The relative sustainability of organic, biodynamic and conventional viticulture

FINAL REPORT to
AUSTRALIAN GRAPE AND WINE AUTHORITY

Project Number: **UA 1102**

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Project Supervisor: **Dr Cassandra Collins**

Research Organisation: **University of Adelaide**

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1. Abstract

Organic and biodynamic viticulture is forecast to grow at over 11% per annum yet there is little information on the benefits or otherwise that can be attributed to these systems of grape production. With industry funding, a six year trial at McLaren Vale in South Australia investigated the changes in soil health, fruit production and wine quality. Organic and biodynamic production led to improved soil quality, with more soil organisms including much greater earthworm populations. Wine quality was also improved, but in the absence of price premiums, this was achieved at a financial penalty to the grower through reduced yields and increased production costs.

2. Executive Summary

Organic and biodynamic viticulture production is expanding as growers seek to improve fruit quality, reduce their environmental footprint and improve grower financial returns. To increase our understanding of the function of the alternative (organic - ORG and biodynamic - BD) systems when compared to the commonly practiced low-input (LCON) and high-input conventional (HCON) approaches, a six-year field trial was conducted in the McLaren Vale region of South Australia. The trial site was incorporated within a 10 ha planting of 20 year old Cabernet Sauvignon vines. Compost was applied to each treatment in a single row of each replicate to determine its influence on the measured outcomes.

Initially the trial was intended to determine the impacts of a changed management regime on soil quality, vine performance and wine quality over the three year conversion period to an organic system. Monitoring the change in soil and vine parameters over this period showed no differences in the first two years. In the third year changes in vine growth generated improved sensory attributes in the ORG and BD wine. The nature of such an experiment decreed an extension of the project was required to attain its full value – a need that was recognised by industry. Funding was provided by the Australian Grape and Wine Authority (formerly the Grape and Wine Research and Development Corporation) while in-kind support from the McLaren Vale Grape Wine and Tourism Association, Peats Soil and many individuals including winemakers and students enabled the trial to proceed for a further three years.

Soil chemistry showed little change between treatments over the trial period. The vines were growing in soil that was inherently fertile, and they have low extraction rates for nutrients. The addition of compost to a row within each replicate was used to determine its role in improving soil characteristics and productivity. The lack of response in vine growth to compost addition confirmed that nutrition was not a limiting factor in vine production.

Soil biological properties (microbial biomass carbon, respiration, earthworm numbers and biomass) as measured in the under-vine zone, were higher on the ORG and BD, most likely due to the soil organisms' nutritional requirements being supplied by the plant growth that was maintained rather than removed with herbicides. The application of compost had desirable impacts on soil quality, increasing total organic carbon (TOC), microbial biomass carbon (MBC), pH, electrical conductivity (EC) and phosphorus (P) levels. Vines on the HCON treatment showed higher petiole concentrations of boron (B), with P and sulphur (S) higher on LCON and HCON.

The number of invertebrates was much greater in November than in February, most likely due to the prevalence of green matter on the vineyard floor still evident in Spring but not Summer. Insects were captured using pitfall traps in the soil, and yellow sticky traps in the vine canopy. The abundance of detritivores (e.g. springtails and millipedes), omnivores (especially ants) and predators (mostly spiders and rove beetles) was greater on the LCON and HCON systems, possibly due to the cultivated soil surface restricting travel on the ORG and BD systems. Rows where compost was applied had higher numbers of omnivores, predators/parasitoids and predators. The complexity of invertebrate ecology and the food web in which invertebrates exist makes it difficult to determine the reasons behind some of the responses observed in this trial. It is possible however that the increased numbers measured may have been due to saprophagous insects grazing on the compost and its associated fungi, which in turn become prey for the omnivores, predators/parasitoids and predators.

The results of trials and surveys conducted elsewhere found that organically produced grapes yielded less than conventional production systems, as water soluble fertilisers and herbicides for weed control were not able to be applied. Those outcomes were supported in this trial, where the ORG, BD and LCON systems yielded 79, 70 and 91% respectively of the HCON treatment, probably due to reduced soil moisture availability at budburst. Cultivation using a dodge plough was the main method of weed control on the ORG and BD treatments, but yield had been suppressed by the time this was implemented.

Traditional measures of fruit quality such as total soluble solids, pH, titratable acidity, anthocyanin and phenolic levels in the juice and berries were not found to be consistently different between management systems and with or without the addition of compost. Differences in wine compositional analysis were observed in some seasons. Wines made from HCON management were generally higher in alcohol as well as anthocyanin and phenolic levels compared to the other management systems. Similar findings have been observed in previous studies.

Wine sensory evaluation was performed by a panel of viticulturists and winemakers from the McLaren Vale region. Panel members were asked to undertake a blind tasting of all wines and write down any attributes they perceived in wines. This language was then analysed using word frequency analysis to determine if certain descriptors were used more often for particular wines and if this corresponded to the management treatments. No differences in the language used to describe the wines made in 2010 were found. In the 2010-2014 wines ORG and in particular BD wines were consistently described as being more rich, textural, complex and vibrant than LCON and HCON wines. These findings support anecdotal evidence from winemakers who have used this language as a reason why they have chosen to make wine from organically and/or biodynamically managed fruit. How wine compositional changes relate to the textural changes perceived by winemakers in the wines made from these systems is yet to be determined.

A critical aspect for growers considering the adoption of alternative management practices is knowing whether it will be financially beneficial. In this trial, a gross margins analysis showed the ORG, BD and LCON systems generated 74, 65 and 91% of the financial return per hectare as the HCON system. This was principally due to reduced yields and higher operating costs associated with the use of tillage for under-vine weed control. It is suggested that the grazing of sheep or mulching the under-vine with straw may reduce water use by the vineyard floor cover, and thereby improve grape yields. It is also possible that the payment of premiums for higher quality ORG or BD fruit would help redress the higher costs of production.

Winegrape production is one of the easiest forms of primary production to manage organically or biodynamically, but as often occurs, the achievable yields are lower than a conventional system. This project has reinforced this notion, but has also shown there are considerable benefits to the broader ecosystem associated with ORG and BD production, such as improvements in soil quality. Growers wishing to adopt systems involving lower chemical inputs therefore have the choice of either improving on their conventional management practices to improve soil quality or use the ORG or BD system but recognise that yields and income may be reduced.

3. Background

3.1 Introduction

Viticultural production systems in Australia are constantly evolving, but steadily maturing as managers determine the best mechanisms for attaining sustainability. In part this is being driven by a recognised need to improve the soil, reduce pesticide use and enhance vineyard biodiversity, which are all promoted as best practice vineyard management. In conjunction with this desire to improve the biophysical management component is the need to remain financially viable. An understanding of the market requirements for the fruit will also determine management practice. The ongoing over-supply of fruit has compromised the prices received by growers, and in some cases made grape production unviable. Access to markets requiring differentiated product (e.g. organic or biodynamic) is an attractive option when demand for conventional fruit is low.

For some growers a move to organic or biodynamic production has enabled them to access alternative market opportunities for their fruit and /or wine. Growers already using a low input production system may accommodate this change quite readily, as many of the practices and allowable inputs are similar. Philosophically, all growers should be conducting their enterprises in a manner that embraces the environmental, economic and social tenets of sustainability. This is also the case for organic production, with systems designed to enable the production of a wide range of crops and products using systems that aim to produce food with minimal harm to ecosystems, animals or humans (Seufert 2012), to minimise undesirable environmental or social impacts while providing an acceptable financial return to producers. This is supported by Sandhu (2010) who noted the enhanced contribution made to ecosystem services in New Zealand arable production by organic systems ($US5528/ha/year) compared with conventional ($US3873/ha/year). They cite simple mechanisms of integrated pest management (IPM) in vineyards using buckwheat planted every 10 rows to provide the floral resources for the wasp parasite (*Dolichogenidea tasmanica*) which then contains light brown apple moth (*Epiphyas postvittana*) to below economic thresholds. The use of organic practices to enhance ecosystem services and potentially create a truly sustainable production environment is therefore worthy of further investigation.

Organic agriculture is practised in 164 countries, and more than 35 million hectares of agricultural land are managed organically by 1.9 million farmers. The global sales of organic food and drink reached almost $US64 billion in 2012 (FiBL and IFOAM 2014). In Australia, organic agriculture is now one of the fastest growing industries, with forecast growth of 10.3% over the period from 2013 – 2018 (Tonkin 2014). The recently released Australian Organic Market Report by Cogo (2014) shows organic grape production to be a $A35 million industry, and when valued added into wine it translates into a $A117 million (Australian retail $91 million, export $26 million) sector of the wine industry. Organic wine in Australia is enjoying a 14% compound annual growth rate, providing an incentive for more producers to enter the sector.

An example of the steady change in industry practice is exemplified by growers in the McLaren Vale region, which is now providing leadership in accreditation for the sustainable viticultural practices they are now embracing. The McLaren Vale Sustainable Winegrowing Australia Program has been designed to provide growers with a self-assessment tool which enables them to move along a continuum towards sustainability as their knowledge and practices improve (Santiago 2013). This does not mean the producers are required to adopt organic or biodynamic systems. However, the McLaren Vale wine region already has 21% of its growers using either biodynamic (11%) or organic (10%) practices and 51% adopting low-input conventional systems including integrated pest management (Santiago 2013).

To determine the comparative sustainability of organic (ORG), biodynamic (BD), low (LCON) and high input conventional (HCON) viticultural systems, a large field trial was initiated in 2008. The vineyard had previously been managed conventionally, so the first three years of conversion to a certifiable ORG or BD provided the basis for Luke Johnston's PhD project (Chapter 5). The trial's last three years, are the outcome of established ORG and BD systems compared to low and high input conventional production (Chapters 6 and 7). As noted below, assessments of this nature are usually made on-farm. This is a valid methodology, but only reflects the results of that particular farmer's practice (which are often not recorded) and which may not relate to other farmers' philosophy of management. Any changes to soil properties may also be masked by antecedent soil differences (Probst et al. 2008). An on-farm research trial as used in this case has the advantage of reduced variability across the site and that the researchers can provide input to the trial management and will have knowledge of all inputs used to achieve the final outcome.

The major criteria requiring assessment were soil quality, vine productivity and fruit and wine quality, invertebrate populations and the financial performance of the differing systems. Previous work has investigated soil quality as influenced by alternative and conventional production systems with mixed results. Recently Angelopoulou et al. (2013) investigated the soil quality on neighbouring ORG, BD and conventionally managed vineyards and apple orchards. They found no differences in soil pH, electrical conductivity (EC), total organic carbon or earthworm populations but the BD system did have higher total N than the conventional. The ORG system displayed better soil structural stability than the conventional, and the ORG and BD displayed greater mycorrhizal infection levels. No differences between ORG and CON management were obtained by Probst et al. (2008) for organic carbon, total N, phosphorus or sulphur. A comparison of conventional and organic vineyards managed for 7, 11 and 17 years revealed that the organic practices after 11 years generated increased total organic carbon, total nitrogen, available potassium, and soil microbial biomass (Coll 2011). Negative impacts from the increased tillage used for weed control included increased soil compaction and decreased earthworm populations. A comparative trial of ORG and BD viticultural systems conducted in California by (Reeve et al. 2005) found no differences in soil quality following the application of BD preparations.

A principal difference often found in vineyard floor management between ORG/BD and CON systems is the use of tillage vs herbicides for weed control in the under-vine zone. Guerra (2012) notes there are advantages in tillage such as improved water infiltration and reduced chemical use, but in the long term it may also lead to soil compaction, loss of structure and reduced fertility. By comparison, they note the benefits in herbicides being their low cost and ease of use, but weed resistance to herbicides, toxicity to the vines and the operator and the leaching of residues, soil compaction and decreased soil fertility were noted as undesirable consequences of herbicide use.

The impact of tillage extends beyond the physical and chemical parameters noted above to invertebrates, many of which provide notable benefits to the soil. For example, ants are widely used as an indicator of ecosystem functioning, as they can affect pest control, soil processes and plant growth. Other beneficial ground-dwelling invertebrate groups include spiders (Araneae), rove beetles (Staphylinidae), and ground beetles (Carabidae) (Sharley 2005). Sharley (2008) investigated the effects of soil tillage on beneficial invertebrate populations habituating the vineyard mid-row. Ants represented the largest portion, and along with beetles, millipedes and centipedes, their populations were significantly impacted detrimentally by tillage. Tillage also adversely affected the population of beneficial wasps in the canopy, including *Trichogramma*, possibly by removal of their food source of floral nectar. It is possible that tillage of the under-vine area, as generally required in organic viticulture, will also impact on invertebrate populations. Herbicides also remove the food source for invertebrates, so the relative impact of these very different under-vine management tools on arthropods required investigation within the project.

According to Wiedmann (2014), consumer interest in organic products has been generated through an increased awareness of issues relating to the environment, individual health and a rise in the number of food scandals. This has led a proportion of consumer wine preferences to be biased towards organic wine based not necessarily on quality but "extrinsic clues like the label indicating organic production" being more influential. At what cost though are the growers paying to produce organic wine? Yields are generally recognised as being lower than conventionally produced grapes (Malusà et al. 2004). Wheeler and Crisp (2009) used a commercial Clare Valley vineyard running parallel production of organic and conventional grapes. They found a 10% overall reduction in organic yields, but in the red wines this was in partly compensated by an improvement in quality. Madge (2005) in a grower survey found the yield of organic grapes to be in the range of 6.5-14.2 t/ha, while conventional yields were from 9.1 – 25.3 t/ha. Santiago (2010) in a survey of 23 growers noted a general yield reduction of 8.6%, but qualified the variability that was apparent as being due to the amount of time since conversion and the scale of operations.

Management of the mid-row and under-vine zones, and the effect on yield has been studied by Smith (2008) and Tesic et al. (2007). The site at Monterey, California was low rainfall (250 mm) and heavily reliant on drip irrigation (Smith 2008). Management of the mid-row with short or long-season cover crops or cultivation (mid-row) or cultivation vs herbicides (under-vine) did not affect the yield, because the vines' production is dependent on water applied through the drippers, and where this is plentiful, other treatment factors are masked. The investigation by Tesic et al. (2007) by comparison was impacted by drought, especially at the hot-dry site (Wagga Wagga). Floor cover ranged from full cover, mid-row cover and under-vine bare, or completely bare using herbicides. Rainfall and irrigation input was significantly reduced, and the vineyard floor management had a direct effect on grape yield. Removing floor cover with herbicides increased soil moisture availability to the vines significantly increasing vine vigour and fruit yield. The McLaren Vale trial site used in this study has a higher average annual rainfall but water stress during long, hot summers may still occur. Vineyard floor management may therefore be an important factor in grape yield for the warm-dry production zones as well.

As noted earlier, improvement in wine quality is often noted as being a driver for people to convert to ORG or BD viticulture. To the best of our knowledge there are no peer reviewed studies that have made a direct comparison between wines made from CON and ORG or BD management. Woese et al. (1997) reviewed past literature and found no significant differences in measurements (ethanol, sugars, acid, extract, fungicides, pesticides) between grape must and wine from organic and conventional production. However, Reeve et al. (2005) found that in specific years BD grapes had higher TSS and phenolics, and better vine balance compared to organic treatments. Based on this grape chemical analysis, Reeve et al. (2005) concluded that there was little evidence to support any improvement in quality from the BD preparations when compared with wines made from ORG grown fruit. In a sensory study by Ross et al. (2009), no major differences in sensory attributes were seen between organically and biodynamically grown Merlot wines, with only one notable exception in the study. In contrast to these results, Julian and Carolann Castagna, who are running a biodynamic vineyard in Beechworth, Victoria, believe that biodynamics is the best way to achieve optimum fruit quality and best express terroir and "dramatically increase the possibility of individuality". While these claims are not scientifically tested, there is sufficient anecdotal evidence of improved fruit quality to warrant further scientific comparison

One of the reasons for growers to convert to organic viticulture is economic, where they expect to be able to obtain a premium price for their fruit and/or decrease the cost of production. To address the dearth of credible information available on the cost of production between biodynamic and conventional viticultural production, Santiago (2010) undertook a survey of ORG and BD growers to determine their cost structures and production outputs. The survey results showed an overall 24% increase in costs for ORG and 7% for BD growers. Canopy management costs reduced by 27% and 75% for ORG and BD growers respectively. Under-vine management costs were 76% (ORG) and 222% (BD) higher than conventional vineyards however, but this varied considerably due to the scale of the operations.

The case study of Wheeler and Crisp (2009) showed a cost penalty of about 20%, which coupled with yield reduction means that price premiums will be required to compare favourably with conventional gross margins. As noted by Madge (2005) the costs of production varied from 15% lower to 47% higher in organic systems. With generally lower yields, the pruning and harvesting costs per tonne of grapes are considerably more for ORG/BD vineyards.

3.2 Defining organic and biodynamic production systems

According to the Organic Industry Standards and Certification Committee (OISCC 2013), to grow products (including grapes) organically means to apply practices that emphasise the:

- use of renewable resources; and
- conservation of energy, soil and water; and
- recognition of livestock welfare needs; and
- environmental maintenance and enhancement, while producing optimum quantities of produce without the use of artificial fertiliser or synthetic chemicals

The emphasis extends well beyond the exclusion of synthetic fertilisers and pesticides to a holistic understanding of an agricultural system and how it must function with minimal detrimental impact on the broader environmental framework.

Biodynamic agriculture is an extension of an organic system. It is defined by (OISCC 2013) as an agricultural system that introduces specific additional requirements to an organic system. These are based on the application of preparations indicated by Rudolf Steiner and subsequent developments for management derived from practical application, experience and research based on these preparations.

The production of winegrapes and wine is generally recognised as one of the forms of primary production best suited to organic production. This is because winegrapes are a relatively hardy crop which also has a low nutrient requirement. Disease control uses the staple fungicides of sulphur and copper, with alternatives such as potassium bicarbonate and some milk by-products now also available. Weed control can be managed using grazing, mowing and cultivation. Each of these practices is not foreign to conventional producers, making conversion to an organic production system less onerous than many other high input crops. While the allowable inputs to organic wine are less than conventional producers have access to, wines of very high quality made by both large and small producers are readily available at price points suited to most consumers.

3.3 Reason for changing to organic production

Improving wine quality is often quoted as a principal reason for converting to organic or biodynamic viticulture. Geissner et al. (2011) found in Germany that consumers believed organic and biodynamic wine was of better quality and also healthier. Santiago (2010) found an important driver for change from conventional to biodynamic viticulture was to attain the fruit quality desired but not achievable with conventional practices.

Madge (2005) in his survey of Australian winegrape growers found the reason for conversion extends beyond fruit quality. For them, other justification included:

- financial (e.g. marketing advantage, cheaper production, income diversity)
- personal and philosophical (e.g. personal health, personal beliefs, sense of responsibility)
- environmental (e.g. environment/wildlife benefits)
- agricultural (e.g. better product quality, agricultural sustainability, easy IPM system)

Despite the widespread interest in organic and biodynamic grape and wine production, there was a paucity of scientific information to support or otherwise the claims of improved soil, grape and wine quality coming from those systems. While several investigations had been undertaken, they often lacked scientific rigour and were therefore of questionable value (Johnston 2010). To answer the question “Are organic and biodynamic viticultural systems more sustainable than conventional systems?” a field trial was established by Luke Johnston in 2008 and with additional funding has continued for a total of six years. The following report describes the outcomes of that trial.

4. Project Aims and Performance Targets

4.1 Project Aims

- To assess the long term impacts of organic, biodynamic and conventional viticultural systems on soil health, vine productivity and wine quality.
- To develop management practices which enhance sustainable viticultural systems including the adoption of organic and biodynamic viticulture.
- To provide a trial site that accommodates the needs of the vineyard owners, post-graduate students and researchers.
- To liaise with grapegrowers, industry suppliers and winemakers to ensure the success of the project.
- To provide the grapegrowing industry with the information required to make informed decisions regarding preferred management systems.

4.2 Performance Targets

Outputs and Activities 2011-2012

Year 1	Output	Target Date dd/mm/yy	Activities
a	Objectives discussed and agreed upon by UA, Gemtree and GWRDC	1/08/2011	Meet with Gemtree management team, GWRDC and UA researchers to discuss and agree upon project objectives.
b	Agreement reached on management systems by working group	31/08/2011	Working group consisting of industry, researchers and GWRDC will meet to discuss and agree on practices to be applied in each of the management systems.
c	Field day for industry, stakeholders and GWRDC	15/12/2011	Introduction to site, delivery of Luke Johnston's findings and launch of the current project.
d	Awareness raised through media campaign	15/12/2011	Media release to industry with details of the objectives of the project.
e	Progress report	3/02/2012	Progress report on 7 months activities and results.
f	Wine evaluation by industry and stakeholders	30/03/2012	Wine evaluations on research wines will be made by invited winemakers, judges and researchers.

Outputs and Activities 2012-2013

Year 2	Output	Target Date dd/mm/yy	Activities
a	Industry journal article summarising project	30/07/2012	Write an industry journal article to inform industry of first seasons findings
b	Innovator network publications	31/12/12	Develop publications in response to industry requirements
c	Progress report	2/02/2013	Prepare report of progress made on understanding the differences between management systems from previous year’s activities.
d	Wine evaluation by industry and stakeholders	30/03/2013	Wine evaluations on research wines will be made by invited winemakers, judges and researchers.
e	Organic workshop at AWITC	30/06/13	Co-organise workshop and present findings to date from Gemtree project

Outputs and Activities 2013-2014

Year 3	Output	Target Date dd/mm/yy	Activities
a	Progress report	2/02/2014	Prepare report of progress made on understanding the differences between management systems from previous year’s activities.
b	Wine evaluation by industry and stakeholders	30/03/2014	Wine evaluations on research wines will be made by invited winemakers, judges and researchers.
c	Field day for industry, stakeholders and GWRDC	15/4/2014	Delivery of findings from the current project.
d	Start industry and scientific papers and material for the GWRDC innovator network	30/06/2014	Produce industry and scientific publications and material for the GWRDC innovator network from the project findings.
e	Awareness raised through media campaign	30/06/2014	Media release to industry to highlight findings after three years.
f	Final report to GWRDC	30/06/2014	Three seasons of data collated, analysed, and written as a report to the GWRDC.

5. Do organic and biodynamic vineyard management practices affect soil properties, vine performance and wine quality over the three-season conversion period?

5.1 Abstract

In Australia, organic and biodynamic vineyard certification is conducted over a three-year conversion period. However, little is known about the changes that occur during this time. The aim of this study was to assess soil parameters, vine performance, berry composition and wine quality of different management systems during the conversion period. In 2008, a 20 year-old Cabernet Sauvignon (*Vitis vinifera* L.) vineyard located in McLaren Vale, Australia was converted to an experimental trial assessing four management systems: organic (ORG), biodynamic (BD), low-input conventional (LCON) and high-input conventional (HCON). A compost treatment was also added to each of the management systems studied to separate compost effects. During the first two seasons, management system had no consistent effect on parameters measured. However, in the third season, ORG and BD treatments had lower shoot length, pruning weight, canopy density, yield, bunch and berry weight compared to LCON and HCON. No significant differences were found with total soluble solids, pH, titratable acidity or yeast available nitrogen between management systems. Total anthocyanin and phenolic levels in berries were inconsistent between treatments and seasons. No differences in wine quality were observed between management treatments in the 2009/10 season however, in 2010/11 ORG and in particular BD wines were described as being more rich, textural, complex and vibrant than LCON and HCON wines. Organic and biodynamic management affected soil, vine and wine parameters over the three-year conversion period.

5.2 Introduction

Recently, organic and biodynamic viticultural practices have received much attention, especially by premium grape growers worldwide (Goode and Harrop 2011). Between 2007 and 2009, the number of hectares of vineyard certified organic around the world doubled (Willer and Kilcher 2011). In Europe, there are almost 167,000 ha of certified organic grapevines, while in the United States of America, it accounts for over 11,000 ha of production (Willer and Kilcher 2011). This growth is coupled with a demand for organic and alternative methods of agriculture due to increasing consumer concern regarding food quality and safety (Magkos et al. 2006).

