only one in the Murray Valley Wine Grape growing region, it is fully replicated and is on a large scale. The vineyard owners are very keen on the results observed so far, so it is expected that this site will be preserved with the potential for further research in future years. Unfortunately the depressed state of the wine industry in this region will preclude the adoption of practices that will cost money in the short term, but it is important that information on improved practices be available to growers when the industry rebounds. .

Cover crop Dry Matter Production

The capacity for soil health in the mid-row to be improved is highly dependant on the organic matter produced by the cover crop and how it is managed. In this trial, the control (cereal crop) was managed by terminating the growth with glyphosate then rolling in September and leaving the mulch on the soil surface. The following years cover crop was direct drilled into the mulch to minimize soil disturbance and organic matter oxidation. This treatment therefore provided a best practice control from which to compare soil properties between treatments.

The danthonia was managed by using Jaguar® herbicide on young broadleaf weeds early in the growing season, then mowing as required for reduction in the seed set of grass weeds, and the management of its growth.

The saltbush was a prostrate species, meaning its management was limited to the control of mostly winter weeds which emerged in areas where the saltbush was not so dense. These weeds were either mown or wiped with glyphosate using a sponge wiper (Plate 7). Due to the severe impact the saltbush was having on vine vigour and grape yield, this cover crop was terminated in July 2009.

The regenerating sward was mown as required to constrain growth. While biomass production was much less than the sown species, it was sufficient to provide an acceptable amount of soil cover.



Plate 7: Sponge wiper application of a non-selective herbicide to control weed growth above prostrate saltbush..

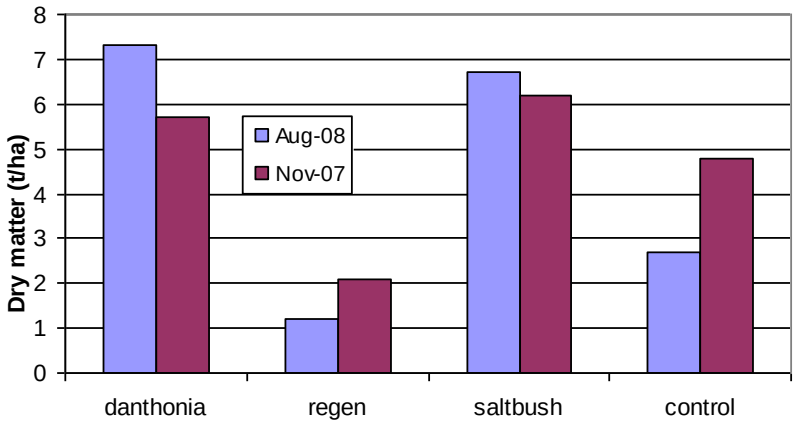


Figure 45: Dry matter production of four treatments at two sampling periods, Nuriootpa Research Centre

Wallaby grass displayed strong characteristics of either competitiveness or allelopathy towards wireweed at Coonawarra (Figure 46) and caltrop at Nuriootpa (data not shown). In evaluating native species as cover crops, producers have to decide on their preferred ground cover, and where wireweed or caltrop are recognized as weeds, plants such as wallaby grass are very effective at their suppression.

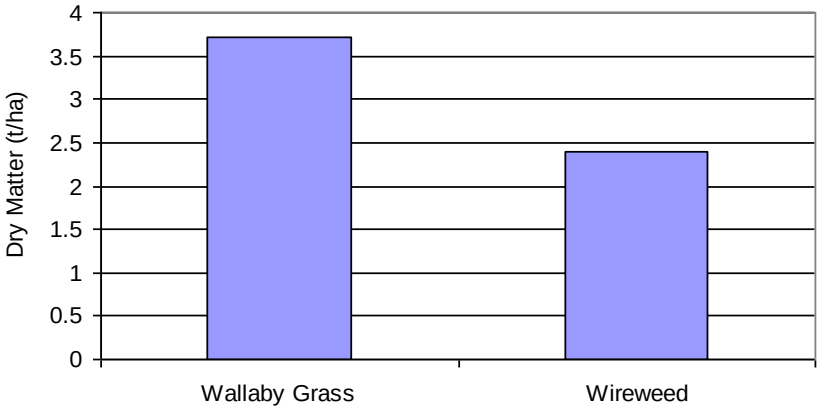


Figure 46: Dry matter production of sown wallaby grass compared to wireweed on the unsown controls, Coonawarra, March 2009.

Saltbush was very competitive against the declared noxious summer weed caltrop (Tribulis terrestris), which is rampant in the Riverland (Figure 47). In the plots void of saltbush, caltrop grew strongly, but it was absent where saltbush was active. Where caltrop is vigilantly controlled with herbicides over summer, the cost may be considerable, and operator safety is a concern when using Spray Seed®, the principle chemical used during the summer period. The maintenance of an active cover crop to provide competition to the caltrop is a very effective cultural management tool, but this should only occur where minimal competition with the vines is likely.

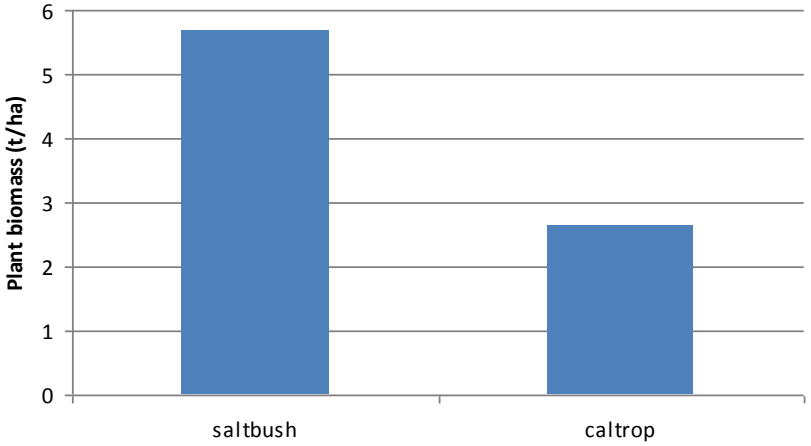


Figure 47: Plant dry matter production of creeping saltbush and caltrop growing on the unsown control, Loxton Research Centre, January 2008.

Soil chemistry

Chemical analysis conducted on soil from the top 10 cm collected within the mid-rows displayed some interesting outcomes over the relatively short period of the trial. An explanation for the results is partly provided by the tissue analysis conducted on plants grown in a glasshouse lysimeter trial, and presented in Table 31.

The acquisition of minerals via the root system to the above ground plant biomass varies enormously between species. After leaves senesce naturally or are mown and left on the soil surface, they decompose and the mineral content is distributed through the surface soil. Of particular interest in Table 31 are the high levels of sodium accumulation in the creeping and ruby saltbush leaf tissue. These plants were grown in non-saline soil, so it is expected that with increasing salinity the acquisition of salt from the soil will also increase. This leads to the potential for the harvesting of salt from vineyards via these sodium acquiring species where salinity has developed. Based on the above figures, if 5 t/ha of saltbush was removed from a vineyard, this would contain over 100 kg of sodium (primarily as sodium chloride).It is therefore recommended that this potential soil salinity amelioration strategy be suggested to industry and if necessary a trial to investigate this potential be established in a vineyard where salinity is a recognized problem.

Table 31: Tissue analysis of glasshouse grown native species. .

Common names	P (%)	Ca (%)	K (%)	Na mg/kg	Mg mg/kg	Zn mg/kg
lagoon saltbush	0.35	0.93	2.80	12600	4000	50
creeping saltbush[1]	0.37	0.76	4.40	23000	4400	30
ruby saltbush[1]	0.34	0.38	3.80	25000	1270	20
windmill grass	0.39	0.34	2.10	1430	990	15
wallaby grass[1]	0.23	0.32	2.60	280	1270	31
bluegrass	0.31	0.44	1.91	90	1430	22
weeping grass	0.19	0.48	2.40	140	1360	23
kangaroo grass	0.17	0.30	1.52	21	1160	16

[1]Creeping saltbush, ruby saltbush and wallaby grass were the principle species in the vineyard trials

Nuriootpa

The saltbush cover crop resulted in significantly higher levels of zinc, manganese, magnesium, sodium, chloride, boron, zinc, copper, sulphur, potassium and phosphorus in the top 10 cm of soil. This also resulted in an increase in soil salinity and a 0.70 unit rise in pH. The Mallee Catchment Management Authority (CMA, 2009) investigated the change in soil properties resulting from well established A. nummalaria (old man saltbush) stands. While this is an erect shrub that is grazed by sheep, some parallels can be drawn. As noted with the creeping saltbush in this project, the Mallee project showed an initial soil pH increase, but with improved leaching due to drying of the soil profile, the surface salt loading and pH declined compared to an adjacent cropping paddock. Should these findings be repeated with creeping saltbush, then concern about adverse impact on soil properties will be unjustified. Again this reinforces the need for long term studies when investigating changes to soil properties.

The increase in berry juice pH associated with the saltbush treatments was discussed earlier. If this is a real effect of the saltbush, as can be surmised from this significant result and the altered topsoil mineral status shown above, it displays the importance of mid row management and its potential impacts on both vine productivity and potentially wine quality in vineyards where there is likely to be mid-row soil exploration by vine roots. In the case of saltbush, the combined effects of yield suppression and raised berry pH provide a strong justification why it should be avoided as a cover crop in all areas except the warm interior viticultural regions.

Coonawarra

Reduced phosphorus levels under the wallaby grass were the only notable outcome for this site. This was probably due to the movement of P from the soil into the wallaby grass root and leaf tissue.

Kingston-on-Murray

Enhanced levels of nitrate nitrogen and sodium were apparent under saltbush at this site, which was consistent with the Swan Hill and Loxton sites despite the fact it was a different species of chenopod growing at this site.

Loxton

Nitrate nitrogen, potassium, electrical conductivity and sodium were elevated by the saltbush, while phosphorus was reduced.

Swan Hill

Elements associated with salt (sodium, chloride) were both significantly higher under saltbush compared with the ryegrass control at this site. This caused the electrical conductivity and pH to increase significantly.

