NATIONAL Wine&Grape Industry CENTRE

Australian Government
Grape and Wine Research and Development Corporation

Floor Management Systems to Reduce Vineyard Inputs and Improve grape quality



FINAL REPORT
Grape and Wine Research and Development Corporation

Project Number: CSU01/01

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Research Organisation: **National Wine & Grape Industry Centre**
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Date: **July 2006** **ISBN 0 7247 1750 4**

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Acknowledgements

This study was supported by Australia's grape growers and winemakers through their investment body, the Grape and Wine Research and Development Corporation, with matching funds from the Australian Government.

Andrew Smith, Leo Quirk, Robert Lamont and Sylvie Sicard are thanked for their valuable technical assistance in the field and laboratory. We are grateful to the CSU Winery managers Andrew Drumm and Greg Gallagher and Mannus Wine Estates former manager Mark Verheyden for allowing access to their vineyards. Many thanks to Ms Janet Wild of New South Wales Department of Natural Resources for providing her soil profile report. Mark Conyers (NSW DPI) contributed valuable advice regarding soil chemical aspects of the project.

Research on beneficial insect diversity was supported by a Charles Sturt University Faculty of Science and Agriculture Seed Grant.

Eric Koetz and Andrew Smith are thanked for providing technical assistance on the plant species diversity studies.

John Blackman is thanked for his contribution to the wine sensory appraisal, as well as Mr Grant Johnson from the *Environmental and Analytical Laboratories* for his support in Nitrogen analysis.

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Abstract

This project investigated the effect of three distinct floor vegetation management treatments on vine performance, grape and wine quality, and plant, arthropod and soil microbial biodiversity in vineyards. The three floor vegetation management treatments applied were (1) unvegetated where the entire floor vegetation was sprayed with herbicide, (2) partially vegetated, which involved the spraying of the undervine area only, and managing the inter-row vegetation by mowing, and (3) vegetated where floor vegetation was managed by mowing with no herbicides used. Increasing levels of ground vegetation led to decreased early-season soil moisture and petiole nutrient status, and strongly reduced vine vegetative growth. After three years, grape yield also became limited. Large treatment differences in vegetative growth, canopy structure and yield contributed to differences in berry weight and composition. Treatment differences in berry quality at harvest also gave rise to differences in sensory perception of wines made from the fruit. Large differences in vine vigour between the treatments were observed at Wagga Wagga whereas these differences were less pronounced in the milder climatic conditions at the Tumbarumba site. Some weed species resistant or tolerant to glyphosate such as annual ryegrass, mallows, stocksbill, wireweed, goosefoot, peppercress, shepherd's purse and skeleton weed increased in dominance over time in the herbicide treatments and have the potential to develop herbicide resistance.

In general, bacterial and fungal counts were significantly lower in the unvegetated treatment. Hot water extractable carbon (HWC) was positively correlated with fungal counts and with cellulolytic, pseudomonad, copiotrophic and oligotrophic bacterial counts in both the inter-row and under-vine soil. HWC was also negatively correlated with soil bulk density. The grapevine rhizosphere bacterial population was dominated by cellulolytic bacteria, which were positively correlated with soil HWC and populations were significantly higher in the vegetated treatment. Beneficial nematodes, namely bacteria-feeders, omnivores, fungi-feeders and predators, were more abundant in the top 0-10 cm soil in the inter-row than in undervine positions. In contrast, higher population densities of plant parasitic nematodes were recorded in under-vine positions. There was no strong or consistent impact of any of the floor management treatments on arthropod richness, abundance or biodiversity in pitfall and sticky window traps. There was some evidence of increased springtail and ant abundance in unvegetated treatments, and increased abundance of natural enemies like ladybird and rove

beetles, lacewings and wasps in vegetated and partially vegetated treatments. Rutherglen bug was consistently more abundant in vegetated than unvegetated treatments at Wagga Wagga. Pilot biological control field trials showed that predation and parasitism rates of grapevine moth eggs were very low in both vegetated and unvegetated treatments. In contrast, high rates of predation of grapevine moth larvae by predatory shield bugs and green lacewing larvae were recorded but there was no significant difference between treatments.

Executive Summary

This study examined sward-vine interactions on irrigated Chardonnay grapevines by investigating three vineyard floor vegetation management treatments that are commonly used in Australia: (1) vegetated where floor vegetation was managed through mowing and no herbicide applications (2) partially vegetated comprising an under vine herbicide strip spray and mowing of inter-row vegetation, and (3) unvegetated involving removal of all floor vegetation by herbicide spray. Research aimed to quantify the effects of these floor management treatments on vine performance, grape yield and quality as well as broader environmental impacts of these treatments on plant, insect and soil microbial biodiversity. We examined how floor vegetation management impacts on vineyard sustainability and whether inputs, like chemical inputs can be reduced while maintaining optimal grape production. To achieve this we monitored (a) shifts in vine water use, vigour, fruit quality and yield due to competition from competing plant species within the vineyard production system, (b) changes in weed species composition due to the use of herbicides and (c) impacts of treatments on soil-borne biota and arthropod biodiversity. This information will underpin the development and promotion of a sustainable low input integrated vineyard management system for vineyard managers.