Organic and biodynamic standards prohibit the use of synthetic fertilisers, herbicides, fungicides and pesticides in the vineyard (AQIS 2013). Organic/biodynamic growers are permitted to use wettable sulphur and copper hydroxide (<8 kg ha^{-1} p.a.) in the vineyard (AQIS 2013), and hence in the warm and dry regions of Australia, conventional and organic growers share similar disease management programs. Therefore, one of greatest differences between organic/biodynamic and conventional viticulture management in Australia, is under-vine weed control. Conventional growers generally use herbicides, while organic/biodynamic growers either cultivate (using a knife, plough or disk) or slash the under-vine area (Bekkers 2012, Marshall 2012). Certification for these management systems is granted once growers use these practices for three seasons, known as the conversion period. However, it is not established what effects these systems have on soil, vine, grape and wine parameters over this period of time.

Biodynamic viticulture is difficult to define as it may vary from grower to grower, depending on one's beliefs and adoption. However, biodynamic growers are bound to the same restrictions as organic growers. In addition, biodynamic growers use a variety of preparations (Preparations 500-508, Table 5.1) as outlined by Rudolf Steiner in his lectures in 1924 (Steiner 1993). In Australia, certified biodynamic growers are required to apply preparation 500 and compost preparations at least once per year (AQIS 2013). However it is recommended that growers use it 2-4 times per season (Biodynamic Agriculture Australia 2015). While the benefits of these preparations are often purported by biodynamic advocates, their mode of action and significance remains unclear (Carpenter-Boggs et al. 2000, Reeve et al. 2005).

Table 5.1 Biodynamic preparations. Source: *Biodynamic Resource Manual* (Mackay 2010)

Horn Manure Preparation (500)	Made from cow manure which is placed in cow horns and buried in the soil over winter. It brings in the calcium forces and helps the soil develop humus and structure. It also attracts earthworms and soil micro-organisms.
Horn Silica Preparation (501)	Made from ground quartz crystal buried in the soil in cow horns over summer. Only a tiny amount is used to take the light forces into the roots and to aid photosynthesis.
Yarrow Preparation (502)	Yarrow flowers placed in a stag's bladder stimulates the potassium, silica, selenium activating bacteria and helps combine sulphur with other substances.
Chamomile Preparation (503)	Chamomile flowers placed in small intestines of the cow – retains nitrogen and calcium, keeping them in the living realm and prevents loss to the atmosphere.
Stinging Nettle Preparation (504)	Stinging nettle conveys intelligence to the soil; helps proper decomposition, aids chlorophyll formation and stimulates iron, potassium, calcium, magnesium and sulphur activity in the soil.
Oak Bark Preparation (505)	Oak bark placed in a cow skull and in water over winter. It helps pull the earthly forces back into the soil, when the water activity is working too strongly, such as after too much rain or at Full Moon.
Dandelion Preparation (506)	Dandelion in the cow's mesentery – stimulates the potassium/silica bacteria in the soil to enable it to work more effectively with the growth forces. Silica makes the plants more sensitive. It can help increase flowering and filling out of fruit e.g. cucumbers. It brings substance to our foods to nourish us. It also stimulates the magnesium, boron and selenium soil activity.
Valerian Preparation (507)	Tincture made of valerian flowers – stimulates the phosphorus process and mobilises the phosphorus-activating bacteria in the soil, as well as selenium and magnesium. It prevents the flowering process becoming excessive.
Fresh Equisetum Tea or Fresh Casuarina Tea (508)	Fresh Equisetum Tea can be made up like an herb tea – used for the morning atmospheric sprays to tighten the fluids in the plant, balance the water in the plant and prevent fungal infestation such as mildews, rusts and moulds.
Cow Pat Pit (Manure concentrate)	Brings in cow manure influence, plus basalt and calcium in forms able to be utilised by plants. Includes the biodynamic compost preparations and aids fertility

Past research comparing organic/biodynamic viticulture practices with conventional have primarily focused on soil properties (Gehlen et al. 1988, Okur et al. 2009, Probst et al. 2008, Reinecke et al. 2008, Stamatiadis et al. 1996). These studies found significant improvements in soil physical, chemical and biological properties when organic/biodynamic management strategies were used in the vineyard. However, in these trials, organic treatments used compost, while the conventional did not use any organic amendments. Compost is well-known to improve soil properties (Pinamonti 1998) with many practitioners now applying it to their vineyards; regardless of whether they are managing their vineyard organically or conventionally.

Research to evaluate the effects of management systems on vine and grape parameters have mostly been conducted in Germany (Corvers 1994, Hofmann 1991, Kauer 1993), northern Italy (Malusà et al. 2004) or north-east United States (Pool and Robinson 1995). Generally it has been shown that overall vine growth and yield can decrease by 15-30% when organic/biodynamic management practices are used (Hofmann 1991, Kauer 1993, Pool and Robinson 1995, Malusà et al. 2004). This reduction in growth was more pronounced in dry seasons, with soils of low nitrogen and clay content, and when the cover crop competed with the vines for nutrient and water. Organic grapes had higher levels of anthocyanins and polyphenols, which were attributed to lower availability of nitrogen (Malusà et al. 2004).

The above studies were all conducted in cool and wet conditions with adequate rainfall. In Australia, where growing season rainfall is often very low and supplemented by irrigation, the effects of organic practices are not well researched. Tesic et al. (2007) compared a permanent sward (similar to the organic system in this trial) to a bare under-vine (similar to the conventional system) on vegetative growth, yield and fruit composition in both Wagga Wagga (dry climate) and at Tumbarumba (wet climate) in NSW, Australia. The permanent sward (organic) significantly reduced shoot growth, pruning weights and soil moisture content compared to the conventional treatment in the dry climate, however, under-vine treatments had minimal effect in the wet climate at Tumbarumba. Studies have also researched how management systems affect berry and wine composition (Otreba et al. 2006, Vian et al. 2006) wine quality (Dupin et al. 2000, Henick-Kling 1995, Lante et al. 2004). Results have been inconsistent and inconclusive.

This chapter describes an experimental trial conducted in McLaren Vale, South Australia comparing four viticulture management systems: organic (ORG), biodynamic (BD), low-input (LCON) and high-input conventional (HCON). A compost treatment (applied under-vine) was also applied to each of the management systems to determine if compost is a major point of difference between systems. The aim of this study was to determine the effects of management systems on soil and vine growth parameters and grape and wine quality over the three-season conversion period.

5.3 Material and Methods

5.3.1 Experimental site and management history

In 2008 a 9.3 ha experimental site was established in a 108 ha commercial vineyard in the McLaren Vale wine region, South Australia (35°207' lat, 138°589' long.). The vineyard was planted in 1989 with own-rooted cv. Cabernet Sauvignon (clone LC10) and trained to a two-tier bilateral cordon with vine spacing of 1.8 m x 3 m (1850 vines ha^{-1}). Vines were mechanically pruned, followed by a manual pass, leaving approximately two to four nodes/spur (60-80 spurs/vine).

Growing season rainfall from September to March (annual rainfall (July-June) shown in brackets) for 2008/09 was 99 mm (480 mm), 2009/10 was 225 mm (642 mm) and 2010/11 was 365 mm (718 mm). The site uses bore water for drip irrigation (EC 1200-1800 µS cm^{-1}) with the amount determined using gypsum block readings. Depending on seasonal rainfall, irrigation was applied at between 0.9-2.3 ML ha^{-1}; 2.3 in 2008/09, 1.4 in 2009/10 and 0.9 in 2010/11. In 2010/11, gypsum blocks were installed at four depths (20cm, 40cm, 70cm and 1m) in two replicates of the ORG and HCON (+/- compost) to analyse soil moisture content. Data were uploaded using a GBUG data logger every two to three weeks (MEA, Magill, South Australia).

High-input conventional practices were used from 1989, however, since 2003 no synthetic fertilisers were applied and sulphur/copper sprays were the main fungicides (depending upon seasonal disease pressure and varietal susceptibility). Prior to 2008/09, under-vine rows received three herbicide sprays (a mixture of Basta® and Roundup®) per year (September, November and May).

The mid-rows were sown with a blend of ryegrass (*Lolium multiflorum*) and burr medic (*Medicago polymorpha* var *brevispina*) in autumn 2009 and kept as a permanent sward, slashed two to four times per year. Soil pits were dug before vineyard establishment, this survey demonstrated that the northern section (replicates 1 and 2) of the trial site is a non-calcareous Red Brown Earth, while the southern section (replicates 3 and 4) is red and brown clay (Vertisol). No leaf plucking, shoot thinning or bunch thinning was applied to vines during this study.

5.3.2 Experimental design and treatment strategies

A randomised split-plot design was established with four management systems (wholeplots): ORG, BD, LCON and HCON, all treatments were with (+) and without (-) compost (subplots). Treatments were replicated four times with each replicate consisting of eight rows (40 vines per row), of which six vines were sampled from (192 vines in total) (Figure 5.1). A four-row buffer zone was established between replicates. Data were collected over three seasons 2008/09, 2009/10 and 2010/11 as per the conversion period. Management systems ORG, BD, LCON and HCON are examples of current practices employed by growers for cv. Cabernet Sauvignon (*Vitis vinifera* L.) in the McLaren Vale region and are detailed in Table 5.2.

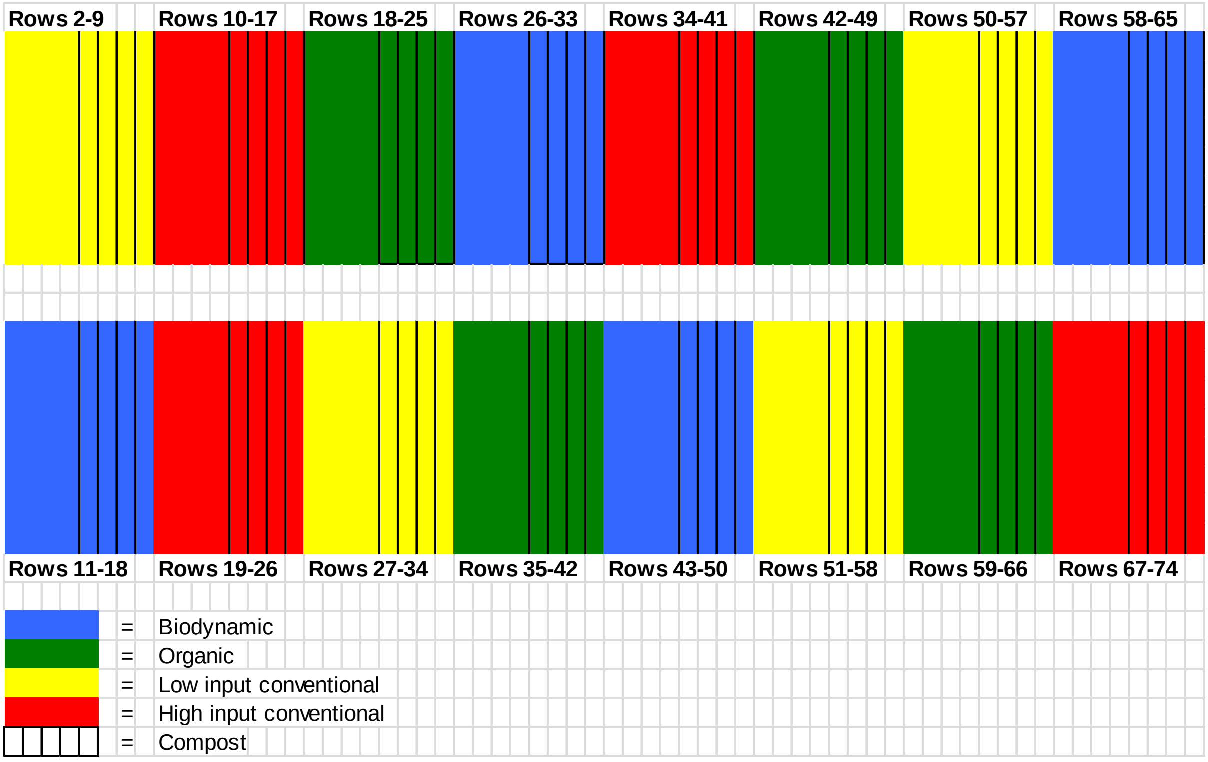

Figure 5.1 Experimental trial design showing four management treatments (biodynamic, organic, low-input conventional and high-input conventional) replicated four times with compost applied to half the trial.

The main difference between ORG and BD was the application of biodynamic preparations (500-508) (Table 5.1). Preparation 500 is derived from cow manure while preparation 501 is from silica. They are both buried in cow horns over the winter and summer months respectively. The biodynamic preparations are not fertilisers, but are claimed to stimulate nutrient cycling and improve plant photosynthesis (Koepf et al. 1990). 500 and cow pat pit (a combination of 502-507) was sprayed between 2-4 times each season, 501 was applied the following day (Table 5.2). The ORG system was sprayed with compost teas in 2008/09 as an additional foliar spray, however were discontinued thereafter due to uncertainty as to their benefits. Sulphur was the principal fungicide applied on all treatments, with copper used as required and additional synthetic fungicides in high disease prone seasons on the HCON system (Table 5.2).

Under-vine weed management differed greatly between ORG/BD and LCON/HCON (Figure 5.2). There was no difference between ORG and BD, both using a variation of cultivation and slashing throughout the trial (Table 5.2). In the first season (2008/09) the under-vine area was lightly cultivated using a Braun knife, twice in the spring and once in the autumn. In the second season (2009/10), weeds were slashed with a Fischer mower, twice in spring and again in autumn. In the third season (2010/11), due to the higher rainfall, weeds were allowed to grow until January and then cultivated using a Dodge plough, resulting in bare soil under-vine for the remainder of the growing season. Herbicides were applied under-vine to both LCON and HCON twice between budburst and flowering and once post-harvest. LCON used a mixture of broad-spectrum herbicides; Roundup® and Basta®, while HCON also used the pre-emergent Pendimethalin (Stomp®).

Figure 5.2 Floor management of the four treatments A (ORG), B (BD), C (LCON) and D (HCON) displays obvious differences between the conventional and alternative practices.

The application of compost in southern Australian viticultural systems is common practice for organic and conventional producers, so it was necessary to apply it to all systems under investigation. The compost was applied using a mechanical spreader in a separate row of each replicate (a sub-plot), to determine its impact independently of each system. Compost (Nitra Mulch, Peats Soils, Willunga, South Australia) was applied in May 2009 at 22 t ha^{-1}. The feedstock of this compost was predominantly green waste from municipal waste and the nutrient details are listed (Table 5.3). The BD compost preparations (502-507) were not used in the composting process.

Table 5.2 Vineyard management strategies for organic, biodynamic, low-input conventional and high-input conventional treatments from 2008-2011, McLaren Vale, Australia.

	Treatments			
	Organic	**Biodynamic**	**Low-input conventional**	**High-input conventional**
Mid-row management	Mown resident vegetation	Mown resident vegetation	Mown resident vegetation	Mown resident vegetation
Undervine management	Mowing and/or cultivation	Mowing and/or cultivation	Glyphosate and oxyflurofen in spring	Glyphosate/ oxyfluorfen/ pendimethalin in spring
Disease management	Wettable sulphur,	Wettable sulphur,	Wettable sulphur,	Wettable sulphur,
	Copper cuprous oxide	Copper cuprous oxide	Copper cuprous oxide	Copper cuprous oxide, trifloxystrobin Myclobutanil 21 g ha-1 in January 2011
Insect management	None	None	None	emamectin benzoate
Other				
	seaweed extract	seaweed extract	seaweed extract	seaweed extract
		BD 500, 501		

Table 5.3 Nutrient analysis of compost (Nitra Mulch, Peats Soils, Willunga, South Australia).

Nutrient	Unit	Amount
N	g kg^{-1}	17
P	g kg^{-1}	2.2
K	g kg^{-1}	11
Total Organic C	g kg^{-1}	250
Water content	g kg^{-1}	300
C/N		15:01
pH		7.2
EC	µS cm^{-1}	4476

5.3.3 Soil sampling protocol and analysis

Following the removal of O horizon material by hand, soil cores (0 to 10 cm) were taken from the under-vine area avoiding soil directly under the irrigation drippers. Three composite samples per treatment and replicate were taken, approximately 10 - 20 m apart. Each composite sample consisted of soil from five individual cores. The samples were kept cool before being sieved (<2 mm) and then divided into aliquots. Half of each sample was oven-dried at 40°C (for determination of pH, electrical conductivity (EC), organic C), whereas the other half was stored in a freezer at -20°C. Before being used, frozen samples were defrosted for 16 hours at 4°C.

The initial sampling (BB08) was done before treatments had been applied to determine variability between blocks (Table 5.4).

Table 5.4 Soil texture, organic C, pH and EC of four blocks at experimental trial site, McLaren Vale, Australia before treatments were applied (n=4, ± standard deviation) at budburst 2008.

Block	Texture	Organic C (%)	pH	EC (mS m^{-1})
1	Silty loam	2.0 ± 0.04	8.1 ± 0.2	108 ± 32
2	Silty loam	2.2 ± 0.21	7.8 ± 0.5	134 ± 31
3	Silty loam	1.3 ± 0.21	7.9 ± 0.2	80 ± 5
4	Silty loam	1.3 ± 0.07	8.0 ± 0.2	74 ± 9
Average		1.7 ± 0.42	8.0 ± 0.3	99 ± 32

Soil samples were taken at five time points (Figure 5.4). The initial sampling (BB08) was done before treatments had been applied to determine variability between blocks. The remaining samplings occurred at BB09, PH09, BB10 and PH10.

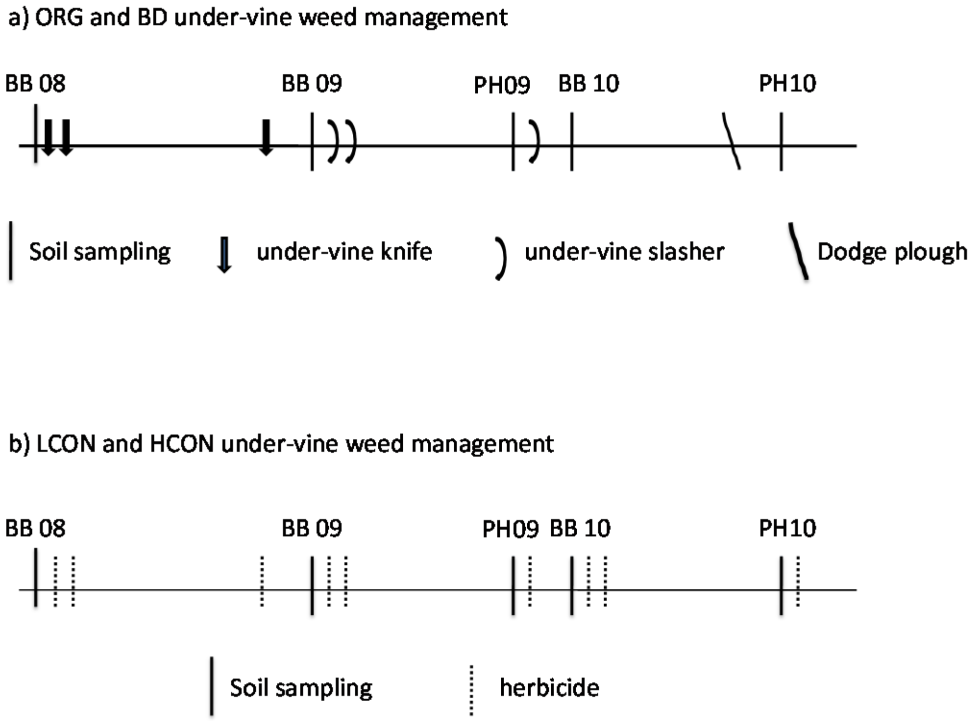

Figure 5.4 Under-vine weed management timeline for a) ORG and BD, b) LCON and HCON.

Soil texture was measured using a hydrometer (Bowman and Hutka, 2002). Soil pH and EC were measured in a 1:5 soil:water suspension after 1 hour end-over-end shaking at 25 °C. Organic carbon was measured using the Walkley and Black procedure (Walkley and Black 1934). Soil water content was determined after oven-drying at 105 °C for 24 hours. Inorganic N ($NH4^{+}$-N and $NO3^{2-}$N) was extracted in a 1:5 soil:2M KCl ratio with 1 hour shaking (Rayment and Higginson 1992). The concentration of ammonium and nitrate was measured using the Kjeldahl method (McKenzie and Wallace 1954). Available P was extracted using anion exchange membranes (Kouno et al. 1995) and P was determined colorimetrically at 712 nm (Murphy and Riley 1962). Organic carbon was measured using the Walkley and Black procedure (Walkley and Black 1934).

To measure cumulative respiration, 30 g of freshly defrosted soil was placed into PVC cores (diameter 3.7 cm, height 5 cm) with a nylon mesh base (0.75 µm, Australian Filter Specialist). The cores were then placed individually into 1 L glass jars together with a vial containing 10 mL of water and sealed with gas tight lids equipped with septa to allow headspace sampling. Using a Servomex 1450 infra-red gas analyser (Servomex, UK), headspace of CO_2 was quantified in each jar. The closed jars were then incubated for 6 days and then the CO_2 concentration in the headspace was measured. Respiration rates over the 6 days were low and the CO_2 concentration in the jars did not exceed 1% CO_2 on day 6.

The infra-red gas analyser was calibrated using known amounts of CO_2 injected into glass jars similar to those used for the samples. Linear regression was used to define the relationship between CO_2 concentration and detector response. This relationship was then used to calculate the CO_2 concentration in the jars with soil. The calculated CO_2 concentration was multiplied by the gas volume of the jars to obtain the mg of CO_2-C respired over the six days.

Microbial biomass C was determined by a modified version of the fumigation-extraction method (Anderson and Ingram 1993; Vance et al. 1987). For each sample two times 5 g of freshly defrosted soil were weighed out. One aliquot was placed in a desiccator and fumigated with chloroform for 24 hours. The non-fumigated soils were stored at 4°C. After fumigation, all samples were shaken for 1 hour with 20 mL of 0.5M K_2SO_4. Samples were then filtered through Whatman #42 paper and stored at 4°C until titration which was carried out using 4mL of extract, 1 mL 0.0667M $K_2Cr_2O_7$, 5 mL H_2SO_4 and indicator, then titrated with acidified ferrous ammonium sulphate (0.033M). Microbial biomass C was calculated as the difference between fumigated and non-fumigated samples.

5.3.4 Vine growth, nutrition and berry composition

At harvest, bunch number per vine, average bunch weight (g) and yield (kg) were measured. During winter, pruning weight and average shoot length were also recorded. These parameters are expressed on a per metre canopy basis. Yield to pruning weight ratios were then calculated. Canopy density was visually evaluated at fruit set (Smart and Robinson 1991).

Fifty petioles were selected from the leaf opposite the inflorescence at flowering from each replicate and oven dried at 40° C. Samples were analysed using an inductively coupled plasma optical emission spectrometer (ICP-OES) (model Optima 2100DV, Perkin Elmer, USA) at Waite Analytical Services (Adelaide, South Australia) for total nitrogen, phosphorus, potassium, calcium, magnesium, boron, zinc, iron, copper, aluminium, sodium, sulphur and manganese. One hundred berries from all treatments and replicates were randomly collected at harvest and crushed for juice elemental analysis. Samples were analysed as for petioles, except that nitrogen was not determined.

A 100 berry sample was taken to determine average berry weight, total soluble solids (TSS), pH, titratable acidity (TA), yeast available nitrogen (YAN), total anthocyanins and total phenolics. The level of total soluble solids was measured as °Brix using a DMA 35N Density Meter (Anton Paar GmbH, Austria). Titratable acidity (TA) and pH were measured using a Crison Compact Titrator 08328 Alella (Crison, Spain), with TA measured by titration to pH 8.2 (Iland et al. 2004). Yeast Available Nitrogen (YAN) was calculated from a measurement of Primary Amino Acid Nitrogen (PAAN) and Ammonia Nitrogen (AN) using enzymatic kits (Vintessential, Australia). Total anthocyanins and total phenolics were obtained using a modified spectrophotometry method described by Iland et al. (2004). Fifty berries from the 100 berry sample were homogenised using a CAT X620 Homogeniser (Ingenieurbüro M. Zipperer GmbH, Germany). Centrifugation was performed in a Hettich D-7200 Tuttingen centrifuge (Hettich Universal, Germany). A Metertech SP-830 Plus spectrophotometer (Metertech, Taiwan) was used to analyse absorbance at 280 nm and 520 nm.