Wallaby grass appears to be having minimal impact on soil nutrition, but the potential impact of saltbush requires further comment. The relocation of salt from deeper in the soil profile to the soil surface is a mechanism for chenopods to survive in saline soils, and a means of reducing competition from other plants by increasing soil surface salinity and thereby preventing germination or reducing plant growth in their vicinity. As the total salt loading of the mid-row soil is not changing as it is not being wetted with irrigation water, it is unlikely in the warm inland regions there will be any adverse impact on the vines or long term impact on the soil due to saltbush in the mid-row. However, longer term monitoring should be undertaken to ensure this is the case. Additionally, as the yield figures suggest, there appears to be little interaction of vine roots with the mid-row in the warm dry growing environments. Changes in the mineral distribution through the soil profile should therefore be of no consequence to the vines, but should instead lead to a stand of greater species purity in the mid row.

Earthworms

Earthworms are regularly used as a measure of soil health. Their benefits to the soil, in terms of creating channels within the soil to improve water infiltration, increase nutrient availability and transfer surface nutrients to deeper in the soil profile, are well recognized. Their assessment was only undertaken at the Barossa site.

Earthworms at the Nuriootpa site were sampled twice in 2008 and once in 2009, and results presented in Figure 48.

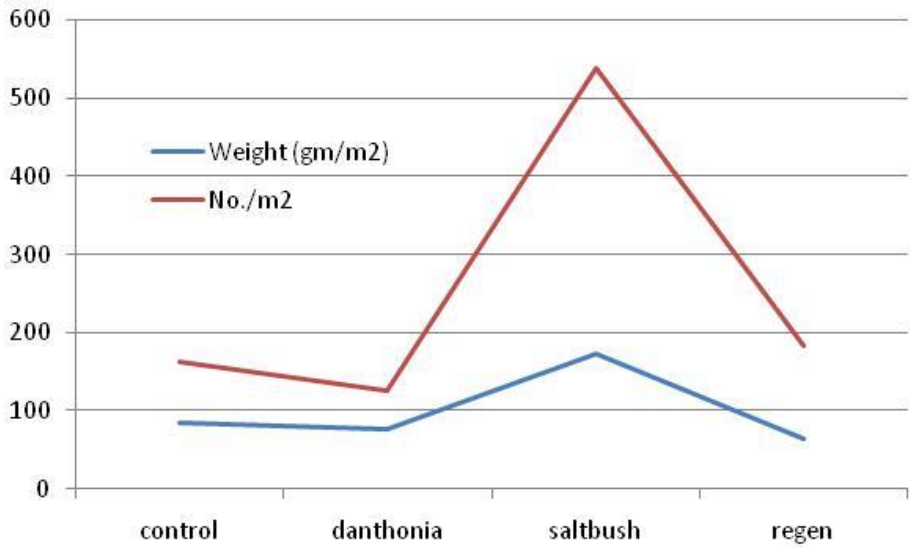


Figure 48: Earthworm population and biomass across four treatments, Nuriootpa, July 2009 (LSD 0.05 weight = 77.5 and population 194.8)

At all sampling times there was a significant increase in populations and biomass in the saltbush treatment. The provision of organic matter on the soil surface encourages earthworm populations (eg. Thomson and Hoffman, 2004). From observation, the saltbush has a high deposition rate of leaf material to the soil surface, and the dense matt of green leaf material would also stabilize soil temperatures. Crude protein levels of approximately 8% would add to the digestibility of this material by the earthworms. The dramatic improvement in earthworm population was only observed at the Nuriootpa site, most probably because the history of the site being a pasture paddock prior to planting

vines in 2005. Drought conditions in the Riverland were also not conducive to encouraging earthworms to break dormancy and move to the soil surface.

The quantification of the benefits of earthworms to a vineyard is difficult but has been attempted by some ecologists. Sandhu *et al* (2008) suggested that one tonne of earthworms per hectare will form one tonne of castings per hectare per year. The earthworm biomass on the saltbush treatment measured in 2009 averaged 1.75 t/ha in the top 10 cm. With the price of soil as used by Sandhu *et al* (2008) of $21.70 /t, this equates to about $40/ha in improved topsoil. While this may seem insignificant, the figure does not take into account any additional value from the earthworms such as improved soil structure, infiltration rates and nutrient availability. It is therefore unfortunate that the yield reduction associated with growing saltbush in the mid-row of the Barossa far outweighs the soil quality improvements that may be associated with growing it over a long period in an area of higher rainfall.

Microbial biomass carbon and nitrogen

It is frequently suggested that perennial native grasses growing in soil which is not tilled and from which no biomass is physically removed, should be effective in sequestering organic carbon over time, particularly through inputs of root biomass. Soil microbial biomass is the living component of soil organic matter excluding soil animals and plant roots. It accounts for less than 5% of the organic matter in soil, but it performs critical functions within the soil. It is both a source of labile carbon, nitrogen, phosphorous and sulphur, and a sink for the same elements. In addition the microbes perform many functions assisting in improving soil health (Dalal, 1998). Microbial biomass typically has a turnover rate of one to five years compared to over 20 years for the remaining soil organic pool, so it is advocated as an early predictor of changes to soil organic matter caused by changes in management practices (Dalal, 1998).

The determination of microbial biomass carbon is important when investigating the potential for carbon accumulation in the soil, and particularly beneath perennial cover crops in low rainfall non-irrigated systems where carbon accumulation will be slower. Figure 49 shows a distinct but non significant increase in microbial biomass carbon in the 0-10cm zone of soil beneath the saltbush, and a predictable decline with depth. While there are no benchmark figures for microbial biomass as a measure of soil quality, the quantity achieved here is within the range for arable cropping soils observed in the literature.

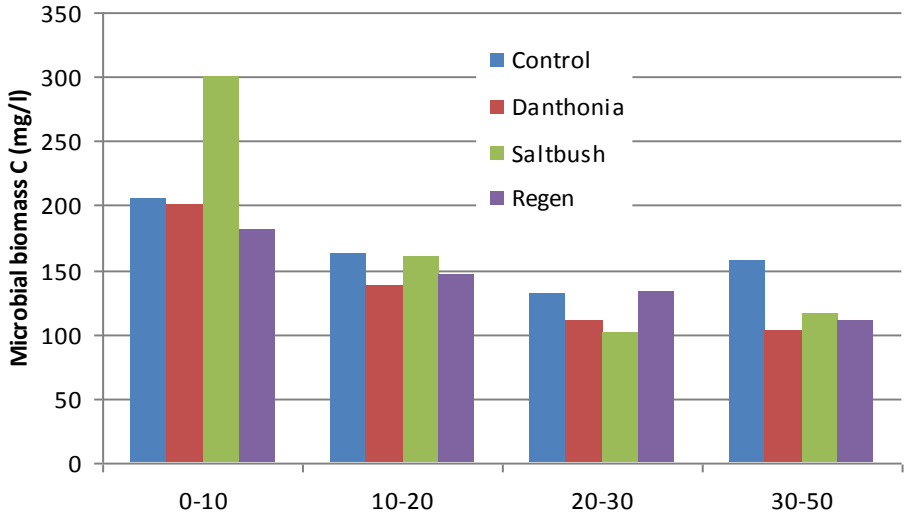


Figure 49: Soil microbial biomass carbon as influenced by cover crop and sampling depth, Nuriootpa, 2009..

The lack of significant difference is not surprising given the high soil variability associated with field based experiments and the relatively short period for changes to occur. The large turnover of saltbush leaf material on the soil surface appears to be affecting the biomass levels, but only in the surface layers. The lack of impact on microbial biomass of the increase in root length density (Figure 53) is surprising given the importance of root mass on microbial biomass. The no-till practices used on the

control were also a likely cause of lack of difference. For instance Gupta et al (1994) observed a significant increase in microbial biomass C and N after only one year of change to zero tillage practice. If the site had been cultivated prior to sowing, as is often commercially done, the outcome could have been quite different, but the trial was intended to display best practice – not achieve significant treatment differences.

Given the intimate relationship between soil carbon and nitrogen there were no significant differences in microbial nitrogen.

Carbon : Nitrogen ratios

The C:N ratio provides an indication of the form of organic matter in the soil and its likely rate of mineralization. Nitrogen is a major rate determinant, so organic matter with a low C:N ratio (eg poultry manure) is able to break down much faster than a high C:N ratio (eg cereal straw). The faster the breakdown, the more rapidly the nutrients contained in the organic matter are available to the soil biology and plant roots. Slow breakdown by comparison would suggest an accumulation of organic matter in the soil.

The microbial C:N ratio in this trial was significantly different at 3 depths (except 0-10 cm), with the saltbush treatment in all cases being the lowest and wallaby grass much higher C:N in the 30-50 cm zone. The mean results over the four depths are presented in Figure 50.

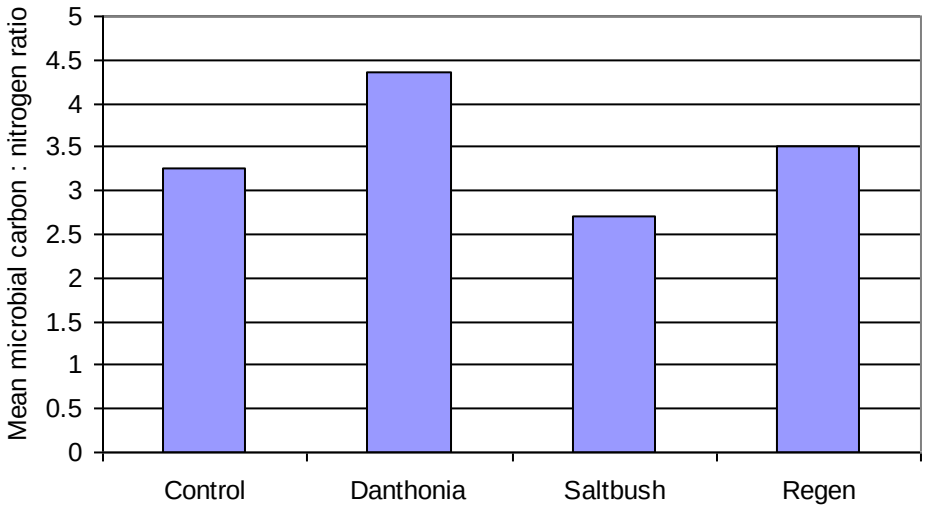


Figure 50: Mean carbon:nitrogen ratios from 4 sampling depths in the 0-50cm zone. (LSD = 0.5)

As was noted in the previous sections, the saltbush produces large amounts of leaf matter containing about 1.3% nitrogen which is distributed through the profile by earthworms and possibly other soil fauna such as ants. As shown in the soil chemistry section, it is possible that saltbush is aquiring nutrients from a larger zone than the other plants, which may also mean nitrogen acquisition. By contrast, the wallaby grass, without any N supplementation, is maximising N extraction from the soil profile. Of interest here is that the high soil microbial biomass C:N of the wallaby grass will be considerably more stable than the saltbush, suggesting that the maintenance of low N levels in the soil with perennial grasses may be of environmental benefit in accumulating carbon. It is expected however that the stand of grass would have to be maintained for several years before differences in soil organic carbon would be measurable.