Viticultural impact of vineyard floor management treatments

Increased floor vegetation led to decreases in early-season soil moisture and petiole nutrient status, and strongly reduced vine vegetative growth, particularly at Wagga Wagga. After three years, grape yield also became limited. The viticultural effects of sward-vine competition for water and nutrients, indirectly resulting from reduced herbicide use significantly reduced vine vegetative growth in vegetated compared to unvegetated treatments, with intermediate values in the partially vegetated treatment. Soil moisture content was significantly higher in unvegetated than in vegetated treatments. The leaf petiole nitrogen content was lower in vegetated than in unvegetated treatments, which might be related to different water availability. Yield of grapes was lower in vegetated than in unvegetated treatments in some seasons, but there was only a slight effect on berry composition. Generally, total berry juice nitrogen levels were lower in grapes produced in the vegetated treatment than those recorded in the unvegetated treatment. The decreased total nitrogen and pH and increased Brix levels in berry juice expressed from fruit grown in the vegetated treatment extended the time for

ferments to reach dryness and the resultant wines were assessed to be organoleptically different by a trained sensory panel.

The use of total or partial floor vegetation was shown to be a powerful tool for controlling vegetative growth of grapevines. However, under hot and dry conditions, competition for water and nutrients, particularly at sensitive growth stages (eg. flowering and berry set), can lead to a substantial decrease in vine yield. Therefore, this strategy of achieving vine balance would need to be modified according to the environment in which it is practised.

From a grape grower's perspective, most effects of vineyard sward described in this report, particularly in the warm dry Wagga Wagga vineyard, would seem negative. However, a number of vineyard floor, nutrition and irrigation management strategies are available to reduce the unwanted effects of sward-vine competition in dry warm areas and thus provide a viable option for accomplishing long-term environmental sustainability, while reducing chemical inputs and achieving economic yields and favourable fruit composition.

Nevertheless, the decreased cost of not using herbicides would probably not offset the decrease in grape yield observed in hot arid environments. It would, however, be too simplistic to recommend maintaining bare soil with herbicides as a sustainable option in such conditions, as there could be other unintended negative effects associated with the use of herbicides.

Some weed species such as annual ryegrass, mallows, stocksbill, wireweed, goosefoot, peppercress, shepherd's purse and skeleton weed became more abundant under vines which were frequently sprayed and have the potential to develop herbicide resistance. Alternative ground covers, crops or pastures and mulches need to be examined in the future for weed management. These outcomes reflect aspects of environmental stewardship the Australian wine industry is endeavoring to pursue to produce high quality wines in an environmentally sensitive manner.

Impact of vineyard floor management treatments on soil microbiology

Presence of permanent floor vegetation led to significant increases in organic carbon and microbial populations in the vineyard soil. After 3 years, the permanent sward had caused significant increases in nearly all bacterial counts, consistent with the tendency of soil bacteria

to act as early indicators of the effects of soil treatments. The grapevine rhizosphere contained much larger populations of most microbial groups studied than the surrounding under-vine soil. Cellulolytic bacteria tended to form a large proportion of the grape-vine rhizosphere bacterial count. Hot water extractable carbon (HWC) was positively correlated with fungal counts and with cellulolytic, pseudomonad, copiotrophic and oligotrophic bacterial counts in both the inter-row and under-vine soil. HWC was also negatively correlated with soil bulk density. Herbicide toxicity may have contributed to the reduced soil microbial population in the unvegetated soil plots and this possibility should be further investigated.

The vegetated treatment had comparatively higher population densities than the others. At the termination of the investigation, beneficial nematodes, especially bacteria-feeders and predators, had increased substantially during the trial particularly in the vegetated treatment. In contrast to beneficial nematodes, plant parasitic nematodes were more abundant in the 11-20 cm layer of soil than the top 0 -10 cm soil layer in the under-vine position. Beneficial nematodes namely bacteria feeders, omnivores, fungi feeders and predators were more abundant in the top 0-10 cm soil in inter-row positions than in undervine positions. In contrast, higher population densities of plant parasitic nematodes were recorded from under-vine positions and in the 11-20 cm soil layer. All feeding groups of nematodes were present in both vineyards with the order of prevalence: bacteria-feeders > fungi-feeders > omnivores > predators > plant parasites. Total populations of free living beneficial nematodes did not differ significantly between the treatments but they differed significantly between sampling positions (inter row > under vine), sampling depth (10 cm > 20 cm) and sampling time (November – December > May –June) regardless of treatments in both vineyards.

Impact of vineyard floor management treatments on arthropod biodiversity

Pitfall trapping revealed no strong or consistent impact of any of the vineyard floor vegetation management treatments on overall arthropod species richness, abundance or biodiversity. High levels of variation between and within treatments were recorded for individual orders or species. There was some evidence of increased springtail and ant abundance in unvegetated treatments, and increased abundance of natural enemies like ladybird and rove beetles, lacewings and wasps in vegetated and partially vegetated treatments. Rutherglen bug was consistently more abundant in vegetated than unvegetated treatments at Wagga Wagga. Sticky window trap results showed that winged beneficial insects were abundant in both vineyards but again there was only minimal or weak evidence of any effect of floor management

treatment on overall beneficial insect abundance. Rove beetles showed the strongest and most consistent response to floor management treatment with higher numbers and richness recorded at both sites in the vegetated treatment. There was some evidence of increased abundance of brown lacewings in the vegetated treatment but this only occurred at Tumbarumba, with the reverse occurring at Wagga Wagga. Pilot biological control field trials showed that predation and parasitism rates of grapevine moth eggs were very low in both vegetated and unvegetated treatments. In contrast, high rates of predation of grapevine moth larvae by predatory shield bugs and green lacewing larvae were recorded but there was no significant difference between treatments.