5.3.5 Winemaking

Once grapes were harvested, weighed and recorded, an equal amount of grapes from the four field replicates was taken and pooled, creating three winemaking replicates of each management system. Cabernet Sauvignon grapes were harvested by hand between 23-26 °Brix depending on the season and each treatment pooled into three 30 kg replicates for winemaking. Each winemaking replicate was comprised of randomly selected bunches of each treatment. A crusher/destemmer (Enoitalia, ENO-15, Italy) was used to process each replicate and juice/must pumped directly into 30 L food grade plastic open fermenters with screw top lids (Winequip products, Magill, South Australia). During crushing 50 mg/L of sulphur dioxide (SO_2) was added as a 20 % solution of potassium metabisulphite (PMS) to all the sampling units. Each ferment was then co-inoculated with 25 g/hL reconstituted dried yeast (Maurivin® AWRI 796, Mauri Yeast Australia, Sydney, Australia). Diammonium phosphate (0.5 g/L) was also added at the time of yeast inoculation when the ferments were between 18-20^{o}C. Once alcoholic fermentation began, wines were co-inoculated with *Oenococcus oeni* VP41 LAB (Lallemand, Underdale, Australia) at 0.2 g/20L to induce malolactic fermentation (MLF). No acid additions were made to the ferments prior to yeast inoculation.

All fermentations were maintained at 18°C ± 2°C and the cap manually plunged every 12 hours for a period of nine days or until fermentations had reached 2˚ Baume. Wines were pressed using a bladder press (Diemme 130 L Laboratory Press, JB Macmahon Pty Ltd, Forestville, Australia) operated using the following protocol; 0.2, 0.4, 0.6, 0.8 and 1 bar each held for five minutes. The wine was transferred to 10L glass demijohns (Winequip products, Magill, South Australia) and stored at 20°C. SO_2 (to reach 80ppm Total SO_2) additions were made to ferments that had completed malolactic fermentation (<0.05 g/L malic acid by enzymatic test kit (Roche, Castle Hill, Australia)). Finished wines were filtered using a pad filter (Colombo-Rover pump & 6 pad filter, Italy) provided with 0.8 µm Z6 cellulose filters pads (Ekwip, NSW, Australia) and bottled into 375 mL bottles with screw cap closures. The wines were then stored at a constant temperature of 16^{o}C for later wine sensory and chemical evaluations.

5.3.6 Wine compositional measures

Standard chemical measurements (SO_2 (ppm), pH, TA (g/L), volatile acidity (g/L), alcohol (%) and residual sugar (g/L)) were performed on the wines at the time of sensory evaluation, following the methodologies described in Iland et al. (2004). Wine samples were analysed for density (au), hue, total anthocyanins (mg/L), and total phenolics (au) as described by Iland et al. (2004) and modified for use with 96-well ultraviolet transparent microtitre plates (Greiner, Sigma-Aldrich, Sydney Australia). Wine samples (50 µL) for total anthocyanins and total phenolics determinations were added to 1 M HCl (5 mL) and incubated for a minimum of three hours at room temperature before aliquots (300 µL) were transferred to 96-well microtitre plates and read at 520 nm (total anthocyanins) and 280 nm (total phenolics) using a Quant Microplate spectrophotometer (Thermo Scientific Multiskan Spectrum, USA). Density and hue were calculated from absorbance values of neat wine (150 µL aliquots in 96-well microtitre plates) read at 420 nm and 520 nm.

5.3.7 Sensory evaluation

In January 2011, wines made from 2009/10 were evaluated by wine experts from the Mornington Peninsula, Victoria. Ten experts noted descriptors of aromas and palate, and scored wines using a 20-point scale. Experts were aged between 22-67 and comprised winemakers, viticulturists and wine marketers with between four and 33 years of industry experience. In May 2012, wines from the 2010/11 were evaluated by 10 wine experts from McLaren Vale, South Australia. Experts used the same procedure as above. Experts were aged between 30-52 and comprised winemakers, viticulturists and wine marketers with between 11 and 35 years of industry experience.

For both sensory evaluation sessions, experts analysed four brackets of wines, each bracket consisting of six wines, totalling 24 wines. Thirty mL of each wine was served in coded, INAO (ISO standard) 215 mL tasting glasses (Arcoroc Viticole, Cardinal International, France). Wines were given a three digit code (generated using Design Express®, Version 1.6, Qi Statistics, United Kingdom), and randomised within the bracket for each expert. This was carried out to prevent first order carry-over effects (Macfie et al. 1989). Experts were required to have a break of at least five minutes between brackets. To avoid palate fatigue and to cleanse their palate, the assessors were provided with filtered water and plain water crackers (Arnotts®, Australia) to have between wine samples.

Each wine was firstly assessed using the Australian wine show standards 20 point score system (Dunphy and Lockshin, 1998, Ewart et al. 1993). Briefly, three points were awarded for colour, seven points for aroma and ten points for palate. Judges were then asked to provide a written description of attributes that best described the wine. All attributes and final wine quality scores used by each judge for every wine were then entered into Excel (Microsoft Excel (Version 2011), Redmond, Washington, USA). Where similar terms for certain attributes were used these were grouped together and shown in Table 5.5. The final lists of attributes from all judges for every wine were then exported from Excel into Nvivo 10 (Version 10, QSR International, Victoria, Australia). Nvivo 10 was then used to count the number of times a particular word was used to describe each wine by all judges. This count was then compared to the total number of judges that assessed the wines to give a proportion of use by the panel of judges for each individual wine. For a word to be considered in the final analysis at least 40% of judges must have used the word to describe at least one of the wines.

5.3.8 Statistical analysis

Vine growth, berry, juice and wine data were analysed using a repeated measures analysis of variance (GenStat® for Windows 15.0, VSN International, United Kingdom). The least significant difference test was used ($P<0.05$) to determine significant differences between treatments, seasons and compost at a given sampling time. ANOVA was also performed on all sensory attribute word frequency data generated from wine evaluations using XLSTAT Version 2012 1.01 (Addinsoft SARL, France). Attributes that were significantly different between treatments were then subjected to principal component analysis (PCA) using XLSTAT Version 2012 1.01 (Addinsoft SARL, France) and presented as biplots. Details of individual analyses are provided in the text or captions.

5.4 Results and Discussion

5.4.1 Soil effects

The soil parameters measured in this study (N, P, Organic C, Microbial Biomass C and Cumulative Respiration) were more strongly affected by compost than by management system. Irrespective of management system, compost increased soil microbial activity and nutrient availability. Only in the absence of compost, ORG and BD management systems increased cumulative respiration compared with LCON and HCON. This was due to under-vine weeds providing available substrate for microbes to metabolise and subsequently respire.

Organic and/or biodynamic viticulture practices have previously been found to increase soil biological properties and improve soil physical properties compared to conventional management (Gehlen et al. 1988; Okur et al. 2009; Probst et al. 2008; Reineke et al. 2008; Stamatiadis et al. 1996). However, compost or manures have often been used in organic management, whereas the conventional practices did not have organic amendments (Okur et al. 2009; Probst et al. 2008; Stamatiadis et al. 1996). Organic amendments have been found to be positively correlated with cumulative respiration and MBC (Carpenter Boggs et al. 2000; Marinari et al. 2006), and hence it has been suggested that increases in soil biological properties in the previous comparative studies are a direct result of compost applications as opposed to organic and biodynamic practices *per se* (Shepherd et al. 2002).

Without compost, cumulative respiration was higher in ORG and BD than in LCON and HCON at PH09 and BB10. There were no differences in cumulative respiration between BD and ORG. Management system did not affect soil organic C content (Table 5.5), however, compost increased soil organic C from 1.9% to 2.3% (average of all sampling times and treatments).

Irrespective of system, compost increased cumulative respiration, MBC, N, P and water content (Table 5.5). Compost had a greater effect on cumulative respiration in the conventional systems than in ORG and BD (Figure 5.4). This is probably due to the absence of weeds in the conventional systems, which limited the availability of labile C to microbes.

Table 5.5 P values from the analysis of variance for soil parameters
∗ Indicates 2 way ANOVA only

	N	**P**	**Org C**	**CR**	**MBC**	**H_20**
System	0.1	0.011	0.484	<.001	0.01	0.003
Compost	0.006	<.001	<.001	<.001	<.001	<.001
Time	<.001	<.001	*	<.001	<.001	<.001
System x Compost	0.709	0.009	0.253	0.004	0.256	0.002
System x Time	0.096	0.077	*	<.001	<.001	0.031
Compost x Time	0.954	0.127	*	0.738	0.002	0.443
System x Compost x Time	0.038	0.21	*	0.543	0.430	0.613

Compost was applied under-vine in May 2009 at the rate of 22 t ha^{-1} which resulted in an increase of soil organic C of about 0.4% in all systems with no differences between sampling times. Pinamonti (1998) found that two applications (40 t ha^{-1} in total) of municipal waste compost over a five year period increased organic matter from 0.4%. Compost was also found to increase soil organic C in other studies (Mylavarapu and Zinati 2009; Whalen et al. 2008).

Compost increased cumulative respiration in all systems at BB09, but only in LCON and HCON at PH09 and BB10. However compost had no effect at PH10. Irrespective of management system, compost increased MBC. Although compost is relatively low in available C compared to its feedstocks, it contains some labile C that is readily respired by microbes (Carpenter Boggs et al. 2000) and explains the initial increase in cumulative respiration at BB09. In other field studies, compost addition has been found to increase respiration, MBC and/or dehydrogenase activity (Carpenter Boggs et al. 2000, Marinari et al. 2006).

At PH09 and BB10, weeds were growing under-vine in ORG and BD and hence the soil samples were taken from the rhizosphere of these weeds. Weed roots and their exudates provide C to the microbes. Higher microbial activity and biomass in the rhizosphere has been shown in various studies (Das and Dkhar 2011; Kelting et al. 1998). On the other hand, the under-vine area in LCON and HCON was weed-free and hence the only additional C source was the compost. This result suggests that weeds (growing or slashed) can stimulate microbes to a similar extent as compost addition.

Irrespective of system, compost increased available N and P, although the increases were small with N increasing by 1.3 µg g^{-1} and P by 8 µg g^{-1} which may be due to the low application rate. Previous studies have also shown increased available N and P to due to compost application (Pinamonti 1998).

In the absence of compost, ORG and BD management systems did not affect soil organic C, available N, P or MBC over the three year trial period. However, cumulative respiration was higher in ORG and BD at PH09 and BB10 compared with LCON and HCON whereas there were no differences among management systems at BB09 or PH10 (Figure 5.5).

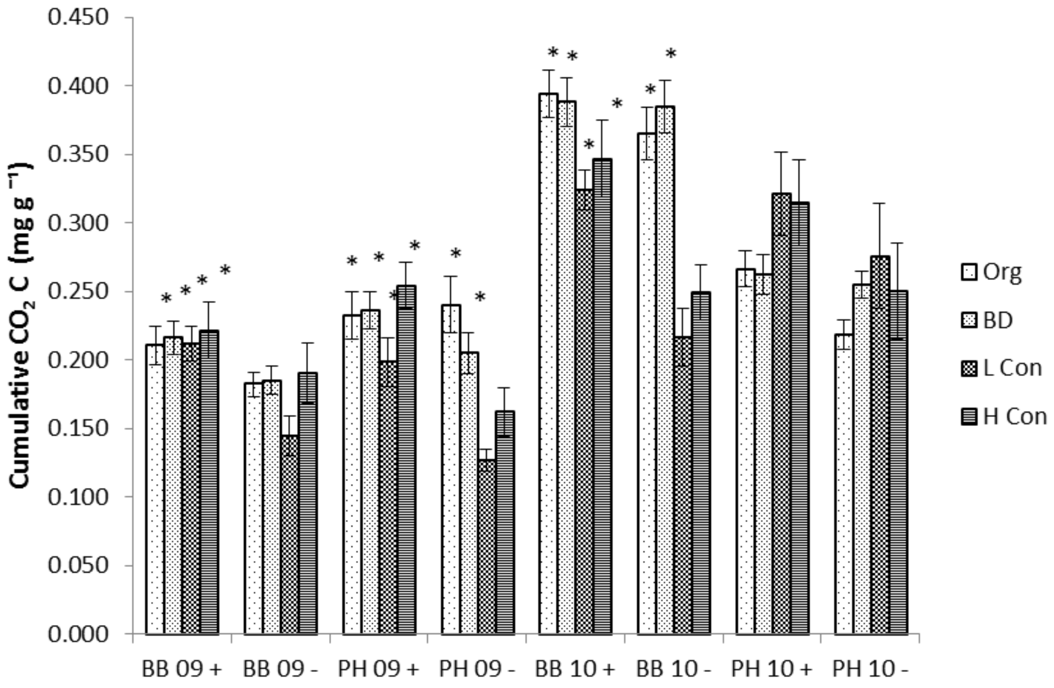

Figure 5.5 Cumulative respiration (CO_2-C mg g $^{-1}$) of four treatments with (+) and without (-) compost at BB09, PH09, BB10 and PH10 (n=4). At a given sampling time, columns with * indicates significant different to LCON without compost (P≤0.05).

In this study, LCON and HCON received two herbicide applications in spring and one in autumn, hence the under-vine area remained free of weed growth during the growing season (Figure 5.4). On the other hand, in the ORG and BD systems, weeds in the under-vine area were allowed to grow over winter and slashed after soil sampling at BB09 and PH09. Weeds were cultivated in January 2011, three months prior to PH10 sampling. Although weeds were present in the ORG and BD systems at BB09, there were no differences in cumulative respiration between management systems. This may be due to treatments having only been applied for 12 months, and hence insufficient weed biomass being produced.

As explained above, the increased cumulative respiration in the ORG and BD systems at PH09 and BB10 is likely due to samples being taken from the rhizosphere of the weeds growing under-vine. However, their effect may be transient because their residues are easily decomposable. The transient nature of the weed effect is also evident in the finding that microbial biomass was not consistently higher in the organic systems (Figure 3) and that microbial activity was similar in organic and conventional systems at PH10, when the weeds had been cultivated 12 weeks before the sampling. Cultivation breaks up soil aggregates, exposing previously occluded C for breakdown by soil microbes resulting in an accelerated decomposition rate that declines once the exposed substrates are decomposed (Brady and Weil 2008).

Without compost addition, the management systems did not differ in soil organic C (data not shown). This suggests that although the weeds in the organic systems increase microbial activity, their C input is not sufficient to increase soil organic C concentrations over a three year period.

Table 5.6 Soil organic C (average over all sampling times) (n=4, ± standard deviation). Values followed by different letters are significantly different.

System	Compost	Organic C (%)
ORG	-	2.0 ab
	+	2.3 b
BD	-	2.0 ab
	+	2.3 b
LCON	-	1.8 a
	+	2.2 ab
HCON	-	1.8 a
	+	2.5 b

5.4.2 Vine growth, yield, soil moisture and plant N

Compost (22 t ha^{-1}) had no effect on vine, berry or wine parameters measured over the three seasons and hence results are a mean of with (+) and without (-) compost (Tables 5.7 - 5.12).

Management system had no consistent effect on vine growth parameters, yield components or petiole N values in 2008/09 and 2009/10 (Table 5.7). However, in 2010/11, ORG and BD had lower shoot growth (~10%), pruning weight (~30%), canopy density (~18%), yield (~20%), bunch weight (~14%) and berry weight (~5%). Management system did not affect bunches per vine, yield:pruning weight ratio (Y/P) or petiole N in the third season.

Grapevine vegetative growth is affected by many interrelated factors such as soil type, water and nutrient availability, sunlight and climate (Smart and Robinson 1991). Therefore it can be expected that the same treatments applied in different climatic conditions and soil types, may also show different results. There are two possible explanations for why management system did not consistently affect vine growth parameters in the first two seasons, yet had a profound effect in the third season, 1) under-vine weed management changed and 2) treatments take time to manifest.

In 2008/09 and 2009/10, weed control for all systems was implemented in early spring (Table 5.2), minimising under-vine weed growth regardless of management (cultivation, slashing or herbicide). In 2010/11, the experimental site received above average rainfall during the growing season (365 mm) resulting in greater shoot growth and higher pruning weights across all treatments (Table 5.7). As a result of the increased rainfall in the final season, under-vine weeds were allowed to grow in ORG and BD treatments until January (veraison, EL Stage 35; Coombe 1995), when they were removed via cultivation. As per standard practice, LCON and HCON received two herbicides in spring, eliminating weed growth. The actively growing under-vine weeds in the ORG and BD systems reduced soil moisture (Figure 5.6) although petiole N remained the same (Table 5.7).

Organic and/or biodynamic management has been found to reduce shoot growth and pruning weight compared to conventional practices (Hofmann 1991, Kauer 1993, Malusà et al. 2004, Pool and Robinson 1995). Under-vine weed management details were not always stipulated in these trials, however, a reduction in plant N levels and soil moisture due to using organic practices are commonly attributed as the reason for lower vine growth (Hofmann 1991, Malusà et al. 2004, Pool and Robinson 1995). This is consistent with Tesic et al. (2007), who found the use of a permanent sward (similar to the organic treatment in this trial) decreased soil moisture and nitrogen compared to a bare under-vine (conventional treatment in this trial) treatment in a warm climate.

Table 5.7 Effects of organic, biodynamic, low-input conventional and high-input conventional management on vine growth parameters in the 2008/09, 2009/10 and 2010/11 growing season, McLaren Vale, Australia.

Variable	Season	Treatment				Season mean	5% LSD	*P*-value
		ORG	BD	LCON	HCON			
Pruning weights	2008/09	0.52 [b]	0.54 [b]	0.52 [b]	0.54 [b]	**0.53**	0.063 (T)	<.001 (T)
per metre of canopy (kg)	2009/10	0.42 [a]	0.49 [ab]	0.50 [ab]	0.50 [ab]	**0.48**	0.046 (S)	<.001 (S)
	2010/11	0.62 [c]	0.63 [c]	0.93 [d]	1.00 [d]	**0.80**	0.098 (T*S)	<.001 (T*S)
	Treatment mean	**0.52**	**0.55**	**0.65**	**0.68**			
Shoot length (cm)	2008/09	63 [a]	69 [b]	69 [b]	64 [ab]	**66**	4.4 (T)	0.002 (T)
	2009/10	68 [ab]	71 [b]	72 [b]	70 [b]	**70**	2.5 (S)	<.001 (S)
	2010/11	92 [c]	96 [c]	107 [d]	112 [d]	**102**	6.0 T*S)	<.001 (T*S)
	Treatment mean	**74**	**79**	**83**	**82**			
Yield	2008/09	2.84 [b]	2.25 [a]	2.59 [ab]	2.52 [ab]	**2.6**	ns (T)	ns (T)
per metre of canopy (kg)	2009/10	2.86 [b]	3.2 [bc]	2.91 [b]	3.32 [bc]	**3.1**	0.22 (S)	<.001 (S)
	2010/11	3.24 [bc]	3.1 [bc]	3.95 [d]	4.06 [d]	**3.6**	0.58 (T*S)	<.001 (T*S)
	Treatment mean	**2.98**	**2.85**	**3.15**	**3.30**			
Bunch number	2008/09	65	66	67	71	**67 [c]**	ns (T)	ns (T)
per metre of canopy	2009/10	63	63	56	67	**62 [b]**	3.6	<.001 (S)
	2010/11	55	53	56	58	**55 [a]**	ns (T*S)	ns (T*S)
	Treatment mean	**61**	**61**	**59**	**65**			
Average bunch weight (g)	2008/09	43.0 [bc]	37.1 [a]	39.1 [ab]	36.5 [a]	**38.9**	ns (T)	ns (T)
	2009/10	46.2 [c]	53.1 [de]	50.9 [cd]	50.3 [cd]	**50.1**	2.3 (S)	<.001 (S)
	2010/11	58.2 [ef]	60.5 [f]	71.6 [g]	70.9 [g]	**65.3**	5.7 (T*S)	<.001 (T*S)
	Treatment mean	**49.1**	**50.2**	**53.9**	**52.6**			
50 berry weight (g)	2008/09	32.9 [a]	33.0 [a]	32.3 [a]	30.2 [a]	**32.1**	1.82 (T)	0.005 (T)
	2009/10	40.4 [bc]	42.6 [c]	43.1 [c]	38.7 [b]	**41.2**	1.60 (S)	<0.001 (S)
	2010/11	46.4 [d]	47.6 [d]	54.2 [e]	52.2 [e]	**50.1**	3.2 (T*S)	<0.001 (T*S)
	Treatment mean	**39.9**	**41.1**	**43.2**	**40.4**			
Yield/Pruning weight ratio	2008/09	5.4	4.4	5.1	5.5	**5.1 [a]**	ns (T)	ns (T)
	2009/10	7.2	7.0	5.9	7.1	**6.8 [b]**	0.55 (S)	<.001 (S)
	2010/11	5.2	4.9	4.3	4.1	**4.6 [a]**	ns (T*S)	ns (T*S)
	Treatment mean	**6.0**	**5.4**	**5.1**	**5.6**			
Petiole nitrogen (%)	2008/09	n/a	n/a	n/a	n/a		ns (T)	ns (T)
	2009/10	1.0	1.0	1.1	1.1	**1.0 [a]**	0.2 (S)	<.001 (S)
	2010/11	0.6	0.6	0.6	0.6	**0.6 [b]**	ns (T*S)	ns (T*S)
	Treatment mean	**0.8**	**0.8**	**0.8**	**0.8**			
Canopy density	2008/09	n/a	n/a	n/a	n/a		4.8 (T)	0.005 (T)
	2009/10	58 [a]	55 [a]	53 [a]	54 [a]	**55**	ns (S)	ns (S)
	2010/11	60 [a]	60 [a]	50 [b]	48 [b]	**55**	6.7 (T*S)	<0.001 (T*S)
	Treatment mean	**59**	**57**	**52**	**51**			

Each value represents the mean of four replicate samples of each vineyard treatment (T) for each season (S).

The 5% LSD values listed are for comparison of vineyard treatments (T) and for comparison of seasons (S).

Where there is no significant T × S interaction (T*S), the vineyard treatment means (across all seasons) are compared using the (T) 5% LSD and the seasons means (across all vineyard treatments) are compared using the (S) 5% LSD.

Where there is a significant T × S interaction (T*S), the 5% LSD value used for comparison of treatments is listed.

Letters following the means indicate significant ($P < 0.05$) differences among treatments.

Letters follow either the individual treatment means where there is a T × S interaction or the overall vineyard treatment mean where there is no T × S interaction.

ns indicates no statistically significant difference among means at a 0.05 level.

Figure 5.6 Mean soil moisture content at 20, 40, 70 and 100cm depth between November and March 2010-11 in organic and high-input conventional treatments.

In 2008/09 and 2009/10, management system had no consistent effect on yield, bunch weight or berry weight. In 2010/11, ORG and BD had lower yield (~20%), bunch weight (~14%) and berry weight (~5%) compared with LCON and HCON, however, there were no differences in bunches per vine (Table 5.7). Flowering and berry development are affected by water stress and nutrition (Srinivasan and Mullins 1981). Therefore, various management practices (whether organic or conventional) such as under-vine weed control and nutrition will influence yield. This trial was conducted on a fertile cracking-clay, and as such management systems did not differ in the application of nutrients, pruning methods or amounts of irrigation. The decrease in yield in 2010/11 is likely to be a result of moisture stress (Figure 5.7), which reduced bunch and berry weight in that season.

Past field trials have shown organic and/or biodynamic practices to decrease yields (15-30%) compared to conventional practices (Corvers 1994, Hofmann 1991, Kauer 1993, Malusà et al. 2004, Pool and Robinson 1995). Unfortunately, many of the past comparative studies did not present yield component data such as bunches per vine and bunch and berry weight, making it difficult to determine what is driving the decrease in yield. Pool and Robinson (1995) found that organic practices decreased yields by 20-30% (averaged over five seasons and three varieties), however, management system had no consistent effect on the variety Elvira. This trial did not have replicates within varieties, and it was concluded that the differences in yield were due to differences in soil types and weed control. Kauer (1993) found that organic practices decreased yield by approximately (14-19%) due to competition by a permanent cover crop on lean soils. However, reductions were not significantly different on sites with high clay content and therefore greater water holding capacity. Malusà et al. (2004) after seven years of using organic practices found yield decreased by 20%. Hofmann (1991) also found that organic management decreased yield, however, these results were inconsistent and dependent on seasonal rainfall and disease pressure.

Yield to pruning weight ratio was not affected by management system in any season. However, yield to pruning weight ratio differed between seasons, ranging from 4.6 in 2010/11 to 6.8 in 2009/10. Vines are thought to be in balance when they have a yield to pruning weight ratio between 5 and 10 (Smart and Robinson 1991). Although not statistically significant, in 2010/11 ORG (5.2) was within this range while BD (4.9), LCON (4.3) and HCON (4.1) fell below this threshold, potentially indicating that the ORG vines were better balanced and less likely to show vegetative characters (Smart and Robinson 1991).