Total Nitrogen and Carbon

Total soil nitrogen is the combination of nitrate, nitrite, ammonia and organic nitrogen, with the latter being the major pool but which requires mineralization before the nitrogen is plant available. The only significant difference was higher total N under the saltbush at the 10-30 cm depth, but a trend towards higher total N under the perennials also existed at the 0-10cm depth (Figure 51).

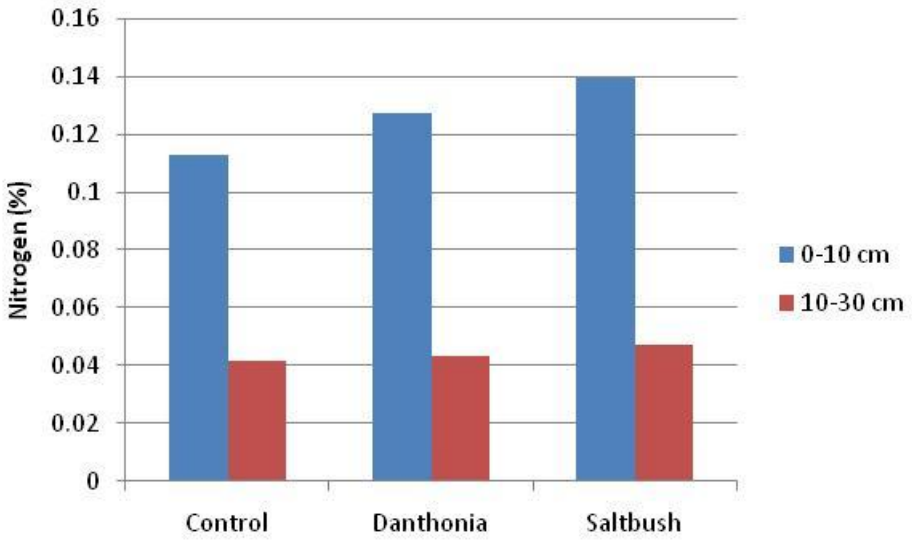


Figure 51: Soil total nitrogen measured at 2 depths – Nuriootpa 2009. (LSD 0.05 = 0.003)

Initially it may be expected that the increase in nitrogen at the 10 – 30cm depth was most likely due to leaching of mobile ammonium and nitrate down the profile. However, the amount of these forms of N within the whole soil profile was very small compared to the organic N. It is likely there is an association with the greater root length exhibited by the saltbush (and wallaby grass) at the 10-30 cm depth, but the roots were removed from the soil prior to this analysis. A definitive answer to this outcome is therefore difficult to provide.

The influence of cover crop species on soil total carbon is displayed in Figure 52. While not significant, there is a trend towards higher soil carbon levels in the 0-10 cm zone of the saltbush and wallaby grass treatments.

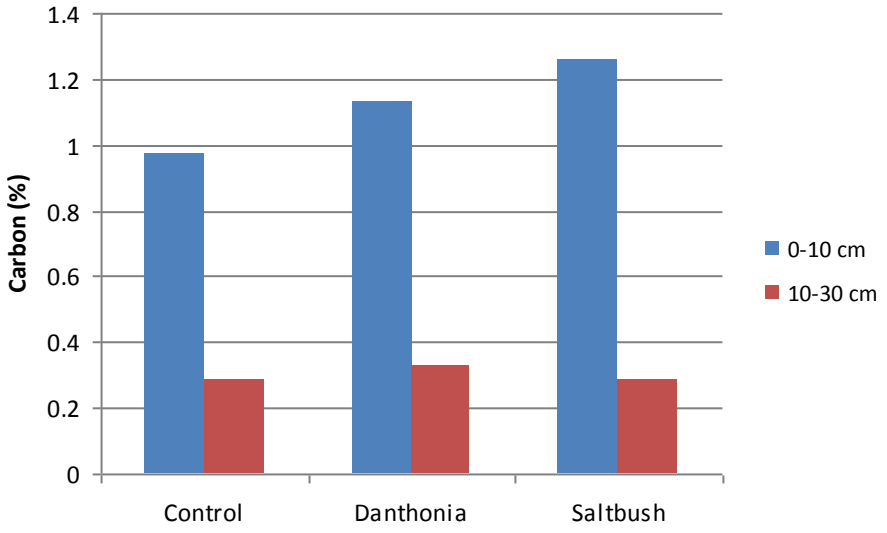


Figure 52: Soil total carbon measured at 2 depths, Nuriootpa, 2009.

Three years is a very short period to see any effect on soil carbon, so the trend displayed is certainly of note. For example grazing trials on native and exotic grasses in New South Wales by Lodge and King (2006) found that after 4 years there were no significant differences in total organic carbon. The reduction in tillage associated with the perennial cover cropping treatments would only be a minor component of the observed trend, as the control also received minimal soil disturbance while sowing the annual cover crop. The microbial biomass accounts for less than 5% of the total carbon pool, negating this as justification for the observed effect. The increase in earthworm numbers associated with the saltbush treatment may be influential on that treatment, while other soil fauna may be incorpoarting the organic matter deposited on the soil surface of the wallaby grass treatment. Again it

is difficult to be definitive in explaining the observed outcomes. As presented in Table 32,, the only strong correlation in measured soil parameters was in total carbon and nitrogen which is expected of a mature soil system.

Table 32: Correlation coefficients between measured soil carbon parameters, Nuriootpa, 2009.

	Organic Carbon	Total Nitrogen	Total Carbon	Microbial biomass C	Microbial biomass N
Organic Carbon	1.00				
Total Nitrogen	0.40	1.00			
Total Carbon	0.42	0.98	1.00		
Microbial biomass C	0.10	0.48	0.47	1.00	
Microbial biomass N	0.11	0.57	0.49	0.64	1.00
Root length	0.27	0.72	0.73	0.51	0.29

Given the short time period of the trial, the soil systems investigated have not developed to a state of equilibrium where stronger relationships between the different components would be likely. Unfortunately this also means it is too early to provide guidance to growers and policy makers of improved practices that may be implemented for carbon sequestration and associated soil improvement. It is therefore important that these soil and plant ecosystems can be monitored in the longer-term as they respond to significant changes to management and vineyard inputs.

Root length density

With an emphasis on environmental sustainability, it was deemed necessary within this project to investigate the capacity for the native perennial cover crops to improve soil health properties. An important facet is the sequestration of carbon to the soil via an active root system. Root length density is a measure of the total root length (without accounting for diameter) as a function of soil volume. Sampling revealed significant differences in root length densities between the annual triticale cover crop and the perennial wallaby grass and saltbush in the surface 30 cms,(FigureFigure **53**) which is the zone recognized by the Australian Greenhouse Office as important in the carbon sequestration debate.

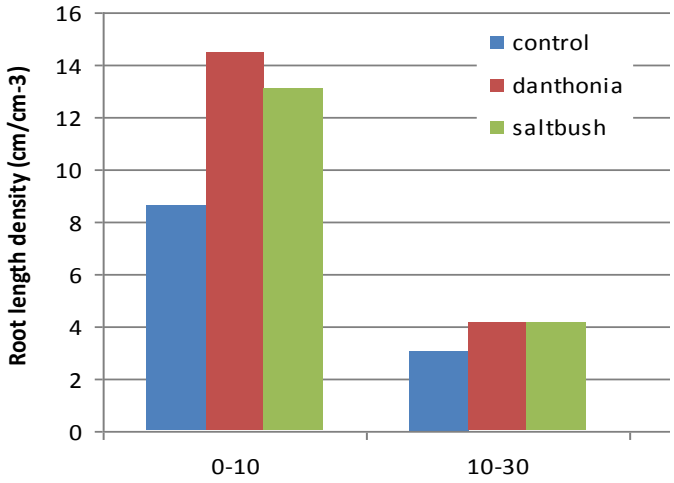


Figure 53: Root length density for three cover crop species at 0-10 cm (LSD 0.05 = 3.2) and 10-30 cm (LSD = 1.13).

The differences seen above are considerable, but they are comparable to work by others. Typical root length densities for annual cereals range from 3.3 to 4.2 cm/cm^3 while perennial grasses may extend to 100 cm/cm^3 in ideal conditions (Barber, 1995). The cereals at Nuriootpa were above this standard, while the native grasses and saltbush were below. This was not surprising given that Australian cereal varieties are bred to perform in harsh conditions, requiring a more extensive root

system than others growing in more temperate conditions. The native species by comparison have had no imposed breeding, so the above and below ground biomass production is expected to be below that reported in Barber (1995). Root length is also influenced by soil moisture and nutrition, and in particular phosphorus. Neither soil moisture nor available phosphorous (46 mg/kg) should have been limiting growth during the winter and early spring period.

The greatest microbial biomass and activity will be found in the rhizosphere, the zone in the immediate vicinity of the roots, where up to ten times the amount of microbes will be present compared to the bulk soil. In the rhizosphere nutrient rich root exudates are an immediate food source to the bacteria, fungi and other organisms. A strong relationship is therefore expected between root length and microbial biomass, but this did not occur in this investigation as there were no significant differences in microbial biomass.

Biodiversity enhancement

Nuriootpa

The following is a précis of the discussion from a paper by Alana Danne submitted to Crop Protection.

Effects of Native Grass Cover Crops on Beneficial and Pest Invertebrates in Australian Vineyard

A. Danne, L. J. Thomson, D. J. Sharley, C. M. Penfold and A. A. Hoffmann

In this study, we compared 3 native treatments to a conventional exotic cereal planted as inter-row cover crops in a vineyard in south eastern Australia. The native cover crops grew successfully over 2 seasons but the influence of cover crop treatment on invertebrate abundance appeared to be greater in the first season. Abundance of a range of parasitoids, earwigs and predatory thrips was increased with the native cover crops, especially windmill grass and saltbush, although there was also an increase in some potential pests. The changes in abundance of carabid beetles and spiders with cover crop treatments is consistent with other studies which suggest vegetation type is important for these predators; any type of vegetation complexity added to agro-ecosystems will likely increase the abundance of such ground-dwelling predators (Frank et al. 2008). Our results suggest that native grasses and saltbush may enhance natural enemy abundance; this is in agreement with a limited number of reports in the literature, including Stephens et al. (2006) who found that creeping salt bush supported the greatest abundance of parasitoids in a comparison of 9 native and exotic plant species.