Results suggest that future insect biodiversity studies in Australian vineyards should concentrate on selected abundant species from a range of arthropod groups rather than quantify changes in the biodiversity of all species or functional groups of arthropods. Future biodiversity studies must also consider plot size and replication because both may have been inadequate in the current study to detect changes in many arthropod species. Plant feeding bugs like Rutherglen bug, springtails, ants and some of the beneficial natural enemies like wasps, predatory beetles and lacewings appear to be the most responsive and abundant bioindicators. Vineyard managers may increase populations of some beneficial insects by maintaining a vegetated vineyard floor. However, this recommendation may have limitations as results are of a preliminary nature from only two vineyards in New South Wales and therefore further research is needed to test these observed trends in other Australian vineyards

1. Introduction

Ron Hutton

A key vision articulated in the wine grape industry 'Strategy 2025' was that Australian wines will meet the future consumer's demand for individualised, customised products which are natural, environmentally friendly and healthy. Increasingly, consumer demand for 'clean-green' food products is becoming an important consideration, especially for export markets. Today's consumers are demanding that primary producers provide quality products that have been grown in a sustainable manner and without any negative effects on the environment.

In Switzerland, the wine industry has adopted an Integrated Production (IP) model that places emphasis on the reduction of inputs and establishes a system that maximises biodiversity. The New Zealand wine industry has adapted the Swiss Integrated Production (IP) model to suit New Zealand conditions and one company estimates that it has made savings in the order of 30 to 40% on agrochemical usage since its inception (T. Hoksbergen, pers. comm.).

Despite all these developments, there is still a great deal to learn about what constitutes a sustainable vineyard. Viticultural regions in Australia are located in a diverse range of climatic zones and consequently, viticultural management can vary enormously from one region to another. We need to be able to translate broad sustainability concepts into practical vineyard management that is applicable to vineyards across all regions and develop a set of indicators that will allow vineyard managers and owners to measure their environmental performance.

1.1 Background

The world trend towards environmental management systems and increased problems with chemical resistance will force the Australian wine grape industry to become more environmentally sustainable in its quest to maintain economic viability. Today's consumers are demanding that primary producers provide quality products that have been grown in a sustainable manner. Growers, consumers and policymakers alike are realising that conventional viticultural practices contribute to environmental degradation and may be non-sustainable.

Some problems which have been associated with conventional viticulture are:

(1) pesticide, fungicide and herbicide resistance of target organisms and potential residues on grapes and in wines;
(2) soil erosion, degradation, compaction and salinity;
(3) poor water infiltration and excessive water use;
(4) low soil organic matter content; and
(5) excessive nitrogen fertilisation and nitrate leaching.

The severity of these problems may be reduced by using sustainable viticultural practices such as cover crops or permanent swards, and optimal timing and dosage of water and nitrogen application.

In Australia, some companies and innovative landholders have adopted Environmental Management Systems that focus on regular assessments of the natural resource base to see what effect vineyard management is having on the whole system. This includes monitoring soil health, water quality and fauna and flora. Regular monitoring of parameters such as these provides valuable information and allows for continuous improvement in vineyard management. However, there is a paucity of information on the effect of various inputs used in the wine grape production system (herbicides, pesticides, fungicides and fertilisers) on the biological component of the soil and research is needed into weed / pest / disease control strategies and the influence of such management practices on soil biological resilience.

But how do you define a sustainable vineyard? What indicators do viticulturists have that will provide them with the confidence that they are indeed sustainable?

1.2 Defining sustainable agriculture / viticulture production systems

Sustainable development is defined as that which meets the needs of the present without compromising the ability of future generations to meet future needs (WCED 1987). The traditional model of agriculture is that of industrialisation, which views farms as factories and resources, and plants and animals as production units. The goal is to increase human quality of life by increasing production of goods and services and consequently increase employment and incomes (Ikerd 1993).

In contrast sustainable agriculture requires a holistic approach to farm management, in which the farming system is managed as a whole. In this model, production units are viewed as organisms that consist of many complex interrelated sub-organisms that have distinct physical, biological and social limits (Ikerd 1993). The ultimate goal of sustainable low-input viticultural systems is to integrate all components of the viticultural ecosystem so that overall biological efficiency is improved, biodiversity is preserved, and productivity is maintained.

Achieving this requires design of a cultural system that mimics the structure and function of the local natural habitat with the economic cropping system integrated into it. That is, a system with naturally adapted and diverse plant species covering the soil, a biologically active soil that promotes natural pest control, nutrient recycling and soil moisture retention to support the economic crop, and a perennial ground cover using a mix of compatible crop associates in addition to employing integrated pest management (or use of 'soft' pesticides based on monitoring) for pest and disease control.

In this context, soil is considered to be a dynamic, living resource whose condition is vital to the production system (Doran *et al* 1996), since our food and fibre production is dependent on soil. With increasing environmental awareness in our society, wine grape producers are being encouraged to develop strategies that conserve their non-renewable natural resources, such as soil. To this end, the improvement of short-term profitability of a production system should not be achieved at the expense of long-term sustainability. Management practices like fertilisation and irrigation address the short-term needs of the crop, but the long-term survival of the production system relies upon the maintenance of soil health.