5.4.3 Berry composition

Management system had no consistent effect on berry composition over the conversion period (Table 5.8). This result is similar to previous studies that found no differences between management systems on TSS, pH and TA (Corvers 1994, Hofmann 1991, Kauer 1993, Malusà et al. 2004, Reeve et al. 2005). Interestingly, despite yield being reduced in ORG and BD by approximately 20% in 2010/11, no change in TSS, TA or pH was found compared to LCON and HCON.

Table 5.8 Effects of organic, biodynamic, low-input conventional and high-input conventional management on berry composition in the 2008/09, 2009/10 and 2010/11 growing season, McLaren Vale, Australia.

Variable	Season	Treatment				Season mean	5% LSD	*P*-value
		ORG	BD	LCON	HCON			
Total Soluble Solids (TSS)	2008/09	25	25	25	26	**25 c**	ns (T)	ns (T)
	2009/10	23	23	23	23	**23 a**	0.25 (S)	<0.001 (S)
	2010/11	23	24	24	24	**24 b**	ns (T*S)	ns (T*S)
	Treatment mean	**24**	**24**	**24**	**24**			
Titratable Acidity (TA) mg/L	2008/09	5.5 bc	4.8 a	5.0 ab	4.9 a	**5.0**	ns (T)	ns (T)
	2009/10	5.8 cd	6.3 d	6.0 d	6.1 d	**6.0**	0.20 (S)	<0.001 (S)
	2010/11	5.8 cd	5.7 cd	5.6 cd	6.0 d	**5.7**	0.53(T*S)	0.002 (T*S)
	Treatment mean	**5.7**	**5.6**	**5.5**	**5.6**			
pH	2008/09	3.7	3.8	3.8	3.8	**3.8 b**	ns (T)	ns (T)
	2009/10	3.4	3.4	3.5	3.4	**3.4 a**	0.04 (S)	<0.001
	2010/11	3.4	3.4	3.4	3.4	**3.4 a**	ns (T*S)	ns (T*S)
	Treatment mean	**3.5**	**3.6**	**3.6**	**3.6**			
Anthocyanin	2008/09	0.63 a	0.67 a	0.74 a	0.95 b	**0.75**	0.080 (T)	0.02 (T)
per g berry weight (mg/L)	2009/10	0.69 a	0.67 a	0.70 a	0.72 a	**0.69**	0.063 (S)	<.001 (S)
	2010/11	1.11 c	1.00 bc	1.04 bc	1.05 bc	**1.05**	0.13 (T*S)	0.008 (T*S)
	Treatment mean	**0.807**	**0.781**	**0.825**	**0.908**			
Phenolics	2008/09	0.82 ab	0.80 a	0.83 ab	1.02 c	**0.87**	0.068 (T)	0.036 (T)
per g berry weight (mg/L)	2009/10	0.92 b	0.89 ab	0.90 ab	0.95 bc	**0.92**	0.054 (S)	<.001 (S)
	2010/11	1.15 c	1.06 bc	1.04 bc	1.05 bc	**1.08**	0.11 (T*S)	0.019 (T*S)
	Treatment mean	**0.965**	**0.916**	**0.921**	**1.007**			
Yeast Available Nitrogen	2008/09	89	86	108	80	**91 a**	ns (T)	ns (T)
(YAN) (mg/L)	2009/10	104	102	104	111	**105 b**	11.2	0.008 (S)
	2010/11	115	112	104	109	**110 b**	ns (T*S)	ns (T*S)
	Treatment mean	**103**	**100**	**106**	**100**			

Each value represents the mean of four replicate samples of each vineyard treatment (T) for each season (S).

The 5% LSD values listed are for comparison of vineyard treatments (T) and for comparison of seasons (S).

Where there is no significant T × S interaction (T*S), the vineyard treatment means (across all seasons) are compared using the (T) 5% LSD and the seasons means (across all vineyard treatments) are compared using the (S) 5% LSD.

Where there is a significant T × S interaction (T*S), the 5% LSD value used for comparison of treatments is listed.

Letters following the means indicate significant ($P < 0.05$) differences among treatments.

Letters follow either the individual treatment means where there is a T × S interaction or the overall vineyard treatment mean where there is no T × S interaction.

ns indicates no statistically significant difference among means at a 0.05 level.

In 2008/09, HCON had higher anthocyanin and phenolic concentrations than LCON, ORG and BD management systems. However, this was not the case in the other seasons. Malusà et al. (2004) found organically managed grapes to have higher anthocyanins and flavonoids than conventionally managed grapes. The opposite was found by Vian et al. (2006) with higher levels of berry anthocyanins found in the fruit from conventionally managed treatments compared with those managed using organic practices. Reeve et al. (2005) compared ORG and BD management systems and found higher sugar, total phenols and total anthocyanins levels in wine made from the BD managed vines.

Management systems had no effect on juice yeast assimilable N (YAN) concentrations over the conversion period. YAN should range between 200-480 mg N/L, with an optimum around 300 mg N/L (White 2009). In this trial, YAN was around 100 mg N/L indicating that they are deficient. YAN is an important measurement for grape quality as it represents the amount of available N for yeasts to metabolise (Jiranek et al. 1995). Despite the under-vine weed growth in 2010/11 in the ORG and BD treatments reducing soil moisture (Figure 5.6) and petiole N in all systems (Table 5.7), YAN was not affected.

5.4.4 Plant and Juice analysis

Leaf blade analysis at the end of 2008/09 demonstrated few differences between management systems, indicating a uniformed base to begin the trial (Table 5.9). Levels of Na were higher in ORG than other management systems, while ORG also had higher Zn concentrations than LCON and HCON. Both Na and Zn concentrations for leaf blade analysis at harvest are not well established (Weir and Cresswell 1993). However, the petioles values for Na and Zn were within the optimal range (Robinson 1992).

Table 5.9 Effects of organic, biodynamic, low-input conventional and high-input conventional management on leaf blade analysis in the 2008/09 growing season, McLaren Vale, Australia.

Variable	Treatment				5% LSD	*P*-value
	ORG	BD	LCON	HCON		
Al	104	101	101	102	ns	ns
B	40	42	36	45	ns	ns
Ca	27750	28750	28250	28750	ns	ns
Cu	50	54	55	58	ns	ns
Fe	114	112	109	111	ns	ns
K	5200	5375	5450	5450	ns	ns
Mg	5075	5225	5000	5025	ns	ns
Mn	86	85	88	72	ns	ns
N	1.6	1.6	1.6	1.5	ns	ns
Na	1022 ^{b}	885 ^{a}	870 ^{a}	880 ^{a}	107	0.031
P	1365	1422	1558	1538	ns	ns
S	1895	1910	1908	1915	ns	ns
Zn	16.1 ^{b}	14.3 ^{ab}	12.5 ^{a}	13.3 ^{a}	2.51	0.043

Petiole analysis was taken at flowering in seasons 2009/10 and 2010/11 (Table 5.10). In 2010/11, LCON and HCON had higher P levels than ORG, while in 2010/11, LCON and HCON had higher P levels than BD and ORG. In 2009/10 P concentrations (regardless of system) were significantly above the optimal range and may be a result of excessive fertiliser use prior to 2003. In 2010/11, ORG and BD values dropped to within the desired range while LCON and HCON remained excessively high. The under-vine weed growth may have contributed to these values dropping.

The excessive use of Cu sprays is a major criticism of organic and biodynamic viticulture, especially in wet climates (Pietrzak and McPhail 2004). In 2009/10, (regardless of system) Cu petiole concentrations (15 mg/kg) exceeded the optimal range (6-11 mg/kg) (data not shown) while in 2010/11 (38.8 mg/kg) they reached high to excessive (White 2009). The increase in the final season was due to the abnormally wet conditions and subsequent greater number of Cu sprays being used (Table 5.2). Kauer (1993) found excessively high Cu under organic management due to Bordeaux mixture being used.

Table 5.10 Effects of organic, biodynamic, low-input conventional and high-input conventional management on petiole elemental analysis in the 2009/10 and 2010/11 growing seasons, McLaren Vale, Australia.

Variable	Season	Treatment				Season mean	Optimum Range	5% LSD	*P*-value
		ORG	BD	LCON	HCON				
Al	2009/10	9.6	12.9	9.7	9.7	**10.48 ^{b}**	**na**	ns (T)	ns (T)
mg/kg	2010/11	2.4	2.7	2.4	2.0	**2.36 ^{a}**		1.85 (S)	<.001 (S)
	Treatment mean	**6.01**	**7.8**	**6**	**5.8**			ns (T*S)	ns (T*S)
B	2009/10	35.2	34.7	33.7	35.9	**34.9 ^{a}**	**35-70**	1.19 (T)	0.002 (T)
(mg/kg)	2010/11	38.7	37.4	35.6	37.9	**37.4 ^{b}**		1.52 (S)	0.002 (S)
	Treatment mean	**36.9 ^{b}**	**36.1 ^{b}**	**34.7 ^{a}**	**36.9 ^{b}**			ns (T*S)	ns (T*S)
Ca	2009/10	16500	16038	16888	16938	**16591 ^{a}**	**12000-25000**	ns (T)	ns (T)
	2010/11	17525	17750	17462	17088	**17456 ^{b}**		565.6 (S)	0.004 (S)
	Treatment mean	**17012**	**16894**	**17175**	**17012**			ns (T*S)	ns (T*S)
Cu	2009/10	15.4	13.6	15.3	15.4	**15.0 ^{a}**	**6 to 11**	ns (T)	ns (T)
mg/kg	2010/11	40.1	37.2	40.5	37.2	**38.8 ^{b}**		2.8	<.001 (S)
	Treatment mean	**27.8**	**25.4**	**27.9**	**26.3**			ns (T*S)	ns (T*S)
Fe	2009/10	19.1	18.5	19.0	18.3	**18.7 ^{b}**	**>30 (mg/kg)**	ns (T)	ns (T)
	2010/11	13.3	13.4	14.9	14.9	**14.1 ^{a}**		0.82 (S)	<.001 (S)
	Treatment mean	**16.2**	**16.0**	**16.9**	**16.6**			ns (T*S)	ns (T*S)
K	2009/10	40125	39500	41000	41750	**40594 ^{a}**	**18000-30000**	ns (T)	ns (T)
	2010/11	45125	41625	41375	42750	**42719 ^{b}**		1448 (S)	0.006 (S)
	Treatment mean	**42625**	**40562**	**41188**	**42250**			ns (T*S)	ns (T*S)
Mg	2009/10	3650 ^{a}	3638 ^{a}	3862 ^{ab}	3800 ^{a}	**3738**	**>4000**	373.2 (T)	0.026 (T)
	2010/11	3562 ^{a}	3862 ^{ab}	4400 ^{c}	4288 ^{bc}	**4028**		169.8 (S)	0.002 (S)
	Treatment mean	**3606**	**3750**	**4131**	**4044**			433.5 (T*S)	0.048 (T*S)
Mn	2009/10	30.0	33.5	37.7	27.5	**32.2 ^{b}**	**30-60 (mg/kg)**	5.94 (T)	0.014 (T)
	2010/11	24.2	32.2	27.3	20.7	**26.1 ^{a}**		3.37 (S)	0.001 (S)
	Treatment mean	**27.1 ^{ab}**	**32.9 ^{b}**	**32.5 ^{b}**	**24.1 ^{a}**			ns (T*S)	ns (T*S)
Na	2009/10	841	756	746	724	**767 ^{a}**	**>5000 is TOXIC**	71.3 (T)	0.004 (T)
	2010/11	1016	966	891	861	**934 ^{b}**		52.8 (S)	<.001 (S)
	Treatment mean	**929 ^{b}**	**861 ^{ab}**	**819 ^{a}**	**792 ^{a}**			ns (T*S)	ns (T*S)
P	2009/10	7588 ^{bc}	7100 ^{b}	8288 ^{c}	8375 ^{c}	**7838**	**2500-5000**	547.8 (T)	<.001 (T)
	2010/11	4975 ^{a}	4525 ^{a}	6975 ^{b}	7612 ^{bc}	**6022**		503.6 (S)	<.001 (S)
	Treatment mean	**6281**	**5812**	**7631**	**7994**			875.3 (T*S)	0.028 (T*S)
S	2009/10	2152	2069	2386	2348	**2239 ^{b}**	**na**	183.9 (T)	0.009 (T)
	2010/11	1569	1506	1732	1771	**1645 ^{a}**		128.1 (S)	<.001 (S)
	Treatment mean	**1861 ^{a}**	**1788 ^{a}**	**2059 ^{b}**	**2059 ^{b}**			ns (T*S)	ns (T*S)
Zn	2009/10	33.63	34.29	31.56	32.7	**33.0 ^{a}**	**> 26**	ns (T)	ns (T)
(mg/kg)	2010/11	45.29	43.68	42.73	41.56	**43.3 ^{b}**		1.72 (S)	<.001 (S)
	Treatment mean	**39.5**	**39**	**37.1**	**37.1**			ns (T*S)	ns (T*S)

na = data not available

Each value represents the mean of four replicate samples of each vineyard treatment (T) for each season (S).

The 5% LSD values listed are for comparison of vineyard treatments (T) and for comparison of seasons (S).

Where there is no significant T × S interaction (T*S), the vineyard treatment means (across all seasons) are compared using the (T) 5% LSD and the seasons means (across all vineyard treatments) are compared using the (S) 5% LSD.

Where there is a significant T × S interaction (T*S), the 5% LSD value used for comparison of treatments is listed.

Letters following the means indicate significant ($P < 0.05$) differences among treatments.

Letters follow either the individual treatment means where there is a T × S interaction or the overall vineyard treatment mean where there is no T × S interaction.

ns indicates no statistically significant difference among means at a 0.05 level.

In Australia, Cu use is far less of a concern than in other countries (Magalães et al. 1985, Brun et al. 2001, Eijsackers et al. 2005); however our study indicates that in wet seasons Cu uptake by the plant can reach excessive or toxic levels. Organic growers do have alternatives to using Cu such as biological controls (eg. *Trichoderma*), oils (eg. White oil), plant defence stimulants (eg. Compost extracts), habitat manipulation (eg. Canopy management) (Jacometti et al. 2010). However, few proven alternatives for organic and biodynamic production are currently available because of the excessive cost of commercialisation, production challenges and regulatory issues (Fravel 1999, Stewart 2001, Gerhardson 2002).

Regardless of system, Mg (3738) petiole concentrations in 2009/10 were lower than the optimal concentration range (>4000). In 2010/11, Mg petiole concentrations increased in LCON and HCON to be within the optimal range, while ORG (3562) and BD (3862) remained low. Fe and Mn were also slightly below the optimal concentration range while K was excessive, possibly due to previous fertiliser applications. B and Ca were both within the optimal range (Table 5.10).

Juice analysis showed that management system had no effect on Ca, Cu, K, Mg, Mn, P and Zn and only slight effects on Al and S (Table 5.11).

Table 5.11 Effects of organic, biodynamic, low-input conventional and high-input conventional management on juice elemental analysis in the 2008/09, 2009/10 and 2010/11 growing season, McLaren Vale, Australia.

Variable	Season	Treatment				Season mean	5% LSD	*P*-value
		ORG	BD	LCON	HCON			
Al	2008/09	3.8 ^{c}	3.9 ^{c}	4.0 ^{c}	4.6 ^{d}	**4.1**	0.16 (T)	0.001 (T)
	2009/10	1.4 ^{b}	1.5 ^{b}	1.6 ^{b}	1.4 ^{b}	**1.5**	0.16 (S)	<.001 (S)
	2010/11	0.9 ^{a}	0.7 ^{a}	0.9 ^{a}	1.0 ^{a}	**0.9**	0.30 (T*S)	0.012 (T*S)
	Treatment mean	**2.0**	**2.0**	**2.2**	**2.3**			
B	2008/09	7.7	8.7	7.8	8.8	**8.3** ^{c}	0.40 (T)	0.044 (T)
	2009/10	6.7	6.4	6.1	6.8	**6.5** ^{b}	0.39 (S)	<.001 (S)
	2010/11	4.9	5.1	4.9	4.7	**4.9** ^{a}	ns (T*S)	ns (T*S)
	Treatment mean	**6.4** ^{ab}	**6.8** ^{b}	**6.3** ^{a}	**6.8** ^{b}			
Ca	2008/09	122	143	139	141	**136** ^{c}	ns (T)	ns (T)
	2009/10	74	72	72	78	**74** ^{b}	7.5 (S)	<.001 (S)
	2010/11	61	61	54	53	**57** ^{a}	ns (T*S)	ns (T*S)
	Treatment mean	**86**	**92**	**89**	**91**			
Cu	2008/09	1.5	1.4	1.4	1.6	**1.5** ^{c}	ns (T)	ns (T)
	2009/10	0.7	0.7	0.7	0.7	**0.7** ^{a}	0.08 (S)	<.001 (S)
	2010/11	0.9	0.9	0.9	0.9	**0.9** ^{b}	ns (T*S)	ns (T*S)
	Treatment mean	**1.0**	**1.0**	**1.0**	**1.1**			
Fe	2008/09	4.7	4.9	5.8	5.6	**5.3** ^{c}	0.29 (T)	0.008 (T)
	2009/10	2.5	2.5	2.7	2.6	**2.6** ^{b}	0.30 (S)	<.001 (S)
	2010/11	1.4	1.3	1.4	1.3	**1.4** ^{a}	ns (T*S)	ns (T*S)
	Treatment mean	**2.9** ^{a}	**2.9** ^{a}	**3.3** ^{b}	**3.2** ^{b}			
K	2008/09	2645	2692	2695	2751	**2696** ^{c}	ns (T)	ns (T)
	2009/10	2222	2186	2162	2190	**2190** ^{b}	122 (S)	<.001 (S)
	2010/11	1846	1784	1886	1827	**1836** ^{a}	ns (T*S)	ns (T*S)
	Treatment mean	**2238**	**2221**	**2248**	**2256**			
Mg	2008/09	141	145	142	149	**144** ^{c}	ns (T)	ns (T)
	2009/10	107	105	105	106	**106** ^{b}	3.7 (S)	<.001 (S)
	2010/11	93	96	90	88	**92** ^{a}	ns (T*S)	ns (T*S)
	Treatment mean	**114**	**115**	**112**	**114**			
Mn	2008/09	0.64	0.58	0.66	0.59	**0.62** ^{b}	ns (T)	ns (T)
	2009/10	0.29	0.30	0.32	0.30	**0.30** ^{a}	0.05 (S)	<.001 (S)
	2010/11	0.31	0.31	0.28	0.26	**0.29** ^{a}	ns (T*S)	ns (T*S)
	Treatment mean	**0.41**	**0.40**	**0.42**	**0.38**			
Na	2008/09	22.5	24.2	22.5	20.5	**22.4** ^{a}	ns (T)	ns (T)
	2009/10	34.2	33.8	33.7	36.6	**34.6** ^{b}	2.74 (S)	<.001 (S)
	2010/11	25.1	23.1	21.3	20.7	**22.6** ^{a}	ns (T*S)	ns (T*S)
	Treatment mean	**27.3**	**27.0**	**25.9**	**25.9**			
P	2008/09	249	243	269	263	**256** ^{b}	ns (T)	ns (T)
	2009/10	154	160	159	150	**156** ^{a}	12.9 (S)	<.001 (S)
	2010/11	156	156	164	154	**158** ^{a}	ns (T*S)	ns (T*S)
	Treatment mean	**186**	**186**	**197**	**189**			
S	2008/09	60.9	61.7	69.4	56.6	**62.2** ^{b}	3.22 (T)	0.041 (T)
	2009/10	52.5	52.2	51.1	52.2	**52** ^{a}	3.95 (S)	<.001 (S)
	2010/11	52.2	52.3	48.9	46.7	**50.0** ^{a}	ns (T*S)	ns (T*S)
	Treatment mean	**55.2** ^{b}	**55.4** ^{b}	**56.5** ^{b}	**51.9** ^{a}			
Zn	2008/09	0.42	0.44	0.42	0.39	**0.42** ^{b}	ns (T)	ns (T)
	2009/10	0.29	0.29	0.29	0.31	**0.30** ^{a}	0.087 (S)	0.002
	2010/11	0.44	0.47	0.52	0.46	**0.48** ^{b}	ns (T*S)	ns (T*S)
	Treatment mean	**0.39**	**0.40**	**0.41**	**0.39**			

Each value represents the mean of four replicate samples of each vineyard treatment (T) for each season (S).

The 5% LSD values listed are for comparison of vineyard treatments (T) and for comparison of seasons (S).

Where there is no significant T × S interaction (T*S), the vineyard treatment means (across all seasons) are compared using the (T) 5% LSD and the seasons means (across all vineyard treatments) are compared using the (S) 5% LSD.

Where there is a significant T × S interaction (T*S), the 5% LSD value used for comparison of treatments is listed.

Letters following the means indicate significant ($P < 0.05$) differences among treatments.

Letters follow either the individual treatment means where there is a T × S interaction or the overall vineyard treatment mean where there is no T × S interaction.

ns indicates no statistically significant difference among means at a 0.05 level.

In 2009, Al was higher in HCON than other management systems, however, there were no differences in the following seasons. Boron (averaged over all seasons) was higher in BD and HCON than LCON. Iron (averaged over all seasons) was higher in LCON and HCON than ORG and BD. Sulphur (averaged over all seasons) was lower in HCON compared with all other systems. Seasonal values of Ca, K, Mg, Mn and P (averaged over all management systems) decreased from 2009 to 2011. Values of Cu, Na and Zn had seasonal variation; however, there was not a decreasing trend

Mineral elements have been found to follow differing trends during winegrape maturation (Esteban et al. 1999). While K has been found to increase over time, Ca was found to decrease (Hrazdina et al. 1984, Esteban et al. 1999), which opposes the findings of the current study. While compositional factors may follow trends during winegrape maturation, variations which may occur within short periods reinforce the importance of precise harvest timing for ideal grape composition. Determination of causes in short-term variation of grape composition demands further research.

5.4.5 Wine analysis

Wine analysis was performed on all wines in the 2009/10 and 2010/11 vintages (Table 5.12). Alcohol content, total anthocyanin, total phenolic colour density levels were all significantly higher in the HCON treatments when compared to other management systems. No significant differences were observed between treatments for pH, TA and hue. Vian et al. (2006) investigated the effect of ORG and/or BD on wine composition relative to conventional management but results were inconclusive.

Table 5.12 Effects of organic, biodynamic, low-input conventional and high-input conventional management on wine compositional analysis in the 2009/10 and 2010/11 growing seasons, McLaren Vale, Australia.

Variable	Season	Treatment				Season mean	5% LSD	*P*-value
		ORG	BD	LCON	HCON			
Alcohol %	2009/10	13.5	13.6	13.9	14.3	**13.8**	0.23 (T)	<0.001 (T)
	2010/11	13.5	13.6	14.0	14.3	**13.9**	ns (S)	ns (S)
	Treatment mean	**13.5** [a]	**13.6** [a]	**14.0** [b]	**14.3** [b]		ns (T*S)	ns (T*S)
Titratable Acidity (TA)	2009/10	7.9	8.0	7.8	7.9	**7.9**	ns (T)	ns (T)
(mg/L)	2010/11	8.2	8.1	7.9	8.0	**8.0**	ns (S)	ns (S)
	Treatment mean	**8.0**	**8.1**	**7.8**	**7.9**		ns (T*S)	ns (T*S)
pH	2009/10	3.48	3.51	3.55	3.50	**3.5**	ns (T)	ns (T)
	2010/11	3.49	3.52	3.52	3.50	**3.5**	ns (S)	ns (S)
	Treatment mean	**3.5**	**3.5**	**3.5**	**3.5**		ns (T*S)	ns (T*S)
Total anthocyanins	2009/10	99.5	107.7	111.6	120.1	**109.7** [a]	7.28 (T)	<0.001 (T)
(mg/L)	2010/11	87.6	92.4	95.7	114.6	**97.6** [b]	3.61 (S)	<0.001 (S)
	Treatment mean	**93.6** [a]	**100.1** [ab]	**103.6** [b]	**117.3** [c]		ns (T*S)	ns (T*S)
Total phenolics	2009/10	31.7	31.4	30.6	33.9	**31.9**	1.68 (T)	<0.001 (T)
(mg/L)	2010/11	31.4	31.8	30.8	34.8	**32.2**	ns (S)	ns (S)
	Treatment mean	**31.6** [a]	**31.6** [a]	**30.7** [a]	**34.3** [b]		ns (T*S)	ns (T*S)
Hue	2009/10	0.82	0.81	0.81	0.79	**0.81**	ns (T)	ns (T)
(no units)	2010/11	0.84	0.83	0.84	0.81	**0.83**	ns (S)	ns (S)
	Treatment mean	**0.83**	**0.82**	**0.83**	**0.80**		ns (T*S)	ns (T*S)
Colour density (au)	2009/10	5.8	6.0	6.3	6.8	**6.2**	0.45 (T)	<0.001 (T)
	2010/11	5.9	6.1	6.2	6.9	**6.3**	ns (S)	ns (S)
	Treatment mean	**5.9** [a]	**6.0** [a]	**6.2** [a]	**6.8** [b]		ns (T*S)	ns (T*S)

Each value represents the mean of four replicate samples of each vineyard treatment (T) for each season (S).