We also obtained direct evidence of beneficial effects of the native cover crops because predation of light brown apple moth eggs increased when these crops were present. This increase in predation may be related to increased abundance of earwigs (Dermaptera) and the predatory thrips. Earwigs are generalist predators and are known predators of light brown apple moth in vineyards, especially in the case of the common European earwig (Frank et al. 2007). The predatory thrip *Desmothrips* sp. (Thysanoptera: Aeolothripidae) is a facultative predator usually of larvae of other thrips but potentially also of LBAM eggs (L. Thomson unpub. obs.).

Nevertheless, these positive effects need to be counterbalanced by an increase in some potential pest species in the native cover crops. The Rutherglen bug, *N. vinitor,* is a native insect which occurs in all states of Australia and can reach pest status in hot, dry areas when their need for moisture drives them into the crop to suck fluid from the shoots, stems and berries of the vine, causing extensive damage (Buchanan and Amos 1992). Curculionids or weevils (Coleoptera: Curculionidae) are herbivorous beetles that damage the grapevines by feeding on leaves and ring-barking the shoots of the vine (Buchanan and Amos 1992). The role of the burrowing bug detected here (*Adrissa* sp.) is unclear. While knowledge of the biology of the family is limited (Henry and Froeschner 1988), they may be beneficial to soil overall due to their burrowing activity, but they are known to feed on the roots of plants and may act as pests, although other Cydnidae are seed eaters (Filippi et al. 2009).

Oats are favoured as a cover crop because they grow rapidly and add organic matter to the vineyards (Ludvigsen 2008). They may also provide shelter and pollen for beneficials but oats flower only in spring. In contrast, the native cover crops trialled here flower

during the grape growing seasons in which we sampled, ranging from November to June (windmill grass) to throughout the year (saltbush) (George 1984), thereby providing greater resources and more complex structure. Perennial cover crops may also provide shelter throughout the year, without the disruption caused by resowing required by an annual such as oats.

The data collected here suggests that native species as inter row cover crops established successfully and have potential to increase abundance of several potentially important natural enemies of vine pests but they might also increase local pest problems. The increase in natural enemies may provide an economic benefit and potentially reduce the need for chemical applications to control pests, as well as increasing the economic and environmental sustainability of the wine industry. However more information is required on the role of different taxa in vineyards, as well as the potential negative impact of native hosts on pest species. Native cover crops increase predation of eggs of an important insect pest (light brown apple moth), perhaps related to an increased abundance of earwigs and predatory thrips.

Coonawarra

At the Coonawarra site wallaby grass was compared to ryegrass. As presented in Figure 54 there was less impact of the wallaby grass as a cover crop on collected invertebrates, with only beetle numbers increased in this cover crop compared to ryegrass. Yellow sticky traps in the canopy collected parasitoids, spiders, predatory beetles and predatory thrips and a very few potential pests (9 Rutherglen bugs and 3 common brown leafhoppers). Importantly, there were more parasitoids overall and especially important, more Trichogramma with wallaby grass when compared to ryegrass as a cover crop. There were also more predatory thrips and predatory beetles. None of these results were significant.

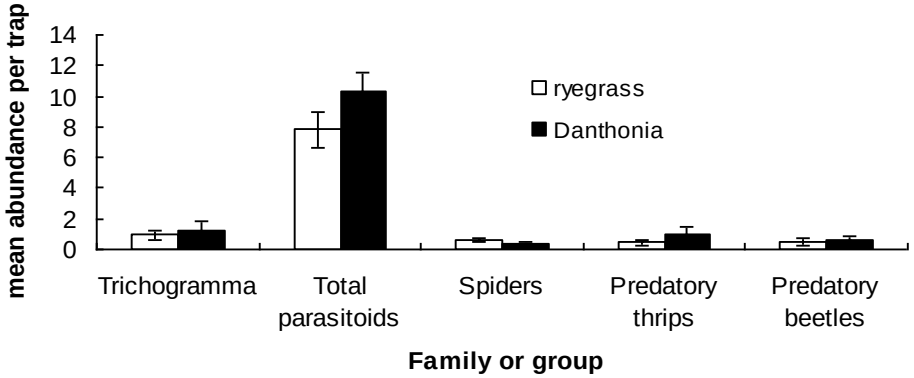


Figure 54: Natural enemy abundance in the vine canopy at the Coonawarra site

This lack of difference was most likely due to the similarity of treatments and their management. While the ryegrass was an annual, its growing season was not that different from the perennial wallaby grass which is active mostly in winter and spring, but will respond to summer rainfall events. Both grasses were allowed to naturally senesce and were not mown until autumn, so a standing cover was maintained on both treatments.

While there was an (non-significant) increase in potential pest bugs with wallaby grass at Coonawarra, these were collected in such small numbers it is unlikely to have an impact.

Swan Hill

At Swan Hill, saltbush was compared to two conventional inter row treatments – a mown regenerated sward and rye grass.

Abundance of a range of parasitoids increased with saltbush (Figure 55). There was an increase in the total number of parasitoids and the number of small parasitoids collected with saltbush as the ground cover. Spiders, predatory beetles and fungal spore eating beetles also increased with saltbush though the increase was only significant for Scelionidae.

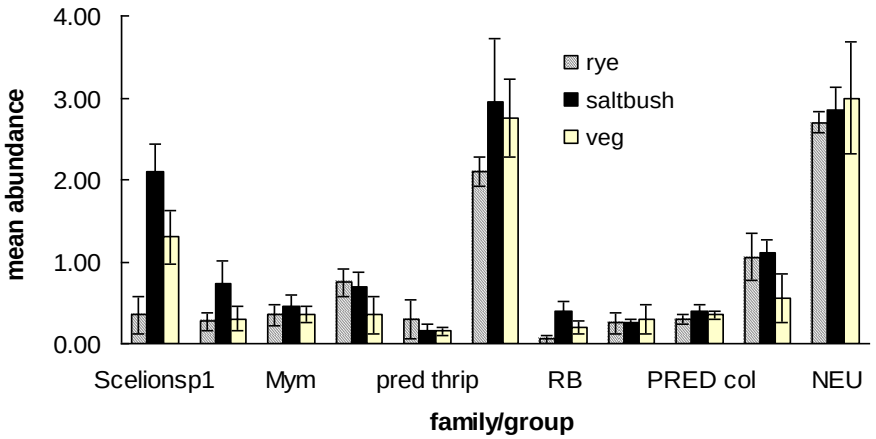


Figure 55: Mean abundance of each group collected per trap at Swan Hill in the canopy with yellow sticky traps. Error bars represent standard errors.

The number of beneficials collected in the saltbush cover crop at Swan Hill was also higher (Figure 55).. The increases in natural enemies may assist in pest control in vineyards. Scelionidae and Eulophidae are genera that contain important biocontrol agents of pests Lepidoptera, Hemiptera and Thysanoptera; Scelionidae are a large family of endoparasitoids of eggs of a wide range of insects, potentially encompassing predators and pests as well as spiders (Austin et al., 2005). Eulophidae are another large and biologically diverse family with range of hosts and biology (Gauthier et al., 2000). A number of species of Mymaridae are also important natural enemies of pests, parasitising insect eggs, especially those concealed in plant tissue or in soil including weevils and auchenorrhynchus Hemiptera such as leafhoppers. *Anagrus epos* Girault has been shown to be an ideal candidate in the control of the glassy-winged sharpshooter (GWSS), *Homalodisca vitripennis* (Germar) (Hemiptera: Cicadellidae). Trichogrammatidae include several well known egg parasitoids of light brown apple moth (Glenn et al., 1997). These and other parasitoids may contribute to control of a range of vineyard pests including light brown apple moth, scale and mealybugs (Thomson et al. 2007).

Saltbush flowers throughout the year so may thus provide greater resources and more complex structure. The data collected here suggests that native species as inter row cover crops established successfully and have potential to increase abundance of several potentially important natural enemies of vine pests.

Predation of light brown apple moth eggs

At Swan Hill direct evidence was obtained of the beneficial effects of the native cover crops because predation of light brown apple moth eggs increased when these crops were present (Figure 56).

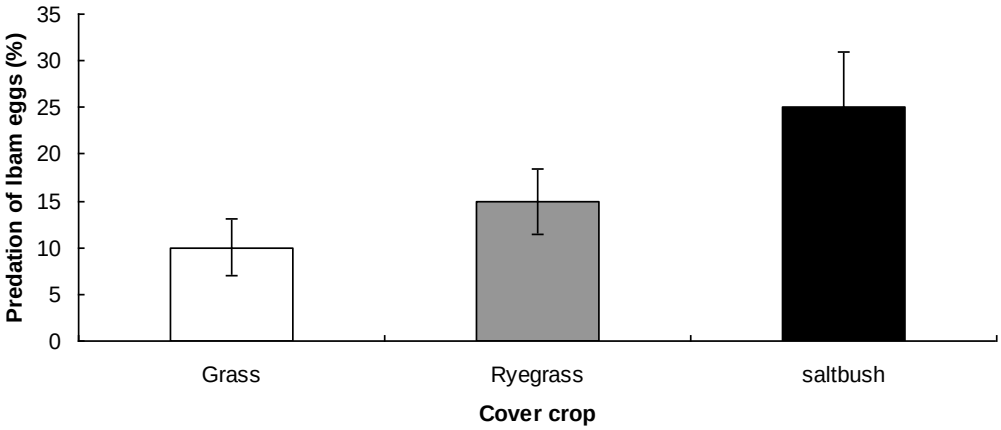


Figure 56: Light brown apple moth egg predation is tending towards being greater with saltbush than ryegrass as a cover crop at Swan Hill in 2008.

While economic thresholds necessitating the chemical control of light brown apple moth are rarely breached in the warm inland regions, these results are still noteworthy. If through other factors (eg caltrop management) growers wish to plant saltbush in the mid rows, then the knowledge that as an added benefit the saltbush is also providing habitat for beneficial invertebrates which will make chemical control of a LBAM outbreak unnecessary, would be welcomed.