1.3 Soil and sustainable viticulture

1.3.1 Soil health

The development of sustainability in a production system is linked to soil health. Soil health can be defined as the ability of soil to perform or function according to its potential. It is affected by management and land-use decisions as much as by natural events like floods or drought (Doran and Safley 1997). A healthy soil is therefore one that allows water entry, holds and supplies water to plants, resists degradation and supports plant growth (Karlen and Stott 1994).

The terms soil health and soil quality are often used interchangeably. The two concepts overlap, although a distinction now widely accepted in the literature is that soil quality is appropriate when the intended use of the soil is specified (Pankhurst *et al* 1997). This is because perceptions of what constitutes a high quality soil may vary depending on the intended land use (Doran *et al* 1994). Soil health has implications beyond its quality or capacity to produce a particular crop, and instead focuses more on the long-term sustainability of the system. Soil health embodies the notion of ecosystem stability, functional diversity and resilience (biological resilience) in response to disturbance or stress (van Bruggen and Semenov 1999).

1.3.2 Soil biological resilience

Soil resilience is the ability of the soil to recover after exposure to a disturbance. Biological soil resilience is the ability of the biological component of the soil (or a specific population) to return to an equilibrium following displacement in response to a disturbance (Swift 1994).

Biological responses to stress are expressed as the extent of fluctuations in microbial and microfaunal populations and the time needed to return to stable, initial conditions (Ettema and Bongers 1993; van Bruggen and Semenov 1999). The general microbial population, or microbial buffer, in a soil is responsible for maintaining homeostasis. The microbial community is made up of an active pool and a reserve pool of micro-organisms. The reserve pool is often more diverse than the active pool and can respond rapidly to perturbations (van Bruggen and Semenov 1999). It has been purported that the greater the diversity and functional redundancy of the microbial buffer, the quicker the soil system can return to homeostasis after exposure to a stress. A healthy soil would have enough functional redundancy so that the soil ecosystem would quickly recover from a disturbance that eliminated part of the microbial community (van Bruggen and Semenov 1999).

Most agricultural production systems are frequently disturbed, for example during harvest and spray applications. A primary measure of sustainability is the level of resilience within a system to maintain soil health in the face of such disturbances (Tiessen *et al* 1994; Seybold *et al* 1999). A number of authors (Swift 1994; Elliott and Lynch 1994; Pankhurst 1994; Hawksworth 1991) have suggested that although the effects of management practices on biological activity may well be understood to some degree, the consequences of these

biological changes for sustainable viticulture in terms of biological resilience have not been assessed.

1.3.3 Indicators of soil health and resilience

The establishment of universal indicators of soil health is necessary for the development of sustainable viticultural production systems. Soil indicators are properties or processes within the soil component of a production system that indicate the state of the ecosystem (Elliott 1997). The search for such indicators is complicated by the fact that they must satisfy both production aims and environmental concerns. They must take into account the multiplicity of physical, chemical and biological factors which control ecological processes and allow for variation in intensity over time and space (Doran and Safley 1997). They should be relatively easy to use under field conditions, be assessable by both scientists and producers, and be sensitive to variations in management and climate over the long-term, but not so sensitive that they are affected by short term weather patterns (Doran et al 1996; Doran and Safley 1997). No one indicator is likely to possess all these attributes and monitoring single indicators may be misleading. Therefore, a set of complementary indicators will be required (Rapport et al 1997; Pankhurst et al 1997).

Threshold values for key indicators must be established, that will vary depending on management practices used and the landscape within which the assessment is being made (Doran and Safley 1997). Indicators fall into categories; those useful for diagnostic purposes to identify the cause of a particular problem, for general screening of soil health, and for risk assessment to estimate potential losses in the face of a particular stress (Rapport et al 1997).

Soil health is inseparable from issues of sustainability. The challenge is to develop approaches for assessing soil health that are useful to producers and scientists for the identification of land-use management systems that sustain production and satisfy environmental concerns (Doran and Safley 1997; Pankhurst *et al.* 1997). Indicators will only be of real value if they measure properties that are important to the production system and can therefore be incorporated into an information package designed to meet farmers needs (Oades and Walters 1994).

Soil organisms contribute to the maintenance of soil health via the decomposition of plant residues, nutrient cycling, the formation and maintenance of soil structure and degradation of

agrochemicals and pollutants contaminating soil. They are potentially useful indicators of soil health because they respond to management in time scales that are relevant to landholders (Pankhurst 1994). Many examples in the literature indicate that changes in microbial biomass or abundance of selected functional groups of micro-organisms may be detected well before changes in soil organic matter content or other soil chemical or physical properties (Powlson *et al* 1987; Gupta *et al* 1994; Miller and Jastrow 1994; Pankhurst 1994). This suggests that biological properties may be more sensitive indicators than other soil properties, responding to management changes within a shorter time frame. Further work is needed to explore this concept and determine the relevance to the issue of sustainability in a range of sites.