The 5% LSD values listed are for comparison of vineyard treatments (T) and for comparison of seasons (S).

Where there is no significant T × S interaction (T*S), the vineyard treatment means (across all seasons) are compared using the (T) 5% LSD and the seasons means (across all vineyard treatments) are compared using the (S) 5% LSD.

Where there is a significant T × S interaction (T*S), the 5% LSD value used for comparison of treatments is listed.

Letters following the means indicate significant ($P < 0.05$) differences among treatments.

Letters follow either the individual treatment means where there is a T × S interaction or the overall vineyard treatment mean where there is no T × S interaction.

ns indicates no statistically significant difference among means at a 0.05 level.

5.4.6 Wine sensory attributes

Principal component analysis (PCA) was used to identify possible relationships between management system and significantly different sensory attribute descriptors used by winemakers in both 2009/10 and 2010/11. No significant differences in the language used to describe wines from 2009/10 were found between treatments. In 2010/11 significant differences were observed between the different management systems (Figure 5.3). The principal component analysis for the first two components accounted for 92.81% of the variation in the data. Principal component 1 (F1) accounted for 76.38% of variance, while principal component 2 (F2) accounted for 16.43%. Wines made from each of the management system were not described differently by the panel in 2010. However, ORG and

BD wines from 2011 were more frequently described as textural, rich, vibrant and spicy compared to LCON and HCON (Figure 5.7). ORG and LCON wines were also described as more earthy than other BD and HCON. HCON and LCON wines in 2011 were more frequently described as green, unripe and having fine tannin. Very few studies have made these comparisons however in a study by Ross et al. (2009) organically grown California Merlot was more preferred by tasters than the biodynamically grown wines.

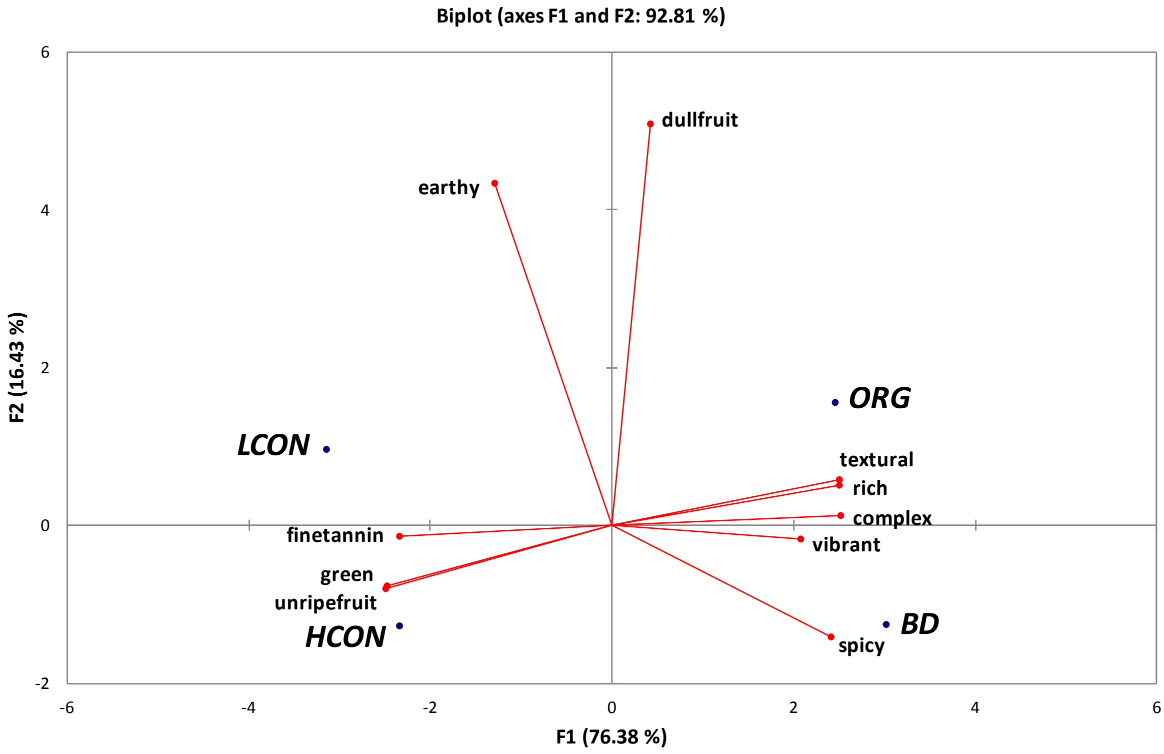

Figure 5.7 Principal component analysis of sensory data for 2010/11 wines from ORG, BD, LCON and HCON.

5.5 Conclusion

One of the objectives of this study was to evaluate what effects management systems have over the three-year conversion period. In this trial, management systems did not affect vine measurements and wine quality until the final season of the conversion period and no consistent differences in berry composition and nutrition were observed. It appears that changes in vine growth had a direct impact on wine quality rather than our more traditional measures of berry quality such as pH, TA and sugar levels.

Trials have collected data over the first three years of the conversion period (Hofmann 1991, Pool and Robinson 1995, Tesic et al. 2007). Hofmann (1991) did not find consistent results between varieties and season, however, a general reduction in yield and vine growth is mentioned. Pool and Robinson (1995) compared three varieties over five seasons and found consistently lower yields and shoot growth. Tesic et al. (2007) collected four seasons of data, in which yield, vine canopy measurements and growth began to significantly decrease in seasons 3 and 4 due primarily to competition for water between the vines and under-vine growth.

It may be argued that the conversion period is not long enough for a perennial crop such as grapevines, where the impacts of management changes are delayed. Of importance to the consumer is the absence of synthetic pesticides and fertilisers in the production system, which the conversion period accommodates, so long as there are no long term residuals in the system. The soil and vines will continue to evolve towards a mature state of equilibrium beyond the three year conversion period, and the resultant wines are likely to display this change. The continuation of this project for a further three years was therefore important in determining the longer term impacts of alternative management systems on soil, vine and wine characteristics.

6. Comparison of organic, biodynamic and conventional management effects on soil properties and vine performance

6.1 Abstract

With industry funding, a six year trial at McLaren Vale in South Australia investigated the changes in soil health, fruit production and wine quality which occurred under organic, biodynamic and conventional viticultural management. The final three years of the trial showed organic and biodynamic production led to improved soil quality, with more organic carbon and soil organisms including much greater earthworm populations. Wine quality was also improved, but in the absence of price premiums, this was achieved at a financial penalty to the grower through reduced yields and increased production costs.

6.2 Introduction

"*We're using biodynamics for three reasons. For the environment, for better wine quality, and for the wellbeing of the people who work here*"*- Gilles Lapalus, Sutton Grange Wines, Central Victoria*

The justification for this project is succinctly expressed by Gilles Lapalus. Globally there is a move towards organic and biodynamic agriculture as cracks appear in the conventional production systems. In part this movement is consumer driven, with support from large retailers such as Tesco and Sainsburys in the UK. With an emphasis now placed on sustainability, improving the soil, reducing pesticide use and enhancing vineyard biodiversity are all promoted as best practice vineyard management. By more than coincidence these are all requirements of organic and biodynamic management as well, for which certification schemes ensure the product is true to label on its environmental credentials.

Despite the widespread interest in organic and biodynamic grape and wine production, there was a paucity of scientific information to support or otherwise the claims of improved soil, grape and wine quality coming from those systems. To overcome this issue, a comparative trial of organic, biodynamic with low and high input conventional systems was established at Gemtree vineyards at McLaren Flat in 2008 by PhD student Luke Johnston. With support from growers and the federal government through the Australian Grape and Wine Authority (formerly the Grape and Wine Research and Development Corporation), the trial was extended for a further three years, to provide a better understanding of the relative performance of the alternative and conventional systems. The following chapters detail the implementation and outcomes in terms of soil quality, invertebrate populations, vine productivity, fruit and wine quality and the financial performance of the four viticultural systems.

6.3 Materials and Methods

6.3.1 Experimental site and design

The trial began in 2008 as the main component of Luke Johnston's PhD project, and further funding enabled continuation from 2012 until 2014.The trial is located within a commercial vineyard located in the McLaren Flat sub-region of the McLaren Vale Wine Region, South Australia (35° 36' 47.86" S; 138° 36'27.89"E, elevation 145 m). The average rainfall for McLaren Flat is 625mm, and additional water is supplied from a bore via drippers at rates up to 2.3 ML/ha, depending on vine requirements and water availability. Annual rainfall during the growing period (October to April) and Mean January Temperature (MJT) for each season is presented in Table 6.1. The vines (*Vitis vinifera* var. Cabernet Sauvignon on own roots) were planted in 1989 on 3 metre row spacing with 1.8 metres between vines. The soil type is a silty loam soil with antecedent organic carbon of 1.7%, pH 8.0 (water) and EC 99 mS m^{-1}.

Table 6.1 Rainfall received during the October to April growing season and the total received for the July to June period from 2011 to 2014; Mean January temperature and evaporation; irrigation applied for the growing season. (McLaren Flat Automatic Weather Station, McLaren Vale Grape Wine and Tourism, 2014).

	Season		
	2011/12	2012/13	2013/14
October to April (mm)	256.6	163.8	188.2
July-June (mm)	758	416	602
Temperature (January average)	21.1	20.7	22
Et (average mm/day January)	6.8	6.5	7
Irrigation (ML/ha)	1.3	0.9	1.4

The total trial site area is 10 ha, providing a substantial buffer from surrounding activities. The monitored area within the trial extended 50m from the central headland, providing a total of 3.8 ha consisting of four replicates of four treatments. Each replicate contains eight rows, which includes a two row buffer from the nearest treatment. Rows 3 and 5 of each replicate were used for measurement, one of which had compost applied under the vine row. This provided 32 rows from which measurements are taken, 16 of which had compost applied in 2009 and 2012. The composted mulch was applied to the 50 cm strip under-vine at an equivalent rate of 126 t/ha (21 t/ha if applied over the whole vineyard floor). This was applied to the soil surface where it remained on the LCON and HCON treatments, but was incorporated into the topsoil with under-vine cultivation on the ORG and BD systems. The compost nutrient analysis is provided in chapter 5 in Table 5.3.

Four treatments were compared viz organic, biodynamic, low input conventional and high input conventional. Details of the treatments are shown below in Table 6.2.

Table 6.2 Management inputs applied from 2012-2014 to the four management treatments; Organic, biodynamic, low-input conventional and high-input conventional at a vineyard in McLaren Vale, South Australia.

	Treatments			
	Organic	**Biodynamic**	**Low-input conventional**	**High-input conventional**
Mid-row management	Mown resident vegetation	Mown resident vegetation	Mown resident vegetation	Mown resident vegetation
Undervine management	Mowing and/or cultivation	Mowing and/or cultivation	Glyphosate and oxyflurofen in spring	Glyphosate/ oxyfluorfen/ pendimethalin in spring
Disease management	Wettable sulphur, Copper cuprous oxide	Wettable sulphur, Copper cuprous oxide	Wettable sulphur, Copper cuprous oxide	Wettable sulphur, Copper cuprous oxide, trifloxystrobin
Insect management	None	None	None	emamectin benzoate
Other	Organic nitrogen (12%N, 2%K), seaweed extract	Organic nitrogen (12%N, 2%K) seaweed extract BD 500, 501	Organic nitrogen (12%N, 2%K) seaweed extract	Organic nitrogen (12%N, 2%K) seaweed extract

6.3.2 Vine growth and plant nutrition measures

In each measured row samples were taken from two panels consisting of three vines each. In July of 2012/13/14 vines on the two measured panels per row were hand pruned to two node spurs, from which the pruning weights, cane numbers and cane lengths were determined (Figure 6.1). Vines were hand harvested when the average °Brix, TA and pH across all treatments was suitable for wine quality assessment. The harvest date was determined through weekly monitoring of maturity and forecast weather conditions. At harvest, two panels (a total of six vines) per row were hand harvested from which yield, bunch numbers and bunch weight were determined.

Vine nutrient uptake was analysed following the collection of approximately 60-80 petioles from the node opposite the basal inflorescence at 50% capfall (E-L 23; Coombe 1995). These were analysed by the Waite Analytical Service (WAS) using ICP (Wheal, 2011) and for N by the combustion technique using an Elementar Instrument.

Figure 6.1 Pruning weights were recorded in July of each year.

6.3.3 Soil assessment

Soils were sampled mid-winter and at flowering. The samples were collected from two depths (0-10 and 10-20 cm) in three locations per plot. Soil chemical, biological and physical properties were determined using the following techniques.

6.3.4 Chemical soil properties

A 1:5 soil water suspension was mixed in an end over end shaker for 1 hour at 25^{o}C prior to determination of the pH and electrical conductivity (EC). Using the technique of Rayment and Higgison (1992), inorganic N was extracted from a solution of 1 part soil to 5 parts of 2M KCl that had been shaken for 1 hour. The ammonium and nitrate concentration was measured using the Kjeldahl method (McKenzie and Wallace 1954). Available (resin) P was extracted using anion exchange membranes (Kouno, et al. 1995) then P was determined colorimetrically at 712 nm (Murphy and Riley 1962). Organic carbon was measured using the Walkley and Black procedure (Walkley and Black 1934).

Herbicide residue analysis for products commonly used in viticulture was conducted by the National Measurement Institute using the NR 47 and NR53 (for glyphosate, AMPA and glufosinate) method, coupled with ultra-high performance liquid chromatography mass spectrometry (UPLC-MS/MS). Due to cost constraints only the ORG and HCON treatments were tested on samples bulked across the four replicates.

6.3.5 Soil biological properties

Soil respiration. To determine soil respiration, 30 g of soil was adjusted to 1.5 g cm^{-3} density then placed in PVC cores (3.7 cm diameter, 5 cm height) with a nylon mesh base. These were placed in 1 L glass jars alongside a vial containing 10 mL of RO water, then sealed with air tight lids. They were incubated in the dark at 21-15^{o}C for 6 days. The headspace gas was extracted via the septum and CO_2 concentration was measured with an IR CO_2 gas analyser (Servomex 1450 Food Package analyser, Crowborough, UK).

Microbial biomass C. A modified version of the fumigation-extraction method (Anderson and Ingram 1993, Vance et al. 1987) was used to determine microbial biomass carbon (MBC). Of two 5g aliquots of soil, one was placed in a desiccator and fumigated with chloroform for 24 hours, while the other was stored at 4°C.

For each sample two times 5 g of freshly defrosted soil were weighed out. One aliquot was placed in a desiccator and fumigated with chloroform for 24 hours. The non-fumigated soils were stored at 4°C. After fumigation, they were shaken for 1 hour with 20 mL of 0.5M K_2SO_4, filtered through No. 42 Whatman filter paper. A 4 mL extract of the sample was titrated with 1 mL 0.0667M $K_2Cr_2O_7$, 5 mL H_2SO_4 and indicator, then again titrated with acidified ferrous ammonium sulphate (0.033M). The difference between fumigated and non-fumigated samples was calculated as the microbial biomass C.

6.3.6 Earthworms

In July of 2012 and 2013 a total of 15 kg of wet soil was removed by shovel from the top 10 cm at three locations within each measured vine row. The soil was hand sorted to retrieve the resident earthworm population, which was counted and weighed (Figure 6.2). Sub samples of soil were oven dried (105^{o} C for 24 hours) to determine dry weights.

Figure 6.2 Collection of earthworm samples in 2013.

6.3.7 Soil Physical Properties

Penetration resistance was measured in July 2013 using a sliding hammer penetrometer (mass 1.54 kg). The number of hits per 5 cm to 30 cm depth was recorded. As this was a comparative assessment only, all soils were deemed to be at similar moisture content across all treatments, as the vines were dormant and very little soil cover was evident.

6.3.8 Invertebrate Biodiversity

In November and February of 2011/12 and 2013/14 invertebrate populations were assessed in the canopy and at ground level. On each measured row three yellow sticky traps (Bugs for

Bugs) were attached to the vines approximately level with the top cordon. At ground level three 120 mL screw cap vials containing 25 mL of ethylene glycol were placed on the mound to the side of the drip line in a 50 mm diameter hole. The traps remained in the vineyard for 10-14 days. Following collection the insects were sorted to family and genus level then allocated to functional groupings.

6.3.9 Financial Costs and Returns

During the trial period all vineyard operations were catalogued. To these real costs and returns were allocated to produce the final gross margins.

6.3.10 Statistical analysis

Soil, vine growth and invertebrate data were analysed using a repeated measures analysis of variance (GenStat® for Windows 15.0, VSN International, United Kingdom). The least significant difference test was used ($P<0.05$) to determine significant differences between treatments, seasons and compost at a given sampling time, while the repeated measures analysis determined what change occurred over time.

6.4 Results

6.4.1 Vine productivity

The ORG, BD and LCON systems yielded 79, 70 and 91% respectively of the HCON treatment over the trial period. Lower yields on the ORG and BD systems were a product of fewer bunches which were also lighter (Table 6.3). Fewer canes that were lighter and shorter on the ORG and BD systems provided further evidence of the reduced vigour on these treatments. Compost increased both bunch and pruning weights but this did not increase fruit yield.

Table 6.3 Vine growth and production for the seasons 2011/12, 12/13 and 13/14.

Variable	Season	Treatment				Season mean	5% LSD	*P*-value
		ORG	BD	LCON	HCON			
Pruning weights per metre of cordon (kg)	2012	0.46	0.51	0.65	0.75	0.59[c]	0.078(T)	<.001(T)
	2013	0.80	0.80	0.96	1.05	0.90[a]	0.051(S)	<.001(S)
	2014	0.63	0.64	0.91	0.86	0.75[b]	ns(T*S)	ns(T*S)
	Treatment mean	0.63[b]	0.65[b]	0.84[a]	0.88[a]			
Shoot length (cm)	2012	70	70	74	80	74[c]	5.5 (T)	0.002 (T)
	2013	99	95	103	107	101[a]	3.8 (S)	<.001(S)
	2014	85	88	92	94	90[b]	ns(T*S)	ns(T*S)
	Treatment mean	85[ab]	84[b]	90[a]	94[a]			
Yield per metre of cordon (kg)	2012	1.4[e]	1.3[d]	2.0[d]	2.2[d]	1.7	0.37(T)	<.001(T)
	2013	1.7[de]	1.5[de]	1.7[de]	1.7[de]	1.6	0.26(S)	<.001(S)
	2014	3.6[bc]	3.2[c]	4.1[b]	4.6[a]	3.9	0.57(T*S)	0.021(T*S)
	Treatment mean	2.2	2	2.6	2.9			
Bunch number per metre of cordon	2012	44.9[d]	40.1[d]	51.3[cd]	54.3[c]	47.7	5.9(T)	0.017(T)
	2013	26.7[e]	24.2[e]	23.7[e]	23.8[e]	24.6	3.6(S)	<.001(S)
	2014	65.7[b]	62.7[bc]	66.7[b]	77.8[a]	68.3	8.4(T*S)	0.015(T*S)
	Treatment mean	45.78	42.37	47.28	52.04			
Mean bunch weight (g)	2012	31.5	33.6	40.8	41.8	36.9[c]	4.3(T)	<.001(T)
	2013	65.4	63.2	70.9	70.5	67.5[a]	2.7(S)	<.001(S)
	2014	55.6	50.3	60.1	60.2	56.5[b]	ns(T*S)	ns(T*S)
	Treatment mean	50.8[b]	49.0[b]	57.3[a]	57.5[a]			
Yield/Pruning weight ratio	2012	3.0	2.7	3.2	3.1	2.9[b]	ns(T)	ns(T)
	2013	2.3	1.9	1.8	1.7	1.9[c]	0.5(S)	<.001(S)
	2014	5.8	5.2	4.9	5.7	5.4[a]	ns(T*S)	ns(T*S)
	Treatment mean	3.7	3.2	3.3	3.5			
Cane Number per metre of cordon	2012	32.1	33.4	37.6	36.9	34.9[a]	1.96(T)	<.001(T)
	2013	32.2	29.7	32.7	34.0	32.1[b]	1.44(S)	<.001(S)
	2014	30.6	30.0	33.1	33.6	31.8[b]	ns(T*S)	ns(T*S)
	Treatment mean	31.6[b]	31.0[b]	34.5[a]	34.8[a]			

6.4.2 Soil and Vine nutrition

Available soil nitrogen at the 0-10 cm depth (Table 6.4) was not impacted by treatment, while available phosphorus was higher on the LCON and HCON in the first year, but this had reversed by the final year when the BD system was higher than LCON and HCON. The microbial biomass carbon and respiration were also higher on the ORG and BD systems. Total organic carbon, microbial biomass carbon, soil pH and EC were higher where compost was applied. At the 10-20 cm depth (Table 6.5), microbial biomass carbon, total organic carbon and phosphorus (2013) were higher on BD, while the application of compost increased phosphorus and carbon levels. Soil chemical residue analysis revealed detectable levels (0.29 mg/kg) of aminomethylphosphonic acid (AMPA) on the HCON system. AMPA is the principal degradation product of glyphosate. Vine nutrient uptake, determined using petiole analysis, showed boron was higher on HCON and phosphorus and sulphur on LCON and HCON (Table 6.6). Compost application increased the concentrations of nitrogen, phosphorus, potassium, calcium, sulphur and zinc.

Table 6.4 Soil properties at 0-10 cm for the 2011-14 period.

Variable	Season	Treatment				Season mean	5% LSD	*P*-value
		ORG	BD	LCON	HCON			
EC	2010/11	84[c]	84[c]	92[c]	109[c]	92	ns(T)	ns(T)
	2011/12	215[b]	219[b]	349[a]	311[a]	274	34.97(S)	<.001(S)
	2012/13	110[c]	101[c]	87[c]	127[c]	107	75.36(T*S)	0.039(T*S)
	Treatment mean	137	135	176	182			
MBC	2010/11	68	55	53	58	58[c]	9.44(T)	<.001(T)
	2011/12	80	92	66	63	75[b]	9.12(S)	<.001(S)
	2012/13	188	185	156	172	175[a]	ns(T*S)	ns(T*S)
	Treatment mean	112[a]	110[a]	91[b]	98[b]			
Resin P	2010/11	21.2[b]	16.1[b]	32.4[a]	30.7[a]	25.1	ns(T)	ns(T)
	2011/12	13.0[b]	15.4[b]	21.0[b]	17.4[a]	16.7	3.746(S)	<.001(S)
	2012/13	25.0[a]	31.2[a]	21.0[b]	19.7[b]	24.2	9.068(T*S)	<.001(T*S)
	Treatment mean	19.8	20.9	24.8	22.6			
Resp	2010/11	0.08	0.07	0.05	0.05	0.06[b]	0.04645(T)	0.001(T)
	2011/12	0.55	0.60	0.47	0.38	0.50[a]	0.04814(S)	<.001(S)
	2012/13	0.12	0.14	0.08	0.09	0.11[b]	ns(T*S)	ns(T*S)
	Treatment mean	0.25[a]	0.27[a]	0.20[b]	0.17[b]			
Toc	2010/11	2.46	2.34	2.19	2.35	2.34[a]	ns(T)	ns(T)
	2011/12	1.94	2.01	1.99	1.99	1.98[b]	0.166(S)	<.001(S)
	2012/13	1.93	1.92	1.54	1.56	1.74[c]	ns(T*S)	ns(T*S)
	Treatment mean	2.11	2.09	1.91	1.97			
pH	2010/11	7.77	7.85	7.88	7.83	7.83	ns(T)	ns(T)
	2011/12	7.78	7.73	7.65	7.98	7.79	ns(S)	ns(S)
	2012/13	7.62	7.65	7.84	7.97	7.77	ns(T*S)	ns(T*S)
	Treatment mean	7.72	7.75	7.79	7.93			
Avail N	2010/11	31	33	30	29	31[a]	ns(T)	ns(T)
	2011/12	22	23	23	23	23[b]	3.611(S)	<.001(S)
	2012/13	16	16	15	16	16[c]	ns(T*S)	ns(T*S)
	Treatment mean	23	24	22	23			

Table 6.5 Soil properties at 10-20 cm for the 2011-14 period.