Soil Moisture

Nuriootpa

Soil moisture tension data was recorded by loggable gypsum blocks (GBugs®) over 2 seasons. Blocks were placed at 4 depths (15, 40, 70 and 100 cm) in centre of the mid-row and 30 cm distant from a vine trunk. Data from September to February is presented below; Figure 57 is for the mid row and Figure 58 for the under-vine sections of the vineyard.. Due to cost constraints of the logging equipment, the recordings were only made from one replicate, but strong correlations generally exist between the two years, supporting the validity of the outcomes.

Soil on the control treatment from 70 to 100 cms was depleted of moisture (> 500 KPa) throughout the growing period (Figure 57 (A)). Despite the barley cover crop being terminated in mid- September, it had still depleted the profile of moisture below 60 cm. When the growth of annual crops such as barley progress from stem elongation to the reproductive phase, their water use increases substantially, suggesting that in dry years, earlier termination of annual cover crops is critical to storing water for the vines.

The wallaby grass treatment (Figure 57 B) entered the growing season with more soil moisture in the 70 – 100 cm zone than the control, but this was utilised by mid-November. The perennial nature of this cover crop displayed a physiological advantage over the annual cereal, by maturing later and minimising the use of stored soil moisture reserves. Given this information, it may be possible to closely mow the wallaby grass in early spring, thereby saving the deeper soil moisture for later in the season. Of note also is that the rain event in December (55mm) supplied about 3 weeks of available moisture to the cover crop.

The saltbush (Figure 57 C), being dormant during the cool months, conserved winter rainfall, but in a 5 week period in spring this was quickly utilized. Again, the December rain added to the soil moisture, but this was all used within a month.

The regenerated sward (Figure 57 D), consisting of salvation jane, mallow, and witchgrass was sprayed out with glyphosate following the December rain, with the intent of encouraging chloris establishment. While the chloris regeneration did not occur, it did conserve water in the profile, which was available for over one month.

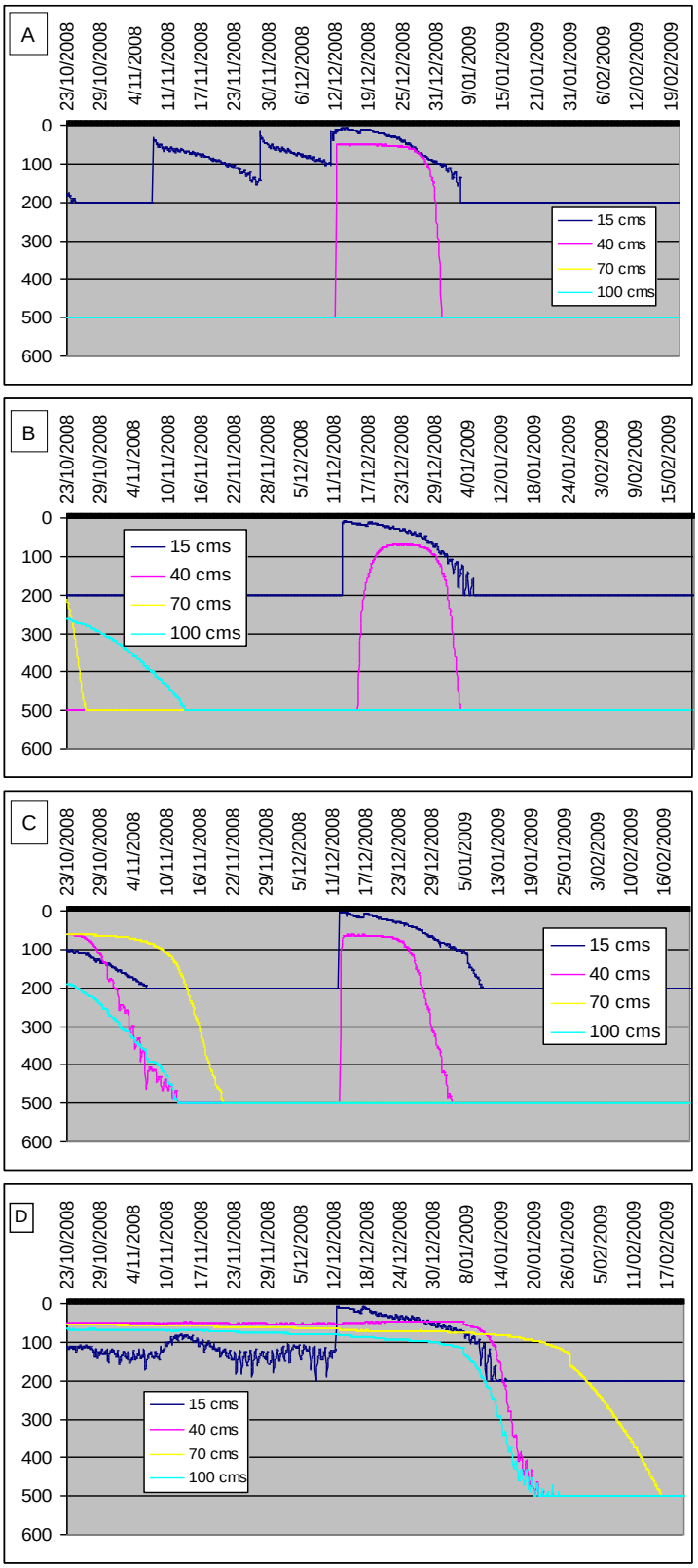


Figure 57: Mid–row soil moisture tensions of cover crops treatments, recorded from September 2008 to February 2009, Nuriootpa Research Station. A control; B wallaby grass; C saltbush; D regenerating sward.

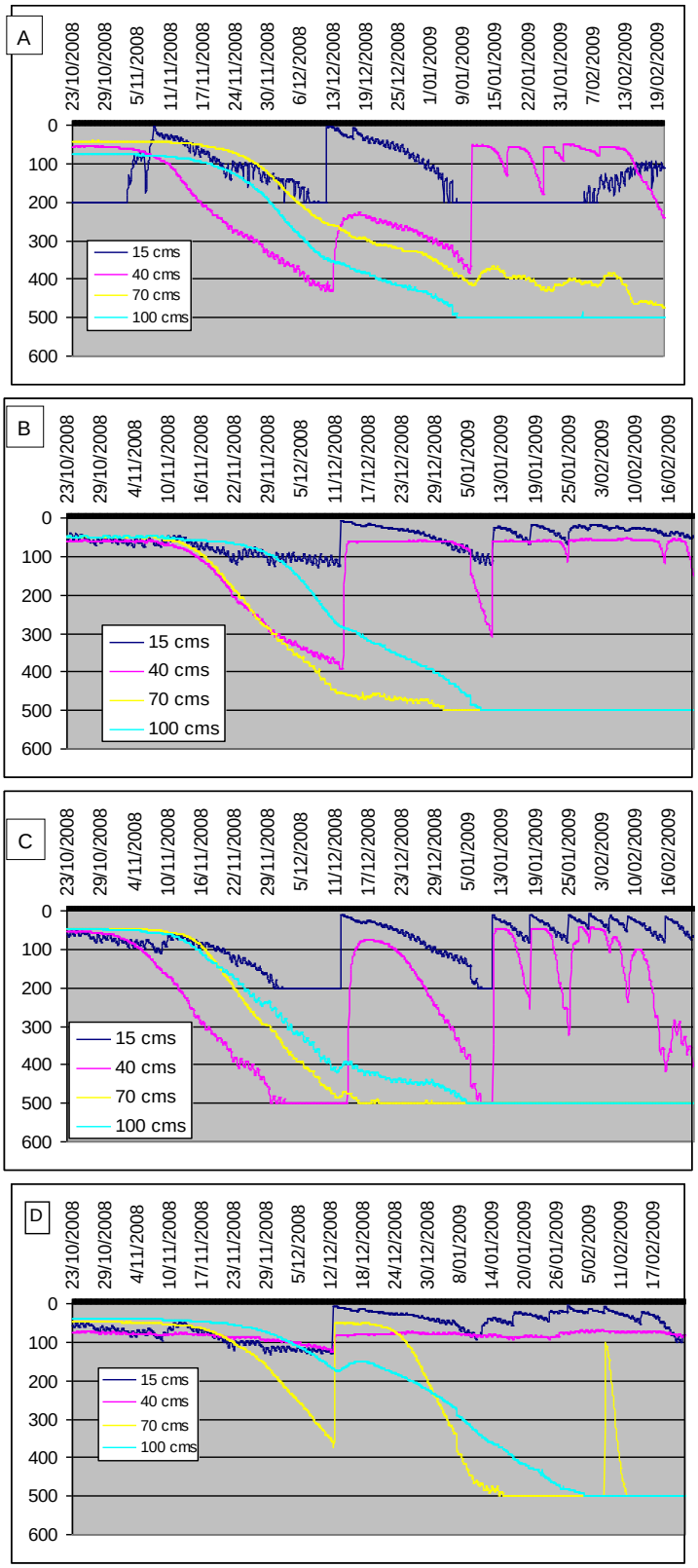


Figure 58: Undervine soil moisture tensions of four mid-row cover crops, recorded from September 2008 to February 2009, Nuriootpa Research Station. A control; B wallaby grass; C saltbush; D regenerating sward.

From the data shown above it would be expected that the regenerated sward would have produced the highest yield if mid-row moisture was the main determinant. Certainly the perennial species drew moisture from the surface 40 cm very efficiently, and then accessed the deeper soil profiles, depleting water reserves for vines.

The measurement of soil moisture immediately adjacent to the vine should reflect available soil moisture as influenced by stored moisture and the drip irrigation system. In a moisture limiting system, where vine production is to varying degrees determined by the additional water applied, it might also be correlated with yield. At the Nuriootpa site, strong differences in moisture drawdown occurred from vines alongside the different cover crop species, as shown in Figure 58.

Vine yield was more closely correlated with undervine soil moisture tension than with mid row soil water tension.. The saltbush completely dried the soil profile by the end of December, leaving little moisture for the vines to access. The moisture curve at 40 cm also showed much greater amplitude than other treatments, caused by the dry soil profile further down. Drying of the profile at depth was slightly delayed in the wallaby grass, then later still in the control and regenerated swards.