1.4 The soil biological environment

1.4.1 Organic matter

Soil organic matter includes all living micro-organisms, animals and plants, the organic materials they release and the residues of plants and other organisms at various stages of decomposition down to humus. Organic matter is a controlling factor that maintains nutrient storage and cycling in soil, therefore the effect of management practices on organic matter indirectly affects soil nutrient cycling. More than 95 % of nitrogen, 15 to 85 % of total phosphorous and 50 to 70 % of sulphur occurring in soil is contained in the organic matter (Tisdall 1992). It also holds potassium, calcium and magnesium in forms that are readily available for plant uptake, and trace elements needed for plant growth. Soil organic matter consists of different components that turnover at different rates. The portion with rapid turnover is highly responsive to management and therefore affects nutrient cycling and availability in the short term (Tiessen et al 1994). Portions with slower turnover rates, the intermediately labile pool, affect nitrogen, sulphur and phosphorous supply over a longer term, contain some of the cation exchange capacity and influence physical properties like bulk density and aggregation (Tiessen et al 1994).

1.4.2 Microbial biomass

The microbial biomass is the living part of soil organic matter. It comprises the total population of micro-organisms in the soil and is responsible for organic matter turnover and nutrient release. It only represents a small portion of organic matter (2-7 percent) but is dynamic and living with a short turnover time of one to two years, and is therefore more sensitive to management practices than total soil organic matter (Powlson *et al* 1987). The microbial population is a labile source of carbon, nitrogen, phosphorous and sulphur. It is an

immediate sink for these elements and is an agent of nutrient transformation and pesticide degradation (Dalal 1998). Unlike nutrients in the soil solution, nutrients tied up by the microbial biomass are not prone to leaching, and are released for plant uptake as a result of predation by microfauna and the death of microbes during soil drying (Gupta 1998).

1.4.3 Soil biodiversity

Biodiversity is the richness of life indicated by the variety of biota and inter-related biochemical processes in a habitat (Elliott and Lynch 1994). It is determined by the number of organisms in the community and the relative abundance of the different components within a community (Pankhurst 1997). The diversity of soil organisms is vast and poorly known relative to organisms that live above the soil surface (Wall and Moore 1999). However, we are limited in our understanding of the importance of biotic diversity and how much is needed for the soil to function.

The debate for conservation of biodiversity in the environment can be divided into three main issues (Anderson 1994; Hagvar 1998):

(1) ethical - a moral argument relating to the intrinsic value of a species;
(2) ecological - the functional role diversity plays in maintaining ecosystem processes; and
(3) utilitarian - the strong economic reason for maintaining biodiversity of micro-organisms relating to the utility value of a species.

Biodiversity has two main components; the species richness, or number of species present, and dominance, a measure of the extent to which communities are dominated by a small number of species. A community is considered more diverse the more nearly each species is present in equal numbers (Magurran 1988). The change from conventional to conservation management practices, like cover cropping, may have little effect on species richness of soil micro-organisms, apart from possibly increasing the populations of the rarest species to above the detection threshold, without some means of migration of species into the field. However an increase in niches provided by additional organic material, as well as a shift in conditions towards those that favour fungi (Hendrix *et al* 1986; Jordan and Kremer 1994) may change the abundance of organisms, or the dominance of species of soil fungi.

Agricultural monocultures and attendant cover crops often comprise only a small number of plant species compared to those that existed in the original native landscape. Because of this, it is likely that the composition and structure of the economic plant community governs, directly or indirectly, the physical, chemical and biological properties of soils more than other biological factors (Beare *et al*. 1995). As such, the species composition of plant, microbial and invertebrate decomposer communities and diversity in fungal communities in wine grape monocultures is tightly related to this production system (Wall and Moore 1999).

There is evidence that links increased biodiversity with improved ecosystem function and stability (Tilman and Downing 1994; Naem *et al* 1995), and links the biodiversity of soil organisms with the maintenance of soil functional processes (Pankhurst 1997). However, many scientists suggest there is no clear evidence that increased microbial diversity increases the stability of the ecosystem, nor is any other effect obvious (Giller *et al* 1997). Such observations are based on the fact that soils have an inherently high level of functional diversity that can also imply a high level of functional redundancy.

It is still uncertain how much biodiversity within a given functional group of organisms is needed to maintain soil resilience after a disturbance or stress (Brussard *et al* 1997; Pankhurst *et al* 1997). Pankhurst (1997) proposed three possible scenarios to explain the relationship between biodiversity and ecosystem functioning. The first is that there is a minimum diversity required to maintain soil functioning, above which loss of species has no effect. Secondly, all species make a contribution and soil functioning declines as species are lost. Finally, ecosystem functioning varies as diversity varies, but the change is unpredictable due to the varied and complex roles performed by soil organisms (Pankhurst 1997).

Relationships between sustainability, soil quality and soil biodiversity need to be investigated. The importance of biodiversity and how management and associated biodiversity will improve soil resilience to ecosystem stability must also be determined. These studies should include looking at the diversity of organisms responsible for desirable processes in the soil with the basic objective of being able to manage biodiversity for maximum soil resilience (Elliott and Lynch 1994).

1.4.4 The microbial buffer and pathogen suppression

A healthy soil is one that allows water entry, holds and supplies water to plants, resists degradation and supports plant growth (Karlen and Stott 1994). The presence of a pathogen in the soil system reduces the ability of the soil to support plant growth. Suppression of soil-borne pathogens may be viewed as one of the characteristics of a healthy soil (van Bruggen and Semenov 1999). The ability of the microbial population in soil to buffer against the introduction of foreign pathogens is an important issue when looking at soil resilience.