Variable	Season	Treatment				Season mean	5% LSD	*P*-value
		ORG	BD	LCON	HCON			
EC	2010/11	197	212.2	266	270.3	236.4^{a}	ns(T)	ns(T)
	2011/12	125.6	194.9	192.3	253.7	191.6^{a}	48.17(S)	<.001(S)
	2012/13	102.8	116.4	86.6	93.9	99.9^{b}	ns(T*S)	ns(T*S)
	Treatment mean	141.8	174.5	181.6	206			
MBC	2010/11	20	24	28	21	23^{b}	7.2(T)	0.046(T)
	2011/12	293	312	293	284	295^{a}	7.56(S)	<.001(S)
	2012/13	8	9	7	9	8^{c}	ns(T*S)	ns(T*S)
	Treatment mean	107^{b}	115^{a}	109^{ab}	105^{b}			
Resin P	2010/11	5.3^{ab}	3.9^{ab}	7.1^{ab}	6.0^{ab}	5.6	ns(T)	ns(T)
	2011/12	9.1^{a}	13.6^{a}	5.0^{ab}	4.1^{ab}	7.9	ns(S)	ns(S)
	2012/13	7.1^{ab}	9.7^{a}	5.7^{a}	8.5^{a}	7.8	5.4(T*S)	0.02(T*S)
	Treatment mean	7.15	9.1	5.9	6.2			
TOC	2010/11	1.5	1.7	1.5	1.6	1.6^{a}	0.14(T)	<.001(T)
	2011/12	1.4	1.7	1.3	1.2	1.4^{b}	0.1(S)	<.001(S)
	2012/13	1.3	1.4	1.1	1	1.2^{c}	ns(T*S)	ns(T*S)
	Treatment mean	1.4^{b}	1.6^{a}	1.3^{b}	1.3^{b}			
pH	2010/11	7.9	7.8	7.8	7.9	7.9	ns(T)	ns(T)
	2011/12	8.2	8.1	8.1	8.3	8.2	0.18(S)	0.003(S)
	2012/13	7.7	7.8	7.9	8	7.9	ns(T*S)	ns(T*S)
	Treatment mean	7.9	7.9	7.9	8.1			
Avail N	2010/11	34.5	34	38	34.1	35.2^{a}	ns(T)	ns(T)
	2011/12	16.3	18.4	16.6	16.3	16.9^{b}	2.5(S)	<.001(S)
	2012/13	14.1	15.2	13.4	13.6	14.1^{c}	ns(T*S)	ns(T*S)
	Treatment mean	21.6	22.5	22.7	21.3			

Table 6.6 Elemental analysis of petiole nutrient status, 2011-13.

Variable	Season	Treatment				Season mean	Optimum Range	5% LSD	*P*-value
		ORG	BD	LCON	HCON				
Al	2011/12	1.8	2.2	4.3	2.1	2.6^{b}		ns(T)	ns(T)
mg/kg	2012/13	4.9	5.4	4.9	4.4	4.9^{a}		1.101(S)	<.001(S)
	2013/14	4.9	5.2	4.6	4.9	4.9^{a}		ns(T*S)	ns(T*S)
	Treatment mean	3.9	4.3	4.6	3.8				
B	2011/12	33	33	33	34	33^{b}	**35-70**	1.015(T)	0.019(T)
(mg/kg)	2012/13	36	36	35	37	36^{a}		0.796(S)	<.001(S)
	2013/14	33	33	33	35	34^{b}		ns(T*S)	ns(T*S)
	Treatment mean	34^{b}	34^{b}	34^{b}	35^{a}				
Ca	2011/12	17575	16625	17812	17400	17353^{a}	**12000-25000**	ns(T)	ns(T)
	2012/13	16825	17175	17425	17062	17122^{a}		624.3(S)	<.001(S)
	2013/14	15250	15425	16375	16138	15797^{b}		ns(T*S)	ns(T*S)
	Treatment mean	16550	16408	17204	16867				
Cu	2011/12	74	80	91	87	83^{b}	**6 to 11**	ns(T)	ns(T)
mg/kg	2012/13	19	18	19	21	19^{c}		7.83(S)	<.001(S)
	2013/14	103	103	92	98	99^{a}		ns(T*S)	ns(T*S)
	Treatment mean	65	67	67	69				
Fe	2011/12	25	24	27	25	25^{b}	**>30 (mg/kg)**	ns(T)	ns(T)
	2012/13	22	23	22	21	22^{c}		1.09(S)	<.001(S)
	2013/14	26	26	27	28	27^{a}		ns(T*S)	ns(T*S)
	Treatment mean	24	24	25	25				
K	2011/12	36250	33375	34375	36000	35000^{a}	**18000-30000**	ns(T)	ns(T)
	2012/13	29125	28625	31750	28125	29406^{b}		1501.1(S)	<.001(S)
	2013/14	24750	26000	28500	26875	26531^{c}		ns(T*S)	ns(T*S)
	Treatment mean	30042	29333	31542	30333				
Mg	2011/12	3375^{b}	3862^{b}	3887^{b}	3737^{b}	3716	**>4000**	332.5(T)	0.037(T)
	2012/13	4463^{a}	4813^{a}	4638^{a}	4825^{a}	4684		172.4(S)	<.001(S)
	2013/14	3888^{b}	4000^{b}	4625^{a}	4350^{ab}	4216		429.8(T*S)	0.047(T*S)
	Treatment mean	3908	4225	4383	4304				
Mn	2011/12	43	41	45	35	41^{b}	**30-60 (mg/kg)**	ns(T)	ns(T)
	2012/13	47	49	49	44	47^{a}		2.699(S)	<.001(S)
	2013/14	41	37	40	33	38^{c}		ns(T*S)	ns(T*S)
	Treatment mean	44	43	45	37				
N	2011/12	0.855	0.884	0.830	0.870	0.860^{b}		ns(T)	ns(T)
	2012/13	0.866	0.892	0.860	0.856	0.869^{b}		0.04401(S)	<.001(S)
	2013/14	0.997	1.023	1.082	1.107	1.052^{a}		ns(T*S)	ns(T*S)
	Treatment mean	0.906	0.933	0.924	0.944				
Na	2011/12	965	848	880	840	883^{b}	**>5000 is TOXIC**	ns(S)	ns(T)
	2012/13	514	482	469	458	481^{c}		84.6(S)	<.001(S)
	2013/14	1200	1155	969	1074	1099^{a}		ns(T*S)	ns(T*S)
	Treatment mean	893	828	772	790				
P	2011/12	0.549^{c}	0.554^{c}	0.746^{ab}	0.790^{a}	0.660	**2500-5000**	116.7(T)	<.001(T)
	2012/13	0.718^{b}	0.733^{ab}	0.830^{a}	0.805^{a}	0.771		0.0302(S)	<.001(S)
	2013/14	0.536^{c}	0.565^{c}	0.743^{ab}	0.745^{ab}	0.647		187.2(T*S)	0.006(T*S)
	Treatment mean	0.601	0.617	0.773	0.780				
S	2011/12	2066^{b}	1881^{bc}	2450^{a}	2462^{a}	2215		116.7(T)	<.001(T)
	2012/13	2049^{b}	2060^{b}	2228^{ab}	2196^{ac}	2133		ns(S)	ns(S)
	2013/14	2060^{b}	2082^{b}	2359^{a}	2462^{a}	2241		187.2(T*S)	0.017(T*S)
	Treatment mean	2058	2008	2345	2374				
Zn	2011/12	40	40	42	41	41	**> 26**	ns(T)	ns(T)
(mg/kg)	2012/13	38	39	38	42	39		ns(S)	ns(S)
	2013/14	40	40	40	43	41		ns(T*S)	ns(T*S)
	Treatment mean	39	40	40	42				

6.4.3 Soil strength

The 0-5 and 5-10 cm depths of the ORG and BD treatments displayed less resistance to penetration than the LCON and HCON (Table 6.7). This outcome is directly attributable to those treatments having been cultivated using a dodge plough for weed control purposes which had loosened the soil in the 0-10 cm zone, and decreased the resistance to the sliding hammer penetrometer. There was no treatment effect below 10 cm or compost impact at any depth.

Table 6.7 The number of hits required to penetrate 5 cm increments using a sliding hammer penetrometer.

Depth (cm)	**ORG**	**BD**	**LCON**	**HCON**	***P* value**	**LSD**
0-5	1	1.5	3.75	4.12	0.003	1.612
5-10	1.88	2.75	6.12	7	0.001	2.266
10-15	6.38	7.25	11.12	11.88	ns	
15-20	12.62	15.88	16	23	ns	
20-25	23.2	25.2	18.6	23.7	ns	
25-30	28.8	31.5	23	24.1	ns	

6.4.4 Soil Moisture

Resource constraints limited moisture monitoring to the ORG and HCON systems only. The ORG system showed higher soil moisture tension in the pre-flowering period compared to HCON at 20 and 70 centimetres. By veraison there were no treatment differences. Compost addition under-vine provided lower soil moisture tension compared to no compost but only at the 20 cm depth, which was the zone where the compost was incorporated during the under-vine weeding process.

6.4.5 Earthworms

The ORG and BD systems generated more earthworms with a greater biomass than both the LCON and HCON systems (Table 6.8). The application of compost was not influential on either their populations or biomass production.

Table 6.8: Earthworm abundance and biomass in years 2012/13

Variable	**Season**	**Treatment**				**Season mean**	**5% LSD**	***P*-value**
		ORG	**BD**	**LCON**	**HCON**			
Number (per m^2)	2012	98	147	43	24	78^{b}	61.2(T)	<.001(T)
	2013	354	324	176	113	242^{a}	49.9(S)	<.001(S)
	Treatment mean	226^{a}	235^{a}	110^{b}	69^{b}		ns(T*S)	ns(T*S)
Wt (g/m^2)	2012	29^{bc}	45^{b}	13^{c}	10^{c}	24	21.84(T)	<.001(T)
	2013	108^{a}	89^{a}	45^{b}	32^{bc}	68	14.37(S)	<.001(S)
	Treatment mean	69	67	29	21		29.01(T*S)	0.045(T*S)

6.4.6 Invertebrates

Populations were monitored using pitfall and yellow sticky traps located in the canopy. The invertebrates were classified to the family level, enabling them to be sorted into functional groupings. Up to 59,000 insects were counted for a sampling period.

Ground dwelling invertebrates caught in pitfall traps. Consistent with the sticky traps data, there was much more invertebrate activity in November than February (Table 6.9). The detritivores consisted mostly of *Collembola* (springtails), *Isopoda* (slaters or woodlouse) and *Psocoptera* (book louse). The 2013 November sampling displayed a high number of springtails and millipedes which were also included in this category, though in some cases they may also be herbivores (e.g. lucerne flea) as well. The predators and parasitoids in the order the *Hymenoptera* consisted of up to 10 families of wasps, thereby displaying considerable biodiversity. Ants were the principal omnivores, with up to 12 genera represented. An inverse correlation with wasp numbers was apparent over the sampling periods. The predators consisted primarily of spiders (*Araneae*) and rove beetles (*Coleoptera*). The herbivores were dominated by large brown garden snails (*Helix aspersa*) and thrips (*Thysanoptera*), neither of which is deemed to affect vineyard productivity, though the snails can be a contaminant of harvested fruit. The fungus gnat (*Diptera*) dominated the fungivores, though at low numbers overall.

Table 6.9: Abundance of invertebrates captured in pitfall traps, shown for each of the main functional groups over four sampling periods.

	Nov-12	**Feb-13**	**Nov-13**	**Feb-14**
Total detritivores	196	586	2301	263
Total predators/parasitoids	46	12	5	242
Total omnivores	2906	2217	1688	200
Total predators	192	280	603	101
Total herbivores	692	49	424	128
Total fungivores	29	3	13	58
Total unknown	1921	2	1045	4

Across the treatments, detritivore, omnivore and predator numbers were higher on the LCON and HCON systems. Rows where compost was applied had higher numbers of omnivores, predators/parasitoids and predators. There were no differences in fungivore or herbivore numbers.

Invertebrates caught in yellow sticky traps in the canopy. Invertebrate abundance during the four sampling periods over the two years varied considerably between collection times (Table 6.10). Only 1% of the total invertebrate numbers collected in November were collected in February, possibly due to the mid-row cover having senesced and been mown by the second sampling. At both sampling times the predominant families were the predator/parasitoid Hymenoptera (wasps) and herbivore Thysanoptera (thrips), with the numbers of the latter being up to 97% greater than the former. The detritivores consisted of predominantly scuttle flies (*Phoridae*) while beetles (*Coleoptera*) dominated the fungivores. Fungus gnats (*Diptera*) maintained very low numbers, rising only once in November 2013. Native bees (nectarivore) were rare, while some ants (omnivore) did move into the canopy. There were more detritivores (particularly scuttle fly) in the canopy of the ORG and BD systems. Not applying compost generated higher numbers of detritivores and saprophages (blow flies) insects, but the numbers of the latter were very low. There were no differences between treatments in fungivore, herbivore, nectarivore, predator/parasitoid or omnivore numbers.

Table 6.10: Invertebrate abundance based on functional groups that were caught in sticky traps placed in the vine canopy during the spring and summer periods of two seasons.

	Nov-12	**Feb-13**	**Nov-13**	**Feb-14**
Detritivore	1135	122	1862	263

Fungivore	576	18	94	58
Herbivore	51049	653	154124	128
Herbivore/detritivore	9	0	210	0
Nectarivore	3	2	0	2
Omnivore	22	17	99	200
Predator	385	57	960	101
Predator/Parasitoid	5771	463	3282	242
Saprophagous	25	24	90	18

6.4.7 Financial analysis

Table 6.11 shows the likely gross margins from the four treatments over the trial period. The fruit was all sold as conventionally produced, but no price premium has been applied for ORG of BD fruit, as such premiums are not a certainty. There were considerable differences between income and expenditure across the treatments, and these impacted significantly on the final outcome. The ORG, BD and LCON produced 74, 65 and 91% of the HCON gross margins over the three year period. Grape yield, as noted earlier, was significantly reduced and operating costs were higher on the ORG and BD systems.

Table 6.11 Hypothetical financial returns of the four treatments over the 2012-2014 period.

Income	**ORG**	**BD**	**LCON**	**HCON**
Grape Yield (t/ha) [1]	7.5	6.7	8.6	9.5
Price $/t [2]	1271	1271	1271	1271
Income ($/ha)	9506	8511	10962	12096
Operating Costs ($/ha)[3]				
Fungicide application	304	304	289	299
Herbicide under-vine			82	82
Mowing mid-row	85	85	85	85
Mowing under-vine[3]	41	41		
Cultivation under-vine	487	487		
Mechanical pruning	280	280	280	280
BD application		8		
Herbicides				
Credit® (glyphosate)			33	33
Bonus® (adjuvant)			33	33
Goal® (oxyfluorfen)			3	3
Rifle®[3] (pendimethalin)				63
Fungicides				
Unishield® Wettable Sulphur	30	30	29	29
Norshield WG® (copper cuprous oxide)	44	44	44	46
Flint®[3] (trifloxystrobin)				18
Insecticide				
Proclaim®[3] (emamectin benzoate)				27
Nutrition				
OFS Organic Nitrogen[3]	19	19	19	19
Seasol® (liquefied seaweed)	60	60	60	60
BD Preparations				
Horn Silica 501		5		
Horn Manure 500		0.3		
Cow Pat Pit (CPP)		0.08		
Operating Costs ($/ha/Yr)	1351	1364	955	1076
Average Gross Margin ($/ha/Year)[4]	8155	7147	10007	11020
% of HCON	74	65	91	100

Notes: [1]Yield: average yield achieved in the years 2012-2014; [2]Price: average price achieved for fruit from that block over three years. No premium for the organic fruit has been included. [3]Operating costs: some operations were only performed in one year; with costs averaged over the three years.[4] Costs of irrigation, harvest, hand pruning and fixed overhead costs are not included.

6.5 Discussion

6.5.1 Yield and Pruning weights

In moisture constrained growing environments such as most of southern Australia, access to adequate soil moisture at critical periods of fruit development is essential to achieve optimal yield levels. Available moisture is influenced by seasonal conditions, soil water holding capacity, irrigation and vineyard floor management. The cover crops in this trial consisted of a regenerated sward across the whole site which was managed by mowing as deemed necessary. It is therefore expected that if plant available moisture is the main reason for yield variation between treatments, then it will be due to competition between the vine and undervine plant growth.

Plants growing under-vine during the winter/spring period were a mixed sward of consisting primarily of *Oxalis pes-caprae, Avena fatua, Lolium rigidum, Plantago lanceolata* and *Medicago truncatula*. They were managed according to the amount of growth that was apparent in early spring, initially using an under-vine mower (2011), then with a dodge plough (2012/13). The whole site was irrigated on the same shift, so no compensation in increased irrigation at the start of the season was made to the ORG and BD treatments. Had this been possible, it may have been a useful mechanism to restore yield levels.

Access to adequate soil moisture at critical periods of berry development is essential to maximising/optimising yields. Yield reduction in this study was due to fewer shoots and bunches, while the shorter and lighter canes on the ORG and BD systems were evidence of water stress prior to veraison (McCarthy 1997). Preventing water stress at budburst is critical to ensuring even numbers of shoots per vine. Higher budburst soil moisture tension (more negative) values were apparent on the ORG treatment at 20 and 70 cm depths, and trended strongly at 40 and 100 cm. The average matric potential for the four depths of ORG was -72 kPa and -57 kPa for the CON treatment. At this early stage of development Van Zyl (1987) found moisture stress was induced when the matric potential exceeded 64 kPa. By veraison however, when it is possible to induce a moisture deficit with little effect on yield, there were no differences in soil matric potential. By this time, under-vine weed control and shading meant the vines were not competing with weeds for moisture. It is proposed therefore, that while the difference in soil matric potential at budburst between the ORG and HCON was not large, it was sufficient to cause lower shoot numbers and therefore bunch numbers. This impact on yield through lower soil moisture early in the vines growth cycle was not reversible, leading to generally lower yields on the ORG and BD treatments.

6.5.2 Soil and Vine Nutrition

Petiole analysis showed iron (25 mg/kg) and magnesium (0.3%) as the only elements measured with concentrations below the recognised standards for adequacy of 30 mg/kg and 0.4% respectively (Singh 2006). Soil and plant nutrition was therefore not deemed to have influenced vine productivity. Some of the measured outcomes require further discussion however. Soil P has very limited mobility, especially in heavy textured soil types. Roots and / or mycorrhizal fungi therefore need to be growing in the immediate vicinity of the P source for root uptake to occur. Soil at the root interface must also be moist to enable solute transfer (Richardson 1994). At both 0-10 cm and 10-20 cm depths, soil P was higher on the BD system in the final year. However, over the three year period of the trial, petiole P was lower in the ORG and BD systems. Soil moisture was also lower on the ORG treatment, and by inference (moisture was only measured on the ORG and HCON systems) on the BD system as well, potentially restricting P uptake. It is also likely the reduced uptake of P on the BD and ORG systems was due to root pruning caused by the under-vine mechanical weeding (dodging), which can destroy shallow roots existing in the zone of highest P concentration. Soil at this site averaged 22 mg/kg resin P (approximately 27 mg/kg Colwell), so access to sufficient P for vine function was not an issue. In situations where soil P was lower, reducing access by pruning the upper roots may compromise the vines nutrient status and productivity.

Following one under-vine mowing in 2011, cultivation was the sole mechanism for weed control. On other blocks, sheep are an important weed management tool during the autumn / winter period. It is possible that their use will constrain the water use of under-vine weeds and lead to yield improvement. Alternatively, to reduce costs and improve the operation's sustainability, it is suggested that trials be conducted in the McLaren Vale bioregion, on the use of cereal straw as under-vine mulch. While expensive to implement, the combined benefits of moisture retention and weed suppression make this an attractive option, particularly for organic growers. Work in Australia and overseas (DeVitter et al. 2014) has shown mulching to be a very effective weed management tool, which can maintain or improve yields when compared to herbicide application. Mulching curtails weed growth and reduces soil moisture loss, and may also lead to increased cytokinin production from the tips of fine white roots growing in the shallow topsoil, which may benefit shoot growth and function (Richards 1983).

6.5.3 Composted Organic Mulch

Compost application underlies the management of soil fertility in most intensive organic horticultural operations. As many conventionally managed vineyards in southern Australia also use compost as a mulch or nutrient source, it was necessary to delineate the impact of compost from the systems under investigation. Compost was therefore applied to half of the monitored trial rows across the site, to determine its impact on the four individual production systems. The application rate was high enough to provide additional nutrients, but not sufficient for weed control.

High levels of available potassium contained in the composted products that are applied under-vine may raise juice pH, which if too high is detrimental to the wine making process. Despite approximately 270 kg/ha of K being applied in the mulch, the wine pH only rose by 0.6% or 0.02 units. Such an increase is insignificant in winemaking terms and should not preclude the use of compost mulch products, particularly when applied to heavy textured soils.

While bunch and pruning weights increased, compost application did not improve fruit yields, despite an increase in total organic carbon and microbial biomass. This outcome would suggest soil nutrition was not a limiting factor on vine yield, and the likely improvement to soil health was not sufficient to impact productivity. Lindsay, et al. (1999), Penfold (2004), Wilkinson and Biala (2001) and many others have conducted investigations into the benefits of applying either fine or coarse textured compost to the under-vine zone of a vineyard. An increase in yield is common, with up to 50% occurring in some situations (Penfold 2004). As highlighted by these results, yield benefits are not universally realised, necessitating the need for growers to conduct their own small trials to determine the worth or otherwise of using such products on their own properties.

6.5.4 Herbicide residues

According to Schuette (1998) glyphosate is relatively persistent, where it binds strongly to cations that are adsorbed to soils (Battaglin, et al. 2005). Its degradation in the soil is dependent on microfloral population and activity. Aminomethylphosphonic acid (APMA) is the primary metabolite of glyphosate, with a half-life ranging from 76 to 240 days (Battaglin et al. 2005). Fungi are the main microbial decomposers of glyphosate. Lane et al. (2012) and Haney, et al. (2000) found total microbial biomass was not impacted by glyphosate addition, but microbial respiration was stimulated in soil which had a history of glyphosate application. The higher levels of microbial respiration on the ORG and BD systems would suggest that the APMA residues detected on the HCON treatment were not impacting directly on the soil processes investigated in this study.

6.5.5 Soil Biology

Microbial Biomass Carbon. Riches et al. (2013) noted the considerable variation reported in microbial biomass carbon (MBC) both spatially, temporally and between laboratories conducting the analysis. Using the same laboratory maintained analytical consistency in this project, but average annual MBC readings still ranged from 52 to 175 mg C/kg in the 0-10 cm profile over the three years. Higher MBC levels found at 0-10 cm on the ORG and BD were expected, given the sensitivity of this measure to changes in soil management. While differences were also apparent at the 10-20 cm depth, they were small and inconsequential.

MBC is suggested by White (2010) as a reliable measure of soil health, despite sampling conditions potentially influencing results. Riches et al. (2013) reports MBC levels ranging from 20 – 700 mg C/kg, with factors such as compost addition raising levels considerably, which concurs with our findings. In a study of four Barossa Valley vineyards under different management systems, Rawnsley (2010) found most sites to have values below even moderate levels of 25-35 µg C/g soil (mg C/kg soil). Values in excess of 50 µg C/g soil were seen as high, which includes all treatments in this study. Without standardisation of sampling, the values achieved cannot be compared. However, within this project, as a comparison of management systems where neither sampling nor analytical technique varied, the outcomes again showed the improved soil health achievable both from the addition of compost under-vine and not using herbicides regularly for weed control. In a study of three different floor management systems at Wagga Wagga, Whitelaw-Weckert, et al. (2004) found reduced microbial diversity (cellulolytic bacteria, Pseudomonas spp. and fungi) from the herbicide (glyphosate, diquat, paraquat, carfentrazone-ethyl) treated soil, which may reduce their resistance and resilience to biotic and abiotic stress. No detriment was noted in vine function on the LCON and HCON treatments where herbicide was applied, indicating again the robust nature of the *Vitis* genus to growing in many different soil environments, most of which would not be recognised as ideal growing media.