These results reinforce the need for conservation of moisture in the undervine area, which is critical to achieving attainable yields in water limiting environments. It would appear as though there is root encroachment from the mid row to the undervine area, possibly at 40 cm and most likely in the deeper soil horizons from the saltbush in particular. As the vines in this vineyard were establishing at the same time as the perennial cover crops it is likely that with soil moisture drawdown under the vines not being so great due to their young age that the saltbush and to a lesser degree the wallaby grass root systems encroached on the vine row. To determine if this is the case, soil pits should be dug at Nuriootpa and the root systems mapped. Wallaby grass needs to be sown in an older vineyard to assess if the yield loss still occurs. If the use of native perennial cover crop species is to be encouraged, such questions will have to be answered before wider adoption by industry is likely.

Kingston-on-Murray

As shown earlier, there was a trend towards yield reduction over the 3 harvests. Figures 59 and 60 show soil moisture tension as recorded by GB Lite gypsum blocks inserted down the soil profile of the mid-row and the undervine zone. Of particular note is the substantial decrease in soil moisture at 60 cm undervine during the growing season from September until February. This result correlated strongly ($r^2 = 0.87$) with the 2007/08 readings, suggesting this was a real effect.

Investigations of root systems at two Kingston-on-Murray sites displayed limestone marl at about 60 cm, with no observable root activity beyond that depth, which possibly explains the absence of differences in soil water tensions at 100 cm in the plus and minus saltbush treatments. Above 60 cm some saltbush plants exploited the undervine moisture via root encroachment, as shown in Plate 8. While this root activity was only apparent at one site, it is likely given similar trends in yield suppression that this was a regular occurrence. A soil pit dug in block 3 displayed only fine roots with none observed venturing beyond the wheel tracks, but this only followed the root system for one plant. A more extensive pit along the wheel track may be required to obtain a more complete picture of vine and saltbush root distribution.

In the mid-row, there was a strong relationship between the two years, adding validity to the outcome observed in Figure 60. While differences in moisture tension were apparent at the different depths, their impact on vine production is questionable. Similar moisture tension curves would suggest a poor water holding capacity of the soil, and / or the saltbush growth was being supported by irrigation water. Another explanation is that evapotranspiration from the saltbush was no greater than direct evaporation from the soil, but this does not explain the moisture loss at 60 cm from the vine row. Further destructive examinations of the plant root system at the location of the gypsum blocks are required to positively identify saltbush roots encroaching on the vine row, but this seems the likely explanation for the observed outcome.

Such observations suggest the need for planting by soil type. Where vine vigour and water use efficiency is good, indicating strong root growth in suitable soils, then saltbush mid-row covers crops in the warm dry interior may be quite appropriate. However, where vine productivity is severely compromised by soil type, managing the resident vegetation to minimize water use may be a better option. Alternatively, saltbush planted every alternative row and mown to reduce leaf area may be sufficient to overcome the water stress observed at this site.

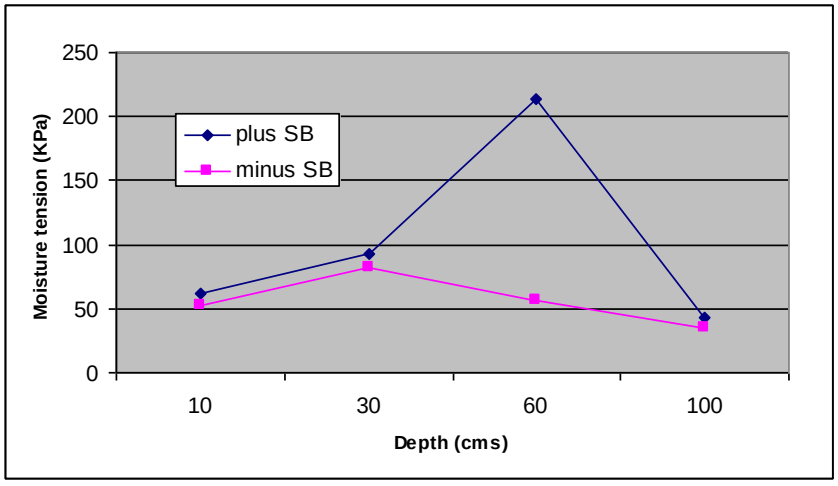


Figure 59: Average soil moisture tension undervine, September 08 to February 09, Kingston-on-Murray.

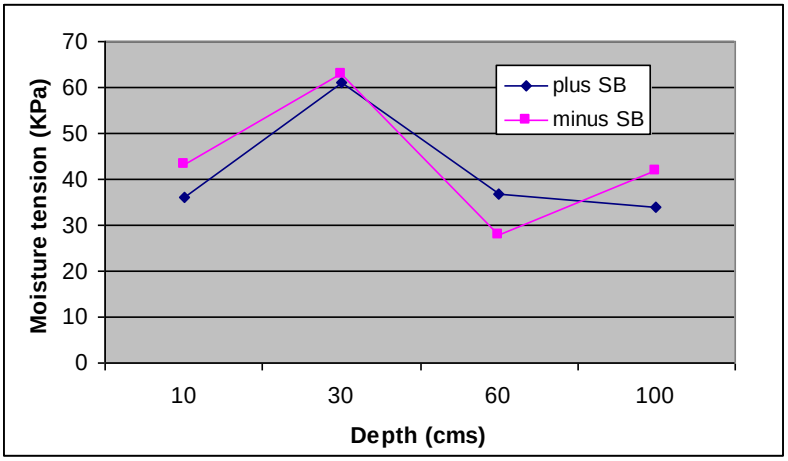


Figure 60: Average soil moisture tension in the mid-row, September 08 to February 09, Kingston-on-Murray.



Plate 8: A ruby saltbush root (painted blue) encroaching on the dripper zone from the mid-row, Kingston-on-Murray, 2007.

Vineyard floor and canopy temperatures

Providing living soil cover in the form of saltbush, has a considerable impact on vineyard floor temperatures at ground level (Figure 61). Predictably the bare soil heated to above 50°C more rapidly and stayed above that threshold for much longer than immediately above the saltbush, or in the shade below the plant. While this was very encouraging, it did not translate into lower canopy temperatures, however this may have been the consequence of the relatively small area of each treatment plot as. on very hot days, movement of large hot air masses would mask any local effects of groundcover.

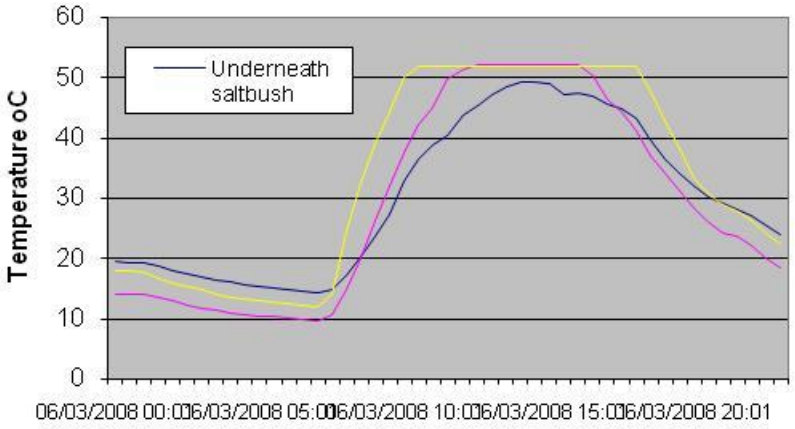


Figure 61: Effect of soil cover on vineyard floor temperature over a 24 hour period during a a heatwave, Loxton, March 2008.

Water use glasshouse experiment

In developing new cover cropping practices for a dry environment, knowledge of the relative water use characteristics of likely candidate species would be valuable. As there was no information in the literature to assist, a glasshouse experiment using lysimeters was established in 2008. Figure 62 shows considerable differences in water use between wallaby grass at the high end of the scale and the two Atriplex saltbush species at the lower end.

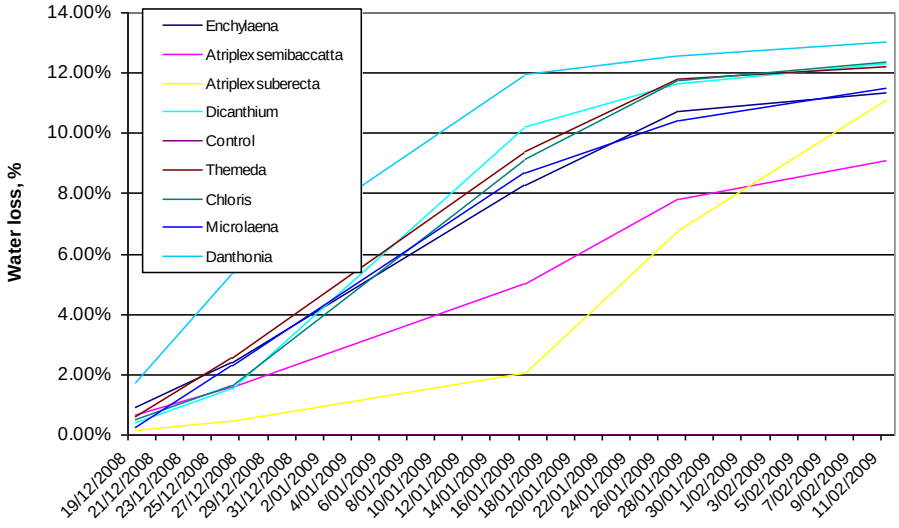


Figure 62: Water use over a seven week period of eight native ground cover species, 2008/9 growing in lysimeters in a glasshouse.

The wallaby grass, being a C3 plant, appears to behave like an annual cereal, adding vegetative matter then going quickly into its reproductive phase, making use of the available water while it is

accessible. The saltbush by comparison conserved water uptake, and unlike the grasses, still had green leaves at the end of the experiment. These results reinforce the need for choosing the best location for the different species. The saltbush, by conserving water but continuing to grow for longer, will compete with the vines further into the growing season, as was shown particularly at Nuriootpa. The wallaby grass by comparison moved into a dormant phase in November which improved the soil moisture availability in the undervine area of the summer period.

If an objective of cover cropping is to achieve a reasonable level of cover over the ground for a minimal amount of water input, then growing plants with high WUE is desirable. The water use efficiency (WUE) of the cover crops studied is shown in Figure 63.