Soil with high levels of organic matter and organism activity, or a specific group of antagonistic micro-organisms, appear to compete with and prevent aggressive soil-borne pathogens from causing serious disease in plants. These soils are called suppressive soils. It is a natural condition that can be disrupted by some agricultural practices. Soils that are naturally suppressive to disease are those in which disease incidence remains low despite the presence of the pathogen, a susceptible host species and climatic conditions favourable to disease expression (Baker and Cook 1974). There are two types of suppressive soils: general and specific. General disease suppression is directly related to the total amount of microbiological activity in the soil at a time critical to the pathogen (Cook and Baker 1983). The total active microbial biomass competes with the pathogen for energy, space, water or carbon and other nutrient sources. Specific suppression in soil is due to specific effects of individual or selected groups of organisms that are antagonistic to the pathogen during one or more stages of its life cycle (Cook and Baker 1983).

The biological basis of suppression in soil has been established by the ability to transfer suppressive characteristics to another soil and the loss of this ability after biocidal treatments (Alabouvette 1986; Wiseman *et al* 1996). It has been suggested that suppression in soils may correlate with total microbial biomass and activity due to competition for resources between the pathogen and the saprophytic microflora, and antibiosis from production of toxic metabolites (Alabouvette *et al* 1996). The hypothesis is that the greater the diversity and functional redundancy of the microbial population, the greater the ability of the soil community to suppress an introduced pathogen (van Bruggen and Semenov 1999). Suppression is more likely to succeed if a soil is encouraged to evolve its own biological defence against pathogens via specific soil management practices.

1.4.5 Beneficial organisms

The ability of the soil to support populations of beneficial organisms is an important aspect of biological soil resilience and production system sustainability. Soil biota that form symbiotic associations with plant roots are examples of beneficial organisms that occur in the soil environment. Nitrogen fixing bacteria, mycorrhizae and other endophytic fungi form mutualistic associations that are beneficial to the plant, thereby improving vine health and production. Mycorrhizae not only influence the nutrient status of a host plant but also its water relations. Water uptake through the external fungal mycelium becomes progressively more beneficial for the host plant under conditions of water stress (Varma 1998). They also produce extracellular hyphae (Wilson and Tommerup 1992) that may extend several centimetres out into the soil and exude organic materials providing a substrate for other soil microbes. These hyphae-associated microbes often produce sticky materials causing soil particles to adhere, improving soil aggregation and consequently aeration, drainage and stability (Tisdall 1991, 1994; Varma 1995a, b). Mycorrhizal fungi are a major component of the beneficial microflora in the soil, and therefore should be included in studies of ecosystem functioning and sustainability (Kling and Jakobsen 1998). However, it should be noted that chemical, gas and physical properties of a soil changes with depth and this is known to affect the distribution of AM fungi (Bethlenfalvay *et al* 1984). It has also been reported that reduced plant diversity negatively affects the density and diversity of AM fungi (Rabatin and Stinner 1989).

1.4.6 Cover cropping and the soil

Inter-row cover crops can provide additional nutrient sources to the crop (e.g. legumes contribute to soil nitrogen), increase soil organic matter, reduce the risk of soil erosion and improve vineyard biodiversity (both above and below ground). This is typically achieved through the use of two different strategies.

(1) Permanent sod culture is where the inter-row crop is permanent, reducing the degree of disturbance in the soil ecosystem. Most sod systems consist of a range of perennial grasses, legumes and herbs. The sod needs to be mown to ensure the continual release of nutrients.

(2) Semi-permanent sods consist of annuals that can be slashed in early summer or can be left to naturally senesce, forming a mulch between the rows.

Conversely, green manure crops are grown annually to be cultivated back into the soil to build up organic matter and nutrients.

1.5 Insect biodiversity and biological control

Conservation biological control is a relatively new term that describes manipulation of the environment to enhance survival and reproduction of natural enemies and thus their effectiveness (Landis et al. 2000). Conservation biological control recognises that many agroecosystems are unfavourable for natural enemies and aims to ameliorate conditions by providing more food resources, alternative prey or hosts, and shelter. Typically conservation biological control has concentrated on enhancing the provision of food resources for natural enemies.

All parasitoids and many predators need a diet of sugars and proteins to survive and reproduce, with nectar and/or pollen the principal components of such a diet for many species. Encouraging the growth of and planting of flowering plants in an agroecosystem is the easiest way to increase the availability of nectar and pollen, which in turn should lead to higher numbers of natural enemies. This can be easily accomplished in a vineyard situation by planting specific flowering species on the vineyard floor or by allowing weeds and grasses to grow and flower on the vineyard floor as has been done in this study.

1.6 Defining a sustainable vineyard

In order to bring vineyards closer to natural conditions, the Swiss IP model, developed at the Federal Research Station in Wädenswil, stresses high biodiversity, sustained soil fertility, optimal growing conditions and minimal unintended environmental side effects while maintaining cost-effectiveness. The model uses an expert system with the aim of protecting the environment, vineyard workers and consumers of grape products. Experimental field trials and grower input during a pilot evaluation period led to the design of a technical manual and a scorecard for application to whole vineyards that encourages continual improvement in vineyard management with progressive steps to what is believed to be best practice.