Microbial respiration. Reganold (1993) as reported in White (2010), noted higher soil respiration on BD than conventional farms, while Reeve et al. (2005) found no differences in ORG versus BD viticultural systems. The increased respiration of the ORG and BD systems displayed in Table 6.4 mirror those of MBC, TOC and reported by Reganold and Reeve. They again reflect the improved capacity for soil microbes to function in the ORG and BD viticultural systems when compared to LCON and HCON systems. Whitelaw-Weckert et al. (2004) found it difficult to differentiate between the direct effect of the herbicide on the soil biota and the loss of living plant material. Given the findings of Haney et al. (2000), that microbial biomass was unaffected by glyphosate, and respiration was stimulated, it seems unlikely that the glyphosate used in this trial had a direct effect on the soil microbes. However, the lower MBC and microbial respiration of the LCON and HCON systems were instead the result of using herbicides to restrict plant growth in the under-vine zone. The lack of plants to provide an energy source for the microbes has apparently reduced their populations, biomass and activity.

Earthworms. The capacity of earthworms to improve the structure of degraded soil and contribute to soil quality is well recognised (Mele and Carter 1999). While it can be argued that earthworms are not a pre-requisite for good soil quality (Riches, et al. 2013) it may also be true that poor quality soil will not support a large earthworm population. Doube and Schmidt (1997) in Riches et al. (2013) believe that earthworms are of little use as soil quality indicators because their population responds to inputs of large quantities of organic matter in moist soils of near neutral pH. However, the differences in earthworm biomass and populations found between treatments in this experiment, which concur with other biological measures (TOC, microbial biomass, microbial respiration), would suggest they are an appropriate soil quality assessment tool when comparing management systems. Authors such as Paoletti et al. (1998) and DeVitter et al. (2014) have come to the same conclusion.

According to Law (2011) earthworm counts above 25 / m^2 suggest very good soil quality, a figure which was exceeded in all treatments over both years, but with a 9 fold increase on the ORG and BD systems, which had an average of 230 / m^2 over the two years of measurement. On the ORG and BD systems, tillage was used for weed control in late winter/early spring. Tillage with a mouldboard plough (silly plough) is performed at slow groundspeed and is a process of soil inversion rather than more aggressive stirring. As such it is unlikely to cause physical damage to the earthworms. The delayed weed control allowed plant growth under-vine to occur over the winter period. Observation showed the earthworms congregating within the fibrous grass roots, presumably feeding on sloughed roots, detritus and rhizosphere nutrients. By comparison, the weed-free under-vine zone of the conventional treatments did not provide the habitat to support a healthy earthworm population, an issue recognised by (Paoletti 1999). This finding is important when the intention is to improve soil quality in vineyards. While regular herbicide application to the under-vine zone is effective in preventing weed growth, it does potentially compromise soil quality including soil hardness, one of the likely criteria for soil health determination, based on the Cornell Soil Health Assessment as reported by (White 2010). Amelioration of hard soils, potentially using a combination of calcium and living or dead mulches is recommended by (Murray and Burk 2010). The benefits that earthworms may provide for improving water infiltration is recognised by Lal (1995), thus reducing the need for additional inputs to develop a porous soil.

Soil copper concentrations beyond 100-150 mg/kg are known to be toxic to earthworms (Paoletti 1999). In this experiment, copper usage was the same on all treatments so its impact, if any, will be relatively similar. The correlation between AMPA in the soil and the suppressed earthworm population would suggest glyphosate residues are affecting the soil fauna. Authors including Springett and Gray (1992) and Zaller, et al. (2014) recognise there are negative effects on earthworm growth/death rates and activity. Dalby, et al. (1995) attempted to replicate farmers' common field applications of pesticides, and found no adverse impact on the earthworm species commonly found in South Australian farmland. This work was supported by Mele and Carter (1999) who found no negative impact of herbicides (including glyphosate at double the recommended rates) on earthworm populations. It is therefore concluded that it was the herbicides very effective removal of plant growth (and habitat) under-vine that has suppressed the earthworm populations, rather than the direct effect of the herbicide on the earthworms.

6.5.6 Invertebrates

Of the mite and insect pests listed by Dunn and Zurbo (Dunn and Zurbo 2014), none was observed at any of the sampling times of this trial. Green habitat is recognised as being required for beneficial insects (Nicholls and Altieri 2000), but during the height of summer this did not exist in the trial vineyard. While some of the trapped invertebrates, such as the herbivorous thrips and fungus gnats, may be regarded as pest species in home gardens or horticultural crops, they are not a concern in vineyards. In this study, their numbers far outweighed those of the predators (thrips, lacewings, spiders) and predator/parasitoids (wasps) (see Table 6.10), but they were still of no apparent relevance to grapevine productivity.

When comparing the populations across treatments there was general lack of differences, possibly due to the lack of treatment differences. The mid-row ground cover was not manipulated for any of the treatments, so the resident winter / spring active vegetation across the whole trial site senesced prior to summer. As has been shown in previous work, invertebrate populations were influenced by the cover crop species growing in the mid-row (Danne, et al. 2010). In New Zealand, Scarratt, et al. (2004) used buckwheat (*Fagopyrum esculentum*) to effectively enhance populations of the Light Brown Apple Moth (LBAM) parasitising wasp, *Dolichogenidea tasmanica*, again showing the influence that mid-row cover crop species can have on invertebrate populations. The cover crops were not managed differently in this trial as the treatments mirrored what most producers in the area implemented. If it was thought necessary to introduce increased biodiversity and thereby natural LBAM control agents, then a change in the species mix growing on the vineyard floor would be necessary. The only differences in floor management were the under-vine treatments. Counter-intuitively, the HCON and LCON treatments with less groundcover also led to the capture of more detritivores, omnivores and predators in the pitfall traps. Possibly the lack of habitat caused them to search further for food, where they succumbed to the trap. If that was the case, they may not have been in greater numbers, but were more readily captured. Alternatively, the rough terrain caused by tillage in the ORG and BD treatments possibly reduced traffic across the ground and the likelihood of insects falling in the traps. Compost application favoured omnivores, predator/parasites and predators. It could also be argued that the compost hosted more saprophage and detritivores (Sparks, K. pers. comm), which led in turn to their grazing by omnivores, predators/parasites and predators.

6.5.7 Financial Analysis

The reasons for entering into organic production systems are numerous, but for some growers, financial returns are an important driver. The financial outcomes from this long-term trial would suggest that by using the practices employed in this project and in that particular grape growing region, less money will be generated for the grower than a LCON or HCON system. The reasons for this are two-fold – lower incomes through reduced yield, and higher costs resulting from mechanical weed control. In some instances the reduced yield can improve fruit quality (Wheeler and Crisp 2009) and possibly generate better prices. A premium price for certified ORG or BD fruit is also possible, but as they are not reliably achieved it was not included in this analysis. Corsi and Strom (2012) for example in Italy found no overall premium being paid for organic wine, but there was a large range (0.8 – 21 euros/L) suggesting premiums were being realised by some producers. Delmas and Grant

(2014) however found there could be substantial price benefits from wine labelled certified organic or biodynamic.

In this case, if premium prices were available, they would need to be in the order of 54% ($1959/t cf. $1271/t) for the BD system and 37% (ORG) to return the same gross margins as the HCON system. However, if the LCON system is taken as standard practice in the region, the premiums required are reduced to 40% ($1779) for the BD system and 23% ($1559) for the ORG system to equate with growers using conventional practices. With premiums of up to 100% in some regions, the required amount is potentially achievable, but supply, demand and the fruit quality will ultimately drive the final price achieved. Where vertical integration enables value adding on the wine, either as “wine made from organic grapes” or as organic wine, a premium may also be realised but this is also not guaranteed.

Alternatively, costs can be reduced and/or yields increased to improve the gross margin. As noted earlier, given the apparent importance of a soil profile at field capacity during budburst, supplying the vines with supplementary irrigation at this time is likely to increase grape yields. However, this may not be necessary if sheep are introduced to the system and water use is thereby reduced over winter/ early spring through reduced weed growth. The use of sheep is unlikely to reduce weed control costs, because cultivation would still be required in spring, but it may increase gross margins by improving yield without the need for increased irrigations.

6.6 Conclusions

The production of wine grapes using organic and biodynamic practices was investigated over a six year period in a large scale field trial at McLaren Vale. They were compared with a low-input system aiming to mimic the conventional practice now implemented in the area, and a high input system as previously used by many growers. The last three years of the project assessed systems that were through their conversion period and in a commercial vineyard would have enabled organic and biodynamic fruit to be sold as certified products.

The project aimed to compare the four systems for a range of sustainability criteria including their impacts on the soil, fruit production, its quality, invertebrate populations and financial returns. While soil chemistry was not affected, the biology did improve on the alternative systems. The reason for this is believed to be due to the growth of plants under the vines where herbicides are not used enhancing the earthworm populations and soil microbial biomass and their activity. Improvements in soil quality did come at some cost however, as reduced soil moisture levels in the top 40 cm reduced bunch numbers, vine vigour and ultimately fruit yield. It also impacted on the potential financial returns that would be realised in a commercial vineyard. The use of herbicides to control under-vine growth, from a financial perspective, is more cost-effective than mechanical control. The combination of higher costs and lower yields reduced the financial returns to the organic and biodynamic systems, but this was in the absence of a premium for the fruit, which growers can often obtain.

As with any comparison of agricultural systems, there are many permutations which could be examined. All of the treatments could have been implemented differently, which may have generated results differing from those obtained in this trial. A trial implemented the same way in a different region may also have quite different results. However, the outcomes generated in this project will provide the viticultural industry with empirical evidence for the potential impacts that occur when adopting an organic or biodynamic viticultural system.

7. Organic and biodynamic management effects on sensory attributes and wine quality

7.1 Abstract

Berry and wine compositional analysis was performed on all wines made from management treatments in 2012, 2013 and 2014. Viticulturists and winemakers from the McLaren Vale region then assessed these wines and provided descriptors for each. This information was then subjected to word frequency analysis and ANOVA to determine whether certain descriptors were used more or less frequently for particular wines. Compost had no significant effect on berry, wine and sensory analysis in any of the three years. Only seasonal differences in berry composition were found between treatments. There were no consistent differences in pH, TA or alcohol between treatments. Total anthocyanin and phenolic levels were higher in HCON treatments in most seasons. In all three seasons ORG and in particular BD wines were described as being more rich, textural, complex and vibrant than LCON and HCON wines. These findings support anecdotal evidence from winemakers who have used this language as a reason why they have chosen to make wine from organically and/or biodynamically managed fruit. How wine compositional changes relate to the textural changes perceived by winemakers in the wines made from these systems is yet to be determined.

7.2 Introduction

Organic and biodynamic viticulture are gaining popularity, driven by both producers and consumers and the perception that these management systems produce higher quality wines. However to date very little scientific literature exists on the influence of organic and biodynamic management on wine quality.

The composition of soluble solids, organic acids and pH in the berries and wine has long been used in the evaluation of wine grape quality (Jackson and Lombard 1993). Maturity, quantity and distribution in the berry have an impact on these measures which also influences the style and quality of the wine (Olarte Mantilla et al. 2012). Defining wine quality is complex and dependant on whether the definition is from a technical, production or consumer viewpoint (Verdu Jover et al. 2004). Some technical methods require sophisticated and expensive instruments for chemical analysis to which few wineries have access or the time to make such analyses (Olarte Mantilla et al., 2012). Descriptive analysis (DA) is an example of a technique which aims to identify significant sensory differences between products or samples by defining and quantifying the intensity of various grape and wine attributes (Heymann and Noble 1987, Olarte Mantilla et al. 2012). This technique involves sourcing available and interested panellists of varying age and gender to participate and can be expensive; +$20,000 for a three month project (Dr. Susan Bastian pers. comm). The monetary costs associated with these types of methods method can be prohibitive to commercial wineries that perhaps lack the time, skills and software to perform such rigorous tests (Lawless and Heymann 2010, Murray et al. 2001). For these reasons researchers are also looking at other more cost effective methods for assessing wine quality.

The aim of this research was to assess the effect of management systems on wine quality using grape and wine chemical composition and sensory attributes of wines made from the treatments. To assess differences in wine sensory attributes, a novel sensory analysis technique has been developed during this project and uses word frequency data generated from expert industry panels.

7.3 Materials and Methods

7.3.1 Berry, juice and wine composition analysis

A 100 berry sample was taken to determine and average berry weight, total soluble solids (TSS), pH, titratable acidity (TA), yeast available nitrogen (YAN), total anthocyanins and total phenolics. The level of total soluble solids was measured as °Brix using a DMA 35N Density Meter (Anton Paar GmbH, Austria). Titratable acidity (TA) and pH were measured using a Crison Compact Titrator 08328 Alella (Crison, Spain), with TA measured by titration to pH 8.2 (Iland et al. 2004). Yeast Available Nitrogen (YAN) was calculated from a measurement of Primary Amino Acid Nitrogen (PAAN) and Ammonia Nitrogen (AN) using enzymatic kits (Vintessential, Australia). Total anthocyanins and total phenolics were obtained using a modified spectrophotometry method described by Iland et al. (2004). Fifty berries from the 100 berry sample were homogenised using a CAT X620 Homogeniser (Ingenieurbüro M. Zipperer GmbH, Germany). Centrifugation was performed in a Hettich D-7200 Tuttingen centrifuge (Hettich Universal, Germany). A Metertech SP-830 Plus spectrophotometer (Metertech, Taiwan) was used to analyse absorbance at 280 nm and 520 nm.

One-hundred berries from all treatments and replicates were randomly collected at harvest and crushed for juice elemental analysis. Samples were analysed according to the method of Wheal et.al (2011), but nitrogen was not determined.

Standard chemical measurements (SO_2 (ppm), pH, TA (g/L), volatile acidity (g/L), alcohol (%) and residual sugar (g/L)) were performed on the wines at the time of sensory evaluation, following the methodologies described in Iland et al. (2004). Wine samples were analysed for density (au), hue, total anthocyanins (mg/L), and total phenolics (au) as described by Iland et al. (2004) and modified for use with 96-well ultraviolet transparent microtitre plates (Greiner, Sigma-Aldrich, Sydney Australia). Wine samples (50 µL) for total anthocyanins and total phenolics determinations were added to 1 M HCl (5 mL) and incubated for a minimum of three hours at room temperature before aliquots (300 µL) were transferred to 96-well microtitre plates and read at 520 nm (total anthocyanins) and 280 nm (total phenolics) using a Quant Microplate spectrophotometer (Thermo Scientific Multiskan Spectrum, USA). Density and hue were calculated from absorbance values of neat wine (150 µL aliquots in 96-well microtitre plates) read at 420 nm and 520 nm.

7.3.2 Winemaking

Once grapes were harvested, weighed and recorded, an equal amount of grapes from the four field replicates were taken and pooled, creating three winemaking replicates of each management system. Cabernet Sauvignon grapes were harvested by hand between 23-24 °Brix depending on the season and each treatment pooled into three 30 kg replicates for winemaking. Each winemaking replicate was comprised of randomly selected bunches of each treatment. A crusher/destemmer (Enoitalia, ENO-15, Italy) was used to process each replicate and juice/must pumped directly into 30 L food grade plastic open fermenters with screw top lids (Winequip products, Magill, South Australia). During crushing 50 mg/L of sulphur dioxide (SO_2) was added as a 20 % solution of potassium metabisulphite (PMS) to all the sampling units. Each ferment was then co-inoculated with 25 g/hL reconstituted dried yeast (Maurivin® AWRI 796, Mauri Yeast Australia, Sydney, Australia). Diammonium phosphate (0.5 g/L) was also added at the time of yeast inoculation when the ferments were between 18-20^{o}C. Once alcoholic fermentation began, wines were co-inoculated with *Oenococcus oeni* VP41 LAB (Lallemand, Underdale, Australia) at 0.2 g/20L to induce malolactic fermentation (MLF). No acid additions were made to the ferments prior to yeast inoculation.

All fermentations were maintained at 18°C ± 2°C and the cap manually plunged every 12 hours for a period of 9 days or until fermentations had reached 2˚ Baume. Wines were pressed using a bladder press (Diemme 130 L Laboratory Press, JB Macmahon Pty Ltd, Forestville, Australia) operated using the following protocol; 0.2, 0.4, 0.6, 0.8 and 1 bar each held for five minutes. The wine was transferred to 10L glass demijohns (Winequip products, Magill, South Australia) and stored at 20°C. SO_2 (to reach 80ppm Total SO_2) additions were made to ferments that had completed malolactic fermentation (<0.05 g/L malic acid by enzymatic test kit (Roche, Castle Hill, Australia)). Finished wines were filtered using a pad filter (Colombo-Rover pump & 6 pad filter, Italy) provided with 0.8 µm Z6 cellulose filters pads (Ekwip, NSW, Australia) and bottled into 375 mL bottles with screw cap closures. The wines were then stored at a constant temperature of 16^{o}C for later wine sensory and chemical evaluations.

7.3.3 Sensory evaluation

In 2012, 2013 and 2014 wines made from 2011/12, 2012/13 and 2013/14 were evaluated by wine experts from the McLaren Vale Wine Region, South Australia. Wine experts noted descriptors of aromas and palate, and scored wines using a 20-point scale. Experts were aged between 31-50 in 2012, 30-67 in 2013 and 29-68 in 2014 and comprised winemakers, viticulturists and wine marketers with between two and 40 years of industry experience.

For all three sensory evaluation sessions, experts analysed four brackets of wines, each bracket consisting of six wines, totalling 24 wines. Thirty mL of each wine was served in coded, INAO (ISO standard) 215 mL tasting glasses (Arcoroc Viticole, Cardinal International, France). Wines were given a three digit code (generated using Design Express®, Version 1.6, Qi Statistics, United Kingdom), and randomised within the bracket for each expert. This was carried out to prevent first order carry-over effects (Macfie et al. 1989). Experts were required to have a break of at least five minutes between brackets. To avoid palate fatigue and to cleanse their palate, the assessors were provided with filtered water and plain water crackers (Arnotts®, Australia) to have between wine samples.

Each wine was firstly assessed using the Australian wine show standards twenty point score system (Ewart et al. 1993, Dunphy and Lockshin, 1998). Briefly, three points were awarded for colour, seven points for aroma and ten points for palate. Judges were then asked to provide a written description of attributes that best describe the wine. All attributes and final wine quality scores used by each judge for every wine were then entered into Excel (Microsoft Excel (Version 2011), Redmond, Washington, USA). Where similar terms for certain attributes were used these were grouped together. The final lists of attributes from all judges for every wine were then imported from Excel into Nvivo 10 (Version 10, QSR International, Victoria, Australia). Nvivo 10 was then used to count the number of times a particular word was used to describe each wine by all judges. This count was then compared to the total number of judges that assessed the wines to give a proportion of use by the panel of judges for each individual wine. For a word to be considered in the final analysis at least 40% of judges must have used the word to describe at least one of the wines.

7.3.4 Statistical analysis

Berry, juice and wine data was analysed using a repeated measures analysis of variance (GenStat® for Windows 15.0, VSN International Limited, United Kingdom). The least significant difference test was used ($P<0.05$) to determine significant differences between treatments, seasons and compost at a given sampling time. ANOVA was also performed on all sensory attribute word frequency data generated from wine evaluations using XLSTAT Version 2012 1.01 (Addinsoft SARL, France). Attributes that were significantly different between treatments were then subjected to principal component analysis (PCA) using XLSTAT Version 2012 1.01 (Addinsoft SARL, France) and presented as biplots. Details of individual analyses are provided in the text or captions.

7.4 Results and Discussion

Berry and wine compositional analysis was performed on berries, juice and wines from all treatment replicates. The main quality parameters measured in the literature included soluble solids, organic acids and pH, colour, phenolics and tannins (Bindon et al. 2008, Bindon et al. 2011, Cirami et al. 1984, Downton 1977, Gawel et al. 2000, Jackson and Lombard 1993, Matthews et al. 1990, Ough et al. 1968, Roby et al. 2004, van Leeuwin et al. 2004, Walker and Blackmore 2012). None of the berry compositional measures in this study revealed any differences between treatments; unsurprisingly only seasonal differences were observed (Table 7.1). This observation was also found in the study by Reeve et al. (2005) when they compared ORG and BD management systems. Wine compositional differences were observed but were inconclusive as seen by Vian et al. (2006). Alcohol, pH and TA differences were found between management treatments but no consistent pattern was observed (Table 7.2). Total anthocyanin and phenolic levels and colour density in the wine were significantly higher in HCON treatments compared to ORG, BD and LCON in 2013 and 2014. Compost had no significant effect on composition (data not shown).

Significant differences in descriptors used by viticulturists and winemakers to describe wines made from fruit produced under the different management systems were observed in 2012, 2013 and 2014 (Figures 7.1-7.3). Consistently ORG and BD treatment wines were described more often as being rich, complex, vibrant, balanced and textural compared to LCON and HCON treatment wines. LCON and HCON wines were also described more frequently as green and unripe compared to ORG and BD. In 2013 and 2014 ORG and BD were more often described as having black fruit and red fruit character. LCON wines in 2012 were also described more as earthy.

Table 7.1 Effects of organic, biodynamic, low-input conventional and high-input conventional management on berry compositional analysis in the 2012, 2013 and 2014 growing seasons, McLaren Vale, Australia.

Variable	Season	Treatment				Season mean	5% LSD	*P*-value
		ORG	BD	LCON	HCON			
	2012	24.3	24.3	24.2	24.0	**24.2** [a]	ns (T)	ns (T)
Total Soluble Solids (TSS)	2013	23.2	23.2	23.8	23.8	**23.5** [b]	0.53 (S)	<.001 (S)
	2014	22.9	23.0	23.0	22.9	**23.0** [c]	ns (T*S)	ns (T*S)
	Treatment mean	**23.5**	**23.5**	**23.7**	**23.6**			
	2012	5.7	5.7	5.9	6.1	**5.8** [b]	ns (T)	ns (T)
Titratable Acidity (TA)	2013	3.1	3.4	2.9	2.8	**3.1** [c]	0.35 (S)	<.001 (S)
	2014	7.3	7.0	7.1	7.1	**7.124**[a]	ns (T*S)	ns (T*S)
	Treatment mean	**5.4**	**5.3**	**5.3**	**5.3**			
	2012	3.39	3.41	3.37	3.35	**3.38** [c]	ns (T)	ns (T)
pH	2013	3.97	3.95	3.96	3.85	**3.93** [b]	0.059 (S)	<.001 (S)
	2014	3.95	4.09	4.08	4.01	**4.03** [a]	ns (T*S)	ns (T*S)
	Treatment mean	**3.77**	**3.82**	**3.80**	**3.74**			
Anthocyanin	2012	0.78	0.83	0.71	0.73	**0.76** [b]	ns (T)	ns (T)
per g berry weight (mg/L)	2013	1.23	1.23	1.15	1.26	**1.22** [a]	0.106 (S)	<.001 (S)
	2014	0.79	0.82	0.86	0.82	**0.82** [b]	ns (T*S)	ns (T*S)
	Treatment mean	**0.93**	**0.96**	**0.91**	**0.93**			
Phenolics	2012	0.78	0.83	0.73	0.73	**0.77** [b]	ns (T)	ns (T)
per g berry weight (mg/L)	2013	1.43	1.42	1.33	1.39	**1.39** [a]	0.106 (S)	<.001 (S)
	2014	0.87	0.89	0.91	0.88	**0.89** [b]	ns (T*S)	ns (T*S)
	Treatment mean	**1.02**	**1.05**	**0.99**	**1.00**			

Table 7.2 Effects of organic, biodynamic, low-input conventional and high-input conventional management on wine compositional analysis in the 2012, 2013 and 2014 growing seasons, McLaren Vale, Australia.