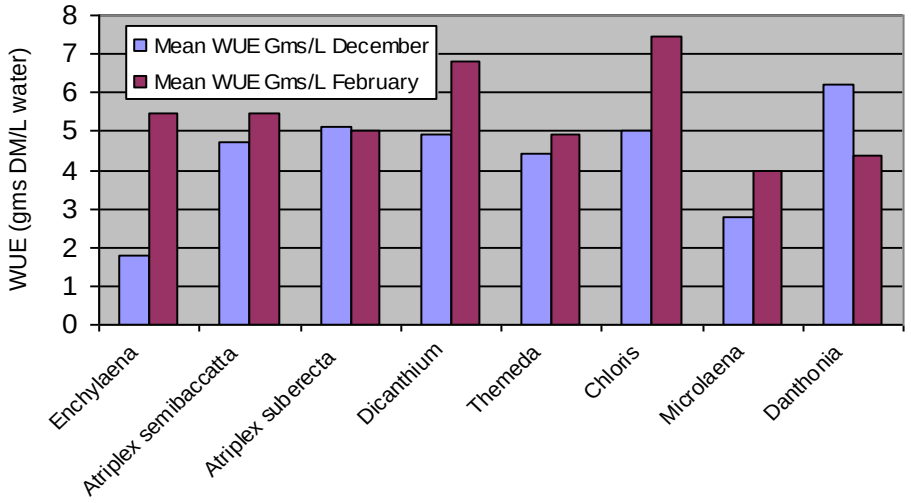


Figure 63: Water use efficiency (g dry matter/L water) for eight native ground cover species growing in lysimeters at Roseworthy, 2008/09,.

The WUE of the native species compares favourably with quoted figures for pasture production in Australia (Bowman and Scott, 2009), which suggest only 3 g/litre of water for annual pastures in the field context. There was remarkable similarity across most of the species, with two of the C4 grasses (Dicanthium and Chloris) showing very high WUE's. Microlaena is found naturally in the wetter and cooler country so its WUE does not have to be so high for survival and reproduction. The three primary species used in this project performed well, but had seasonal preferences for growth which were related to their photosynthetic pathways. For example, Enchylaena (ruby saltbush) exhibited strong summer growth, with seed production occurring from February until May. The wallaby grass (danthonia) by comparison was more active in spring, going dormant in summer unless adequate soil moisture is available to continue growth. The water use efficiency figures therefore reflect the varied growth patterns of the different species.

Financial implications

Often it is the bottom line financial figures that will decide whether a new practice is to be implemented. Costs of production for the 3 principal cover crops investigated are presented in Table 33. The data presented are based on experience gained in growing these species over the last three years, with costs extracted from published farm budget guides. While the perennial native species have high upfront seed costs, when amortized over a five year period, they are actually less costly than the barley crop. With stand expectancies of at least 10 years, the cost of the perennial species diminishes further.

The other impacts on cost/benefit will be their influence on yield, quality and other environmental benefits. Results from this project have shown a 30 % reduction in yield at Nuriootpa. Unless a significant premium was paid for fruit from the lower yielding vines, such yield reductions would be unacceptable. Therefore if wallaby grass is to be used in regions such as the Barossa then other species with less biomass production, or alternative management practices that reduce water use will have to be employed. This may not however preclude the use of wallaby grass in naturally high vigour sites such as deep alluvial soils which exist to some extent in all regions like the Barossa.

By contrast, in the cooler and wetter Coonawarra site, old dry grown vines on wide row spacings displayed no impact on yield or quality. With other possible environmental benefits such as long term carbon storage and beneficial invertebrate habitat to also be recognized, the use of wallaby grass in this environment seems logical. It is also expected that consumer respect for environmental credentials gained via the use of native species within the vineyard will be beneficial for wine brands. Additional income can also be generated from the native grasses by harvesting them from the mid-rows, from where the seed can either be used for further plantings or for sale.

Table 33: Approximate costs of production for three cover crop species over a five year period using a contractor for field operations.

	Wallaby grass	Saltbush	Barley
Seed	$800	$500	$100
Operations			
seeding	$180	$180	$900
spraying	$400	$250	$500
mowing	$688	$375	$312
Herbicides			
Jaguar	$116	-	-
Glyphosate	$14	$42	$35
Basta	-	-	$400
$/ha/5 years	$2198	$1347	$2247
$/ha/year	$440	$270	$450

The saltbush, based on establishment cost alone, is the cheapest of the mid-row cover crop options investigated. Results presented here support its use in the better soils of the Riverland/Sunraysia/MIA and yield suppression is not a factor due to soil type and water availability. There is still scope for further species selection to ensure suitability for purpose with the saltbush. A prostrate, less woody form of ruby saltbush has been undergoing seed increase on weed mat at Roseworthy over recent years and seed supply is increasing. Should this form of ruby saltbush perform to expectations, it is predicted that it will be suitable for inland vineyard regions.

Based on cost alone, the use of native perennials as cover crops would appear to be a feasible option to the conventional cereal crops when viewed over a longer time frame. The high upfront costs of seed however may require growers to introduce the native species in small blocks, with the potential for harvesting their own seed from stands as they become established. It will be critical however for managers to utilize systems which ensure yields are not compromised to the extent that vineyard income is significantly reduced.

Outcomes and Conclusions

The objective of this work was to determine the potential for native plant species to replace exotics as the principal cover crops in vineyards. The plants which grew successfully in this project were *Austrodanthonia richardsonii* , a species of wallaby grass and two chenopods – *Atriplex semibacatta* and *Enchylaena tomentosa* (creeping and ruby saltbush). Seed for the native species, while expensive and of variable quality, was readily available. Plant establishment was at times problematic, usually due to inadequate rainfall to overcome dormancy and start the germination process. Weed control was at times challenging, as there are a limited range of selective herbicides available for use in vineyards that are suitable for use with the native species. Broadleaf weed control in the wallaby grass was manageable but in the saltbush a sponge wiper was necessary to remove weed competition. Once established, the grass and saltbush species competed strongly with weeds in spring and summer, negating the need for weed control during that period. This is an important benefit of the perennial native species, as the mid row area generally requires considerable management input to contain problem weed species growing during this period.

The project has determined that native perennial cover crop species can fit well within the vineyard production system. As with any crop though, care must be taken in selection of species to ensure their suitability to each situation. When grown in unsuitable situations the spring and summer active

native species can impact significantly on vine yield through competition for water. For example, wallaby grass grown in the Barossa Valley reduced the yield of young shiraz vines by 30%, but in Coonawarra there was no yield impact on old wide spaced vines in a dry grown vineyard. Prostrate saltbush, which also proved to be very competitive at Nuriootpa, in most cases fits well into the vineyard production system of the warm dry interior such as the Riverland and Sunraysia regions.

An important assessment for this study and the subject of an honours thesis was the influence of saltbush and wallaby grass mid row cover crops on invertebrate biodiversity. The outcome was a significant increase in parasitoid and predatory invertebrate populations in the vineyard due to the native species providing desirable habitat. This supports the Winemakers Federation of Australia's biodiversity policy, which in part reads *" WFA acknowledges that biodiversity is relevant at many scales – from soil fauna and flora through to groundcover species on the vineyard floor and that biodiversity can be reinstated by activities including the use of native groundcover species on the vineyard floor"*. On this basis alone, further work on other native plant species which will fit a broader range of environmental and management requirements is necessary, with the goal being that insecticide application in vineyards will eventually be unnecessary.

The benefits to soil health of planting native species remain equivocal. Through reduced mechanical disturbance and using perennial species, it was expected that some measures of soil carbon would display improvement, however, while encouraging trends were apparent it is thought that such treatments would have to be in place for many years before significant change occurred. Creeping saltbush is a chenopod, suggesting it has some tolerance to soil salinity. The plants semi-permeable root membrane enables the uptake of many elements, but especially sodium and potassium cations which are initially stored in the leaf vacuoles then shed on the soil surface in sufficient quantities to raise the soil pH of surface layers. It was also the likely cause of an increase in juice pH for the saltbush mid row treatment at Nuriootpa, but this effect was not measured at other sites. While it is expected there will be no harm from the relocation of salts to the soil surface, as with rainfall it is likely to leach through the soil profile, there is a need for the continued monitoring of this phenomena to ensure no deleterious impact on the soil, vines or the juice quality occurs. The capacity for salt acquisition does however raise the prospect of using saltbush to mine salt from the soil for later mechanical removal.

The envisaged potential for perennial native grasses to sequester carbon was not realized in the short term of this trial. While the root length was greater with wallaby grass than annual cereal, it was not sufficient to increase soil carbon. The reduction in soil nitrogen under the wallaby grass may however lead to slower mineralization of the roots, with long term benefits in soil carbon increase then likely.

Saltbush displayed other benefits such as a significant increase in earthworm populations at the Nuriootpa site, and decreased vineyard floor temperatures at Loxton, but unfortunately neither of these benefits is of economic value to vignerons. A financial analysis of the costs involved in establishing and managing native perennials vs. annual cereal cover crops over a five year period revealed that saltbush would be cheaper than an annual cover crop, while the perennial native grass and the annual cereal were very similar. Unfortunately it remains difficult to apply meaningful financial rewards to environmental benefits such as enhanced biodiversity, reduced erosion and CO_2 emissions, but these will also add to the attractiveness of using perennial species in suitable environments.

There has been a considerable amount of interest shown in this project by the grape growing sector, despite the unprecedented drought years and low commodity prices reducing grower's capacity to adopt management changes that will have up-front costs. Despite this, native grasses have now been sown on seven vineyards following exposure to this study at field days and through industry publications. The importance of the vineyard floor to vineyard productivity and overall sustainability has been highlighted in this study, which has shown the growth of suitable native perennial species in the correct environment is likely to provide long term economic and environmental benefits to the vineyard and its management.

Recommendations

Soil profile modification and under vine surface management

The selection of either ripping or adding mulch to the under vine soil surface primarily depends on the expected response of the vine to the applied treatment and the cost of implementing. This study has shown that whilst it is clear that roots in the mid-row benefit vine growth, what is less clear is whether ripping of the mid-row that is void of roots will result in a benefit to the vine. Hence, more research is required before a more reliable prediction of vine response to ripping can be made. On the other hand, this project has shown that the effect of applying mulch to the under vine soil surface on vine growth tends to be more predictable. The shortcoming to this study was that only one mulch type was applied at each site and that the sites were impacted by developing salinity problems, hence, further studies are required before predictable vine responses can be determined. The difficulty in studying the effect of soil management practices on vine performance is that the outcomes can a number of years to materialize and the responses can be long lasting. The areas of work that need further investigation include:

- The effectiveness of different mulches and composts on altering vine performance through both water savings and nutritional additions,
- Quantifying the effect of mulch on the movement of soil salinity and its net effect on salt accumulation in the vine,
- Surveying industries experience in the effectiveness of ripping in altering vine performance and its potential relationship to soil conditions and rainfall
- The development of a booklet on soil surface and profile management related to specific soil conditions and expected vine responses for different vine regions.