Europe and North America are rapidly introducing sustainable agricultural systems. The success of the Swiss IP model has led to its recent adoption by the International Organisation for Biological and Integrated Control (IOBC), making it the standard for their West Palaearctic Regional Section, which includes Europe, the Mediterranean Region, and the

Near- and Middle East. The IOBC defines IP in viticulture as '*the economical production of high quality grapes, giving priority to ecologically safe methods, minimising the undesirable side effects and use of agro-chemicals, to enhance the safeguards to the environment and human health*' (IOBC/WPRS 1999). The wine industry-driven American Viticulture and Enology Research Network has made the development of IP for vineyards a national research priority (wineserver.ucdavis.edu/avern/avern1.html). The Californian Central Coast Positive Points System (PPS) for evaluating the extent of sustainable practices being used in vineyards (www.vineyardteam.org/pps/index.htm) is remarkably similar to the Swiss model. Accordingly, the University of California, Davis, vineyard has been converted in 1998 from 'old-school' to bio-responsible management using vegetational diversity in and around the vineyard (Bugg and Hoenisch 2000). Oregon's Low Input Viticulture and Enology (LIVE) program (www.LIVEInc.org), which is also based on the Swiss model, is currently seeking IOBC endorsement (M.C. Vasconcelos, pers. comm.). Similarly, the Integrated Wine grape Production Scheme in New Zealand is an adaptation of the Swiss model (D. Jordan, pers. comm.).

Interest in sustainability is also growing in the Australian wine industry. Examples include the IP workshop held during the recent 5th International Symposium for Cool Climate Viticulture & Enology in Melbourne, the 1st National Wine Industry Environment Conference & Exhibition in Adelaide, BRL Hardy's Banrock Station vineyard, Yalumba's Environmental Management Policy and several successful approaches to organic viticulture (such as Temple Bruer, Glenara Wines and others). Given the desire by the industry to reduce agrochemical input (GWRDC Five Year R & D Plan) and the competitive advantage of clean and green produce, it is essential that novel production systems are implemented to meet these requirements.

1.7 Towards optimising vineyard biodiversity

To achieve positive economic results, at least in the short term, simplification in landscape management, as is the case with viticultural practices, generally involves maintaining large numbers of a few dominant species including the economic crop in question. Generally, agricultural activities are frequently attributed to loss of biodiversity through major direct and indirect impacts, namely

(1) The conversion of natural habitat to agricultural production;
(2) The increase in susceptibility of native biotic communities to competition by introduced exotic species through habitat alteration; and
(3) The indiscriminate application of agricultural chemicals

The concept of sustainable viticulture being inclusive of enhanced biodiversity is a relatively recent response to the observed decline in the quality of the natural resource base of standard production systems that is often associated with modern, energy intensive, monocultures typically found in Australian wine grape growing regions.

Although the trend toward reduced biodiversity in managed environments continues, systems for sustainable use of natural resources exist and are growing in number. With sustainability, reduction of external inputs and improved management of species diversity of the system can be achieved concurrently with a constant level of economic productivity. However, this process requires elevated knowledge of input resources and focuses on the inter-relatedness of all component inputs in a whole-of vineyard system, accounting for the complex dynamics of interacting environmental and vineyard ecosystem processes.

The fundamental ecological approach to arresting the decline in biodiversity attributable to intensive cropping systems is to go beyond the use of alternative practices to develop vineyard systems with low dependence on high agrochemical and energy inputs that support their productivity and develop improved crop protection through use of interactions and synergisms between biological components. Enhancing functional biodiversity in agro ecosystems is a key strategy to sustaining long-term productivity (Pankhurst, 1997; Altieri, 1999; Altieri, M.A. and C.I. Nicholls 1999).

The type and abundance of biodiversity in viticulture will differ with vine age, diversity, structure and management across the spectrum of cultural systems as well as being subject to

temporal variations due to seasonality. For the sake of simplicity, viticultural biodiversity may be broadly classified into 2 groups (Swift and Anderson, 1993; Vandermeer and Perfecto, 1995).

(1) Productive biota – that is, annual and perennial crops, as well other introduced flora/microflora and insect species. These play a determining role in the diversity and complexity of the viticultural production system. This is managed by the property manager and will vary according to management inputs and crop spatial/temporal combinations.

(2) Associated Biodiversity – that is, the mix of biota that influences or colonises the viticultural production system from the surrounding environment will impact on system sustainability to varying degrees, depending on the management practices employed. These organisms may be further classified as naturally occurring biota that directly contribute to productivity through their affect on pollination, biological control, decomposition etc., and destructive biota – namely, weeds, insect pests, microbial pathogens, etc that managers aim to reduce through cultural practices.

Such functionally diverse inputs to a viticultural production system provide compositional diversity that contributes both in magnitude and capacity of organisms to contribute synergistically to improved soil resilience through organic matter decomposition and nutrient cycling (Zak *et al*, 1994) and biological control of pests and diseases. These systems are considered to be more sustainable, providing improved productivity and reduced reliance on agricultural chemicals over longer periods of time (Franklin *et al*, 1989). Nevertheless, whilst some anecdotal evidence for such relationships has been established there is no evidence of cause-&-effect (Odum, 1984; Paoletti *et al*, 1989; Paoletti and Pimentel, 1992; Altieri, 1999).