Variable	Season	Treatment				Season	5% LSD	*P*-value
		ORG	BD	LCON	HCON	mean		
	2012	14.7 [a]	14.8 [a]	14.9 [a]	14.7 [a]	**14.8**	0.13 (T)	<.001 (T)
Alchohol %	2013	13.9 [bc]	13.5 [c]	14.2 [b]	14.8 [a]	**14.1**	0.20 (S)	<.001 (S)
	2014	13.3 [c]	13.3 [c]	13.6 [c]	13.7 [c]	**13.5**	0.35 (T*S)	0.003 (T*S)
	Treatment mean	**14.0**	**13.9**	**14.3**	**14.4**			
	2012	3.68 [c]	3.68 [c]	3.66 [c]	3.67 [c]	**3.67**	0.013 (T)	<.001 (T)
pH	2013	3.70 [b]	3.77 [a]	3.77 [a]	3.70 [b]	**3.74**	0.014 (S)	<.001 (S)
	2014	3.67 [c]	3.68 [c]	3.68 [c]	3.60 [d]	**3.65**	0.026 (T*S)	<.001 (T*S)
	Treatment mean	**3.65**	**3.69**	**3.70**	**3.71**			
	2012	8.1 [cd]	8.0 [cd]	8.3 [b]	8.1 [cd]	**8.1**	0.15 (T)	0.016 (T)
TA	2013	8.1 [d]	8.0 [d]	7.9 [d]	7.8 [d]	**7.9**	0.09 (S)	<.001 (S)
	2014	11.8 [a]	11.6 [ab]	11.2 [b]	11.3 [b]	**11.5**	0.20 (T*S)	<.001 (T*S)
	Treatment mean	**9.3**	**9.2**	**9.1**	**9.1**			
Total Anthocyanins (mg/L)	2012	357 [a]	364 [a]	375 [a]	365 [a]	**365**	19.6 (T)	0.002 (T)
	2013	307 [b]	306 [b]	294 [bc]	375 [a]	**321**	18.8 (S)	<.001 (S)
	2014	228 [c]	232 [c]	241 [c]	271 [bc]	**243**	ns (T*S)	ns (T*S)
	Treatment mean	**297**	**301**	**303**	**337**			
	2012	54 [a]	54 [a]	52 [a]	47 [b]	**52**	ns (T)	ns (T)
Total Phenolics (mg/L)	2013	48 [b]	47 [b]	47 [b]	52 [a]	**48**	1.4 (S)	<.001 (S)
	2014	29 [d]	31 [d]	28 [d]	32 [cd]	**30**	2.7 (T*S)	<.001 (T*S)
	Treatment mean	**44**	**44**	**43**	**44**			
Colour Density (au)	2012	9.9 [c]	10.5 [b]	9.5 [c]	9.0 [cd]	**9.7**	0.28 (T)	0.002 (T)
	2013	11.5 [a]	11.7 [a]	11.2 [ab]	12.2 [a]	**11.6**	0.39 (S)	<.001 (S)
	2014	7.8 [d]	8.5 [d]	8.4 [d]	9.2 [c]	**8.5**	0.68 (T*S)	0.002 (T*S)
	Treatment mean	**9.7**	**10.2**	**9.7**	**10.1**			
	2012	0.75 [ab]	0.77 [a]	0.74 [ab]	0.74 [ab]	**0.75**	0.010 (T)	0.023 (T)
Hue (no units)	2013	0.67 [c]	0.70 [b]	0.71 [b]	0.67 [c]	**0.69**	0.008 (S)	<.001 (S)
	2014	0.74 [ab]	0.73 [b]	0.74 [ab]	0.74 [ab]	**0.74**	0.017 (T*S)	<.001 (T*S)
	Treatment mean	**0.72**	**0.72**	**0.73**	**0.73**			

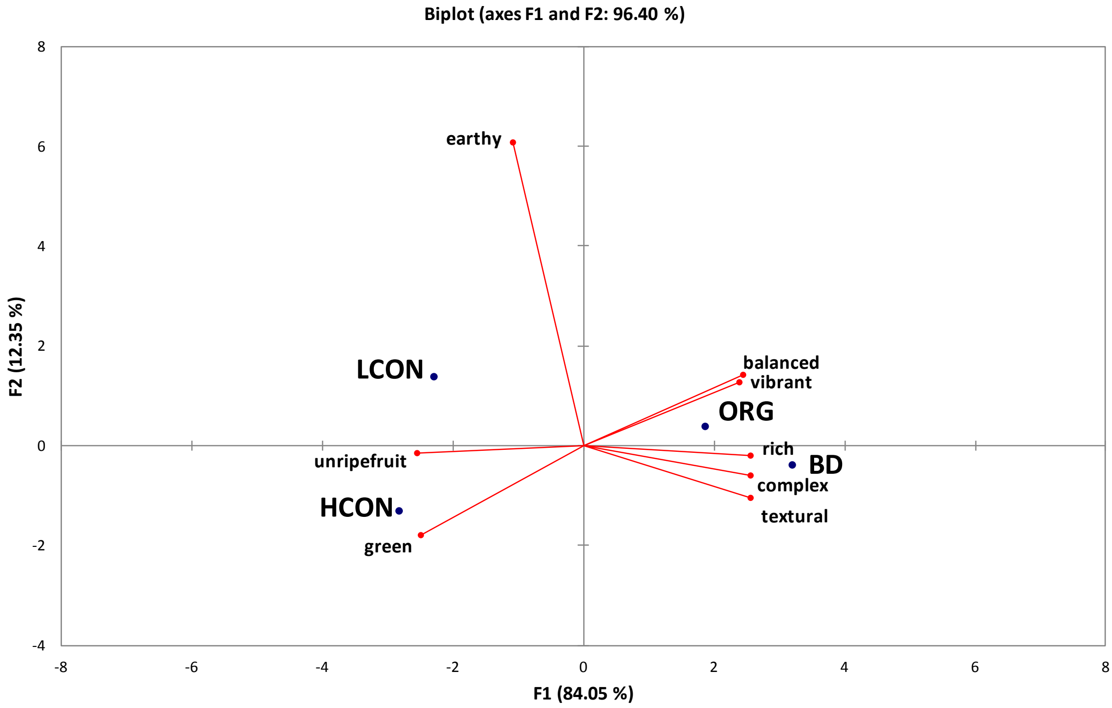

Figure 7.1 Principal component analysis of sensory data for 2012 wines from organic (ORG), biodynamic (BD), low-input conventional (LCON) and high-input conventional (HCON).

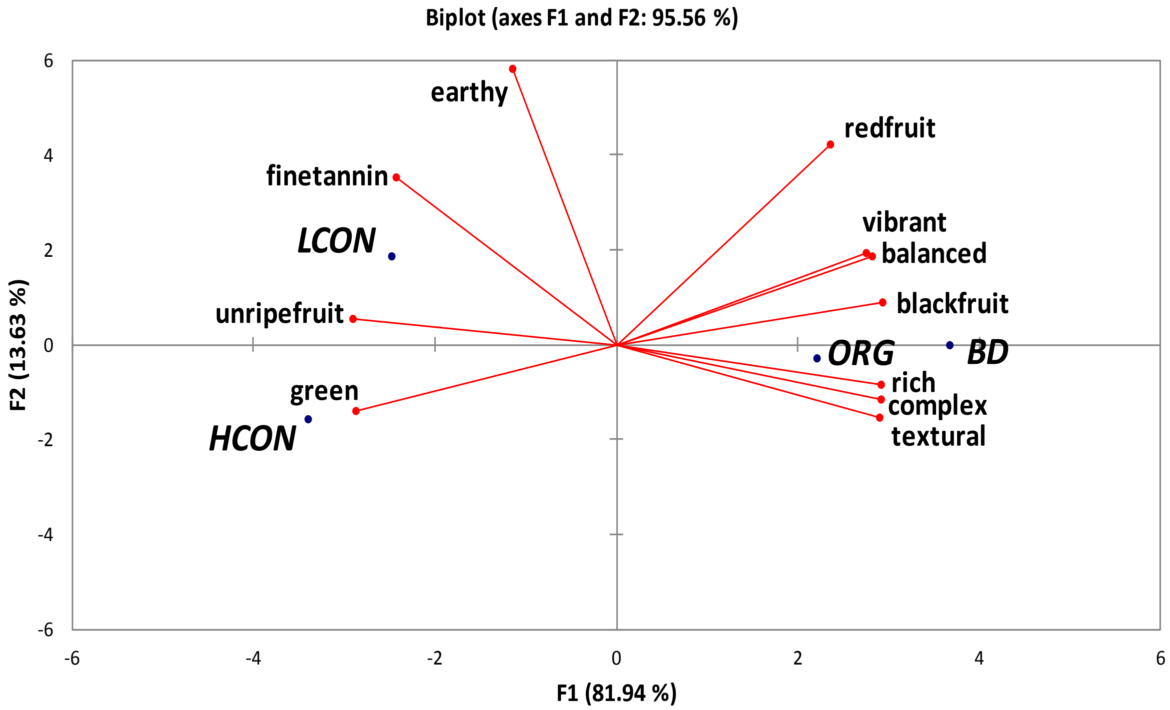

Figure 7.2 Principal component analysis of sensory data for 2013 wines from organic (ORG), biodynamic (BD), low-input conventional (LCON) and high-input conventional (HCON).

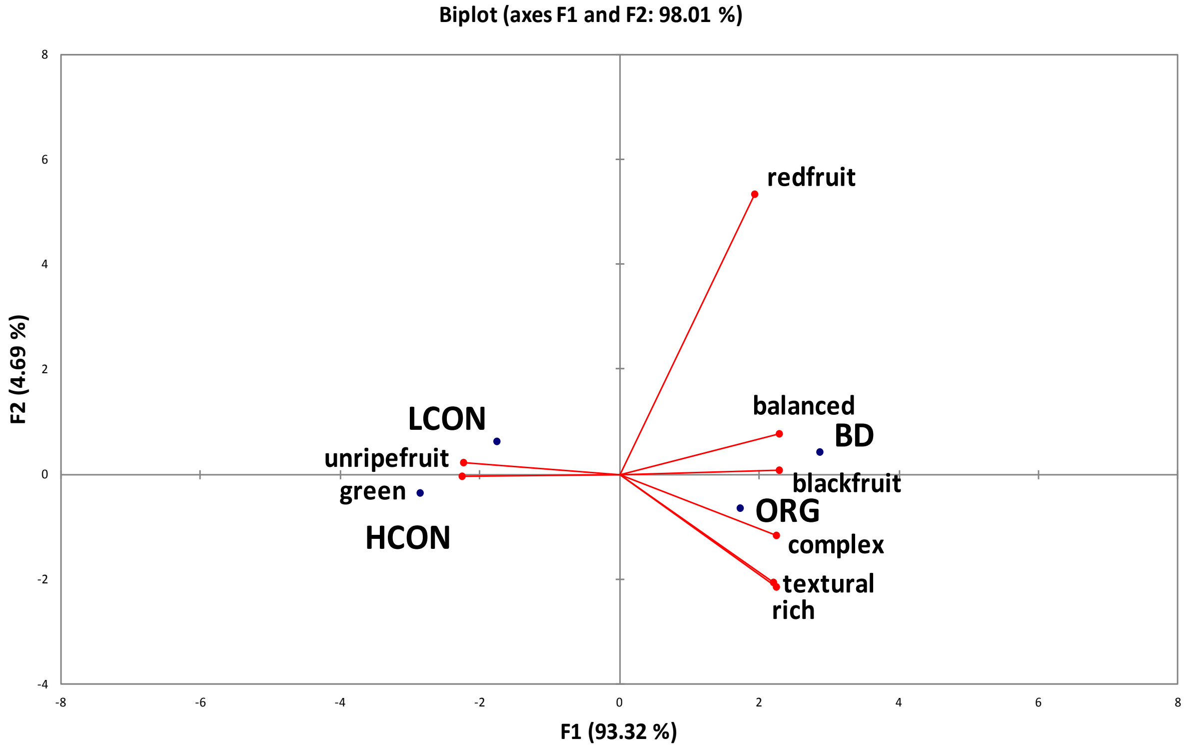

Figure 7.3 Principal component analysis of sensory data for 2014 wines from organic (ORG), biodynamic (BD), low-input conventional (LCON) and high-input conventional (HCON).

There has been much advancement in berry and wine sensory techniques, which have been made possible through the use of various statistical models and techniques (Cadot et al. 2010, Johnson et al. 2013, King et al. 2011, Olarte Mantilla et al. 2012, Perrin et al. 2005, Siegrist and Cousin 2009, Verdu Jover et al. 2004). However, one of the limitations to many of these methods is the cost and time required to perform the analysis. This project did not have the budget to undertake a descriptive analysis on the wines made during the project. This led to the development of the method described above which as shown can discriminate between wines made from fruit grown using different management practices. While not as informative as more traditional methods like descriptive analysis this method has the potential to be used as a screening tool to determine if any differences are perceived between wines before investment is made in more costly and time consuming methods.

7.5 Conclusion

These findings support previous research that found that our more traditional measures of quality did not reveal differences between alternative and conventional management treatments. The sensory evaluations made during this study also potentially support anecdotal evidence that ORG and BD management can improve certain wine sensory attributes and this should be explored further. This method of assessing wines has the potential to more cost-effectively assess experimental wines before undertaking more detailed sensory analysis.

8. Outcome/Conclusions

Field trials can be fraught with problems, often beyond the researcher's control. Weather, pests, diseases, inadvertent activity and personnel issues can all impact on the correct implementation of a field trial. In this case, we had excellent cooperation from the owners/managers/staff at Gemtree Vineyards, who respected the nature of research and the integrity of the trial site and the treatments within, which were implemented to a high standard.

Writing of scientific papers is now in progress and media releases and Innovators' Network fact sheets will also be extracted from this report. The need for further extension to industry is well recognised by the key personnel, so this will occur during 2015.

Meeting of project objectives

- *To assess the long term impacts of organic, biodynamic and conventional viticultural systems on soil health, vine productivity and wine quality.*

A comprehensive systems based assessment of the four viticultural systems was methodically and efficiently carried out.

- *To develop management practices which enhance sustainable viticultural systems including the adoption of organic and biodynamic viticulture.*

New management systems were not developed, but a much better understanding of the issues surrounding the management constraints of organic and biodynamic viticulture have now been formalised. The problems of under-vine weed control for conventional and organic growers are now being addressed in a new AGWA-funded project being conducted by the CI.

- *To provide a trial site that accommodates the needs of the vineyard owners, post-graduate students and researchers.*

The trial site provided the base for one PhD (Luke Johnston), two Masters (Ben Pike and Paula Chodin Param) and one Honours student (Chris Coffey). This was managed with minimal impact on the vineyard owners who continued to conduct their commercial operation.

- *To liaise with grapegrowers, industry suppliers and winemakers to ensure the success of the project.*

Awareness of the project led to numerous invitations by regional groups to present findings form the research being conducted (see Presentations). Feedback gained from these and other informal conversations was always valued by the research personnel.

- *To provide the grapegrowing industry with the information required to make informed decisions regarding preferred management systems.*

This comparison of management systems is one of the few conducted globally, and along with Geisenheim University, one of the most comprehensive. It will provide the grapegrowing industry with both practical information and strong empirical data on the impacts of the various management practices on the sustainability of their operation.

The Australian viticulture and wine industry is highly innovative and responsive to demands of the marketplace. It has transitioned from producing large tonnages to quality fruit and now to a consumer driven environmental focus. Organic and biodynamic production still only represents a small portion of total production. However, the existence of credible organic and biodynamic practitioners and researchers in the field means their influence extends strongly into conventional practice. As the industry constantly strives to improve its environmental performance, the adoption of practices previously only used by organic growers steadily becomes standard conventional practice.

Identifying direct benefits to growers that were generated by the project is difficult. Common feedback from presentations to growers is that if just one little piece of information that they believe will improve their operation has been provided at the forum, this may have substantial ramifications over the long term.

Important learnings from this research are:

- Growers should not enter into growing organically with the expectation of substantial financial reward without doing lots of background research first. Nature does place obstacles in the way of a smooth transition to an organic system which can increase the risk if the tools are not available to deal with the problem. For example, weeds can be an issue, but with heavy mulching or mechanical devices they can generally be dealt with, albeit at a cost. Premiums may not always be available to counter the higher costs of production, but demand is presently strong enough that growers should always have a market for quality certified grapes.

- Organic and biodynamic wines were consistently and more frequently described in winemaker tastings as being more complex, textural, rich and vibrant compared to the conventional wines. This validates the belief of some growers that producing organically was the only way to achieve the fruit quality they required. The combination of environmental and quality benefits ascribed to the organic and biodynamic production systems legitimises their stake as valid viticultural production systems for much of southern Australia.

9. Key Recommendations

Recognition that research into organic practices can have considerable benefit to the wider industry sector, and not just organic growers, is critical to the advancement of environmental best practice in Australian viticulture. Weed control in conventional systems has issues of chemical resistance, and as highlighted in this project, compromised soil quality. Non-chemical weed management systems are often of poor efficacy and high cost. Floor management research needs to continue so it can ultimately provide practitioners at both ends of the chemical input spectrum with improved systems of management.

Pursuing research consistent with "Environmental Best Practice" is critical to maintaining consumer confidence and market share in an increasingly discerning marketplace. Disease resistance, alternatives to sulphur, copper and synthetic fungicides and weed management alternatives to herbicides are obvious areas of research, as they account for the main sources of chemical input. Alternatives do not necessarily mean another product though, as these are usually very expensive to develop. Cultural practices employed by some growers already, and others yet to be developed, may provide answers to some of the problems.

Research on market signals is also essential to growers, particularly where large decisions such as changing management practice are concerned. Is the market for organic fruit large enough to sustain a dramatic increase in tonnage produced, and will prices be sustained if that occurs? Such market intelligence could have a significant impact on the uptake or otherwise of organic systems.

Appendix 1: Communication

Articles in scientific and industry journals regarding various aspects of the project have been published (see below). Some of this work has also been presented at the Australian Wine Industry Technical Conference as well as other national and international meetings, workshops and conferences. In addition, a Research to Practice module summarising the current state of knowledge on organic and biodynamic viticulture has been written of which some of the content has been based on this work (see below). The interest from many regions in low-input and/or organic and biodynamic practices is displayed in the numerous presentations made at the invitation of the regional groups.

During this project we have had the support and interest of a number of industry individuals and companies. In particular, we have been involved in discussions with grape growers and winemakers in the McLaren Vale, Adelaide Hills, and Barossa Valley regions. Both the proposed research and the results of each season's work and its potential for the industry have been discussed. Discussions and presentations to key personnel in other regions have also occurred. The feedback we have received has been useful in guiding and refining our experimental design and research direction. We will continue to engage the industry as we progress this work.

Industry and Scientific Presentations

Collins, C. (2014) A comparison trial of Organic, Biodynamic and Conventional Viticulture in Australia. AWRI Webinar Seminar Series.

Penfold, C., Collins, C., Johnston, L., Marschner, P., Bastian, S. (2014) The Gemtree Trial – Organic, Biodynamic and Conventional Viticultural Systems Compared. Gemtree cellar door, September 2014

Penfold, C. (2014) Non-chemical weed control options. Groundsprayers conference, Glenelg, July 2014.

Penfold, C. (2013) Low input viticulture and soil management. Stanthorpe, 19 June 2013

Johnston, L. Australian Wine Industry Technical Conference Organic Viticulture" workshop, Sydney, 13 July 2013

Penfold, C. (2013) From the ground up – less may be best "weed" management practice. Griffith, December 2013

Penfold, C. Collins, C. (2013) Organic viticulture. Ararat, July 2013

Penfold, C. (2013) From the ground up – less may be best "weed" management practice. Clare, September 2013

Johnston, L. Comparing organic/biodynamic/conventional viticulture. Western Australian Wine Industry, Swan Valley, Margaret River, Denmark, 28-30 May 2012

Johnston, L. 8th International Cool Climate Symposium, Building vineyard biodiversity for improved wine quality and business profitability, Hobart, 3 February 2012

Penfold, C. (2012) From the ground up – less may be best management practice. Mornington Peninsula, 14 August 2012

Penfold, C. (2012) From the ground up – less may be best management practice. Tumbarumba, 6 September 2012

Penfold, C. (2012) Vineyard floor management, Lecture to Waite students, September 2012/13/14

Penfold, C., Collins, C., Johnston, L. Marschner, P., Bastian, S. (2012) Organic, biodynamic and conventional viticulture compared – the Gemtree trial, Coonawarra Cabernet Symposium, 18 October 2012

Johnston, L. Conventional, organic and biodynamic vineyard management: Effects on soil properties, vine physiology, grape and wine quality, Managing Winery Residues for Economic and Environmental Gain, d'Arenberg Winery, 24 November 2011

Johnston, L. Conventional, organic and biodynamic vineyard management: Effects on soil properties, vine physiology, grape and wine quality. Growers' Field Day, McLaren Vale, 11 November 2011

Johnston, L. Conventional, organic and biodynamic vineyard management: Effects on soil properties, vine physiology, grape and wine quality Charles Sturt University, Wagga Wagga, 5 October 2011

Johnston, L. Conventional, organic and biodynamic vineyard management: Effects on soil properties, vine physiology, grape and wine quality. University of Adelaide "Crush" Conference, Adelaide, 30 September 2011

Collins, C. and Kaur, R (2011) Organic management below the ground. ASVO seminar "Below Ground Management for Quality and Productivity" 28-29 July, Mildura, Australia.

Johnston L. Soil survey: comparison of 'organic' and 'conventional' viticulture ASVO seminar (2011) "Below Ground Management for Quality and Productivity" 28-29 July 2011 Mildura, Australia.

Johnston, L. Mornington Peninsula Vignerons Association, Moorooduc Estate, 14 January 2010

Johnston, L. Australian Wine Industry Technical Conference Organic Viticulture" workshop, Adelaide, 3–8 July 2010.

Poster Presentations at Conferences

Pike, B.P.A., Scott, E. S., Penfold, C. and C. Collins (2014) Effect of organic, biodynamic and conventional vineyard management inputs on grapevine powdery mildew. 7th International Grapevine Downy and Powdery Mildew workshop, 30 June – 4 July, Vitoria-Gasteiz, Spain.

Pike, B.P.A., Scott, E.S., Penfold, C. and Collins, C. (2013) The effect of organic, biodynamic and conventional vineyard management inputs on growth and susceptibility of grapevines to Botrytis bunch rot and Powdery mildew. 15th Australian Wine Technical Conference, 13–18 July, Sydney, Australia.

Collins, C., Johnston, L., Penfold, C., Bastian, S., Marschner, P. (2013) A comparison trial of Organic, Biodynamic and Conventional Viticulture in Australia. 18th International GiESCO Symposium, 7-13 July 2013, Porto, Portugal.

Johnston, L., Marschner, P., Penfold C. and Collins, C. (2010) Conventional, organic and biodynamic management: Effects on soil properties, vine physiology and grape and wine quality. 14th Australian Wine Technical Conference, 3-8 July 2010, Adelaide, Australia.

Johnston, L, Marschner, P, Penfold C and Collins, C. Conventional, organic and biodynamic management: Effects on soil properties, vine physiology and wine grape quality. University of Adelaide Research Day, 2008.

Workshops

Penfold, C. Managing weeds organically; Biodiversity enhancement and ground cover management in vineyards; From the ground up – less may be best management practice; Organic viticulture; Low input viticulture; Mid-row soil management and soil health. Oxley, Victoria, 4 December 2012.

Journal Articles

Penfold, C., Johnston, L., Brown, M., Marschner, P., Bastian, S., and Collins, C. (2013) Comparing organic, biodynamic and conventional vineyard management. Australian and New Zealand Grapegrower and Winemaker, **591**, 51-53.

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Johnston, L. and Pike, B. (2010) Managing Powdery Mildew…organically. Australian Viticulture **14**, 20-25.

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Johnston, L. (2009) Organic practices abroad – observations from a tour of Germany, France and the US. Australian Viticulture **13**, 26-31.

Appendix 2: Intellectual Property

The intellectual property developed in this project is outlined in the above report. Some information has already been published in refereed or industry journals so that it is freely available. Some remaining work is still being prepared for publication and will be made available as soon as possible. Much of this work has been discussed in other, non-print forums. The IP described pertains to advances in the understanding of the differences and similarities between organic, biodynamic and conventional vineyard management. Some IP is contained in methods developed to measure sensory differences in the wines produced from this research trial and in the analysis of these results. All results and publications are checked before external discussions for any IP that may be deemed as suitable for protection. As we are trying to develop methods that will have a practical outcome we are very aware of the issues involved with intellectual property protection.

Appendix 3: References

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Appendix 5: Budget Reconciliation