Cover crops

Cover crops can potentially be used to control the vigour of vineyard blocks and maintain winegrape quality. Current findings suggest that this is a function of the soil moisture status in the profile during spring. Partial reduction of the width of cover crop through spraying in spring could be used to control vine vigour if the soil moisture status is low. Whilst there is clear evidence of cover crops impacting on vine growth several areas of research still remain unresolved. These include:

- Determining the impact of cover crops in reducing vine vigour as function of annual rainfall,
- Determining the relative impact of various cover crops on reducing vine vigour, and
- Develop a set of criteria that establish the potential of cover crops to impact on vine performance.

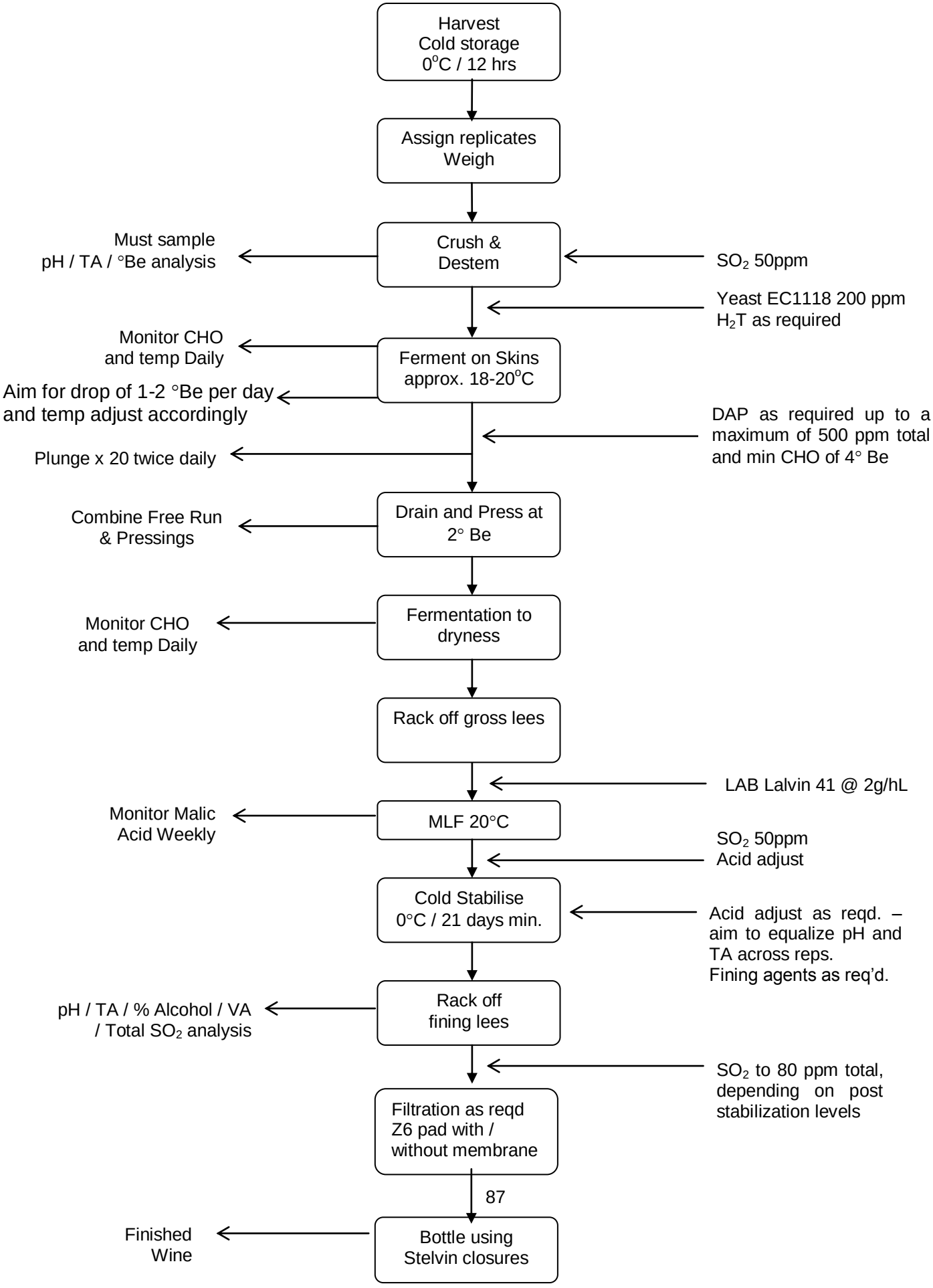
Australian native cover crop species and vine performance

This project has shown that native perennial cover crop species can fit very well within the vineyard production system. As with any crop though, care must be taken in selection of species to ensure their suitability to each situation. When grown in unsuitable situations the spring and summer active native species can impact significantly on vine yield through competition for water. Further, native species have been shown to negate the need for weed control, an important benefit of the perennial native species, however, there still remains a number of areas that need further investigation. These include:

- The feasibility of saltbush to mine salt from the soil for later mechanical removal and its impact of salt accumulation in the soil profile,
- The potential for perennial native grasses to sequester carbon and its interaction with soil nitrogen use by native perennials,
- Quantifying financial metrics associated with enhanced biodiversity, reduced erosion and CO_2 emissions,
- Expanding the range of species explored to include others likely to display similar benefits but without the yield penalties encountered in this project,

- The development of management practices that enable the incorporation of native perennial species cover crops into the vineyard without yield penalty, or using them as a means of restoring vine balance on sites displaying excess vigour
- The establishment of long term monitoring sites to quantify the changes in important soil characteristics, and
- Establishing a web site dedicated to vineyard cover cropping covering recommendations and research outcomes.

Appendix 1: Small lot (50kg) red winemaking process (Provisor)



Appendix 2: Communication

Publications

Danne A, Thomson LJ, Sharley DJ, Penfold CM and Hoffmann AA (2009) Effects of Native Grass Cover Crops on Beneficial and Pest Invertebrates in Australian Vineyard. Crop Protection (accepted for publication).

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Pudney S, Lanyon D and McCarthy M (2008) *The effect of soil type, ripping and surface mulch application on vine parameters*. *McLaren Vale Data Summary 2006/07 to 2007/08.* Report to Fosters Wine Estates. July 2008.

Presentations and workshops

Howell CL, Lanyon DM and McCarthy M (2007) Soil management for yield and quality. Report back of research results, 9 May 2007, Pemberton, Western Australia.

Howell CL, Lanyon DM and McCarthy M (2007) Effect of vineyard traffic and soil management practices on berry growth, grape juice parameters and yield of Shiraz in the Barossa Valley. Australian Wine Industry Technical Conference, Adelaide, Australia, July 2007.

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Pudney S (2008) Soil management for yield and quality: The effect of soil type, ripping and surface mulch in vine parameters. Presentation to Foster estates viticultural technical group. McLaren Vale 23 July.

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Field Days

Wine Industry Environment Conference, Native cover crops at Nuriootpa Research Station, September, 2009.

Powder Bark Ridge vineyard, Frankland with students undertaking studies in viticulture and oenology at Curtin University of Technology, Margaret River, 17 August 2009

Coonawarra, Fosters Undoolya vineyard, Native gasses for cover cropping. May 29, 2009

Nuriootpa Research Station Field Day, Native cover crops, February 19, 2009

Powder Bark Ridge vineyard, Frankland with students undertaking studies in viticulture and oenology at Curtin University of Technology, Margaret River, 19 September 2008

Future Field Day: "Rainfall harvesting and storage: How good is your system?" Viticulture Field Day at Gilberts Wines, Friday 8 February 2008

Powder Bark Ridge vineyard, Frankland with students undertaking studies in viticulture and oenology at Curtin University of Technology, Margaret River, 5 September 2007

Frankland, Pemberton and Mount Barker field trip with Australian researchers on vineyard floor management. 8-9 May 2007

Powder Bark Ridge vineyard, Frankland with NRM staff in conjunction with the Oyster Harbour Catchment Group on water management in viticulture and the Premium Wine Project. 14 December 2006

Powder Bark Ridge vineyard, Frankland with students undertaking studies in viticulture and oenology at Curtin University of Technology, Margaret River. 22 August 2006

Powder Bark Ridge vineyard, Frankland with DAFWA Soils Technical Officers. 2 August, 2006

Margaret River Field Days, Poster presentation May 6 2006

Appendix 3: Intellectual Property

Intellectual property is held by participating organizations

Appendix 4: References

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Appendix 5: Staff

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Appendix 6: Acknowledgements

The authors would like to recognise the following contributors to this project, without whom it would not have been possible. Our apologies to those whom we may have inadvertently missed,

The Grape and Wine Research and Development Corporation for providing funding to this project.

The tremendous assistance and support from;

- SARDI Research station personell at Nuriootpa (Treva Hebberman), Loxton (Andrew Biele, Gary Grigson, Brenton and Ian) and Griffith (Julian Connelan).
- Linda Thomson and her team from CESAR (Alana Danne, honours student, Dave Sharley, Michael Nash) for the invertebrate population studies and subsequent publication
- Technical assistance from Tony (dec.) and Julie Stevens, Penny Day and Louise Moylan.

Vineyard managers and assistants at;

- Fosters Group (Darren Ayworth, Kym Ayliffe, David Hansen, Nick Baverstock & other vineyard staff)
- Wynns Coonawarra (Stuart Sharman, Scott Jolley, Angela Pomery, Tristan Arney)
- Banrock Station (Shylo Williams, Paul Harrington, Josclin Kelly)
- Brown Brothers Mystic Park (Catherine Anderson, Ross Endersby, Matt McAleer, Brett McClen, John Lazerick)
- Fabals Langhorne Creek (Nick McDonald, Steve)
- McWilliams Hunter Valley (Tony Summers DPI NSW, Peter Rohr, Kevin)
- Domain Chandon Yarra Valley (Jim White, Dan Dujic, Kerry Price, Greening Australia)

Appendix 7: Budget reconciliation