It is not only important to monitor the biological contribution of diverse species to sustainable low input viticulture, but also the biological function conferred on the modified production system relative to existing production systems (Gliessman, 1998b; Altieri, 1999; Paoletti, 1999). Therefore, the assessment of the status of biodiversity needs to account for:

(1) The temporal and spatial diversity of productive biota in stable vineyard cropping systems;

(2) The composition and abundance of non-crop vegetation within and surrounding the vineyard, including tolerable levels of naturally occurring weed species to provide

undergrowth diversity that potentially provides shelter and alternative food for incidental biota including natural predators to maintain the localised biodiversity;

(3) The type and intensity of management;
(4) Local variations in climate, topography and pest complexes; and
(5) Edaphic factors.

The key is to identify the desirable mix of biota necessary to maintain and/or enhance the benefits of biodiversity, and then to determine the best management practices that will encourage the maintenance of those components that exploit the complementarities and synergies that biodiversity can bring to sustainable crop production. However, the effects of diversification can only be determined experimentally across a limited range of environments since the degree of biodiversity is necessarily site-specific.

The selection of component plant species that might contribute to the production system is arguably an important factor. To this end, systematic studies are needed on the 'quality' of plant diversification with respect to the abundance and efficiency of natural enemies. Spatial heterogeneity may also have a strong effect on species diversity within a vineyard. At the localised level, the abundances and activities of individuals belonging to each species define community structure. Within a community structure, each species occupies a niche, which may be described as the fundamental role of the organism in the community – that is, what it does and its relation to its food and its enemies (Ricklefs and Miller, 2000).

The botanical structure within a vineyard is by and large relatively simple. It usually consists of a top canopy of *Vitis vinifera*, which is usually managed to be of a consistent height and width. The vineyard floor may consist of a variable, but small, range of plants depending on the weed and inter-row crop management practices and the below ground component possess a heterotrophic layer that utilises the carbon stored by autotrophs as a food source, transfers energy, and circulates matter by means of herbivory, predation in the broadest sense and decomposition.

The stratified surface soil horizons (top 15-25cm of the soil) in non-till production systems typically found in viticulture are more homogeneous with respect to physical characteristics and residue distribution than in cultivated soils more usually found in broad acre agriculture. Nevertheless, the loss of a stratified soil microhabitat due to conventional management

practices causes a decrease in the density of species that inhabit such soils. Such biodiversity reductions are deleterious because of the change in balance between organic matter, soil organisms and plant diversity necessary for a productive and balanced soil environment and its effect on nutrient recycling.

Horizontal patchiness further adds to the physical complexity of such communities. The patchy distribution of groundcover plants is a product of both the physical and biological environment. In terrestrial communities, soil structure, soil fertility, moisture conditions, and aspect all influence the micro-distribution of plants and soil biota.

Soil is arguably the most important natural resource a vineyard possesses. The French term '*terroir*' captures its vital significance to wine quality. This term is described by Thomas (1949) to be inclusive of "…*all the climatic, ecological and other natural factors which determine how far land can be used for the production of crops. [It] is conserved under any system of farming provided such a system is technically capable of being continued indefinitely (sustainable system).* Thomas emphasises the concept of sustainability and the holistic nature of soil fertility. The sustainable use of soil as a natural resource demands the continued maintenance of its health and quality.

Soil health in a vineyard may be defined as the capacity of a soil to function within the boundaries of a productive vineyard system that sustains biological productivity, maintains water quality, and promotes plant health (Doran and Safley, 1997). This definition portrays soil as a living, dynamic entity. The organisms residing within the soil matrix are a vital component of viticultural cropping systems. They play an important role in regulating the soil ecosystem processes, performing a number of vital functions (Paoletti *et al*, 1994) including:

(1) Decomposition of litter and cycling nutrients;
(2) Conversion of atmospheric nitrogen into organic forms, and reconversion of organic nitrogen to gaseous nitrogen;
(3) Suppression of soil-borne pathogens through antagonism;
(4) Synthesis of enzymes, vitamins, hormones, and allelochemicals that regulate populations and processes;
(5) Alteration of soil structure; and
(6) Interaction with plants through mutualism, commensalisms, competition, and pathogenesis.

It is therefore important to identify and encourage viticultural management practices that increase the abundance and diversity of soil organisms by enhancing habitat conditions and resource availability (Roper and Gupta, 1995). However, the reported responses to heterogeneity of soil biota and the effect of biodiversity on the stability of viticultural systems remain unequivocal (Pankhurst *et al*, 1996). It is acknowledged that if some component of the system is changed, such as quality or quantity of soil organic matter and nutrient inputs, climate or soil parameters, then the whole functioning of the community may shift to a new equilibrium.

Reduced tillage creates a relatively stable environment and encourages development of more diverse decomposer communities and slower nutrient turnover. Available evidence suggests that conditions in no-till systems favour a higher ratio of fungi to bacteria, whereas in conventionally tilled systems, bacterial decomposers may predominate. Residue also has an important effect on organic substrate availability and soil micro-climatic characteristics. Soils with residue chopped and left as mulch generally support higher populations of surface feeding earthworms. Microbial and protozoan activity and collembola populations also tend to increase after surface mulching.

Nutrient cycling, residue decomposition, soil structure and pest balance is paramount to the productivity and sustainability of all agricultural systems. The major influence of viticultural management practices on soil biological activity relate to nutrient cycling, changes in C and N inputs, the soil physical environment and negative impacts of synthetic chemical use on soil microbial and faunal activity. However, the large number of micro-organisms present in soil as well as the wide-ranging diversity, estimated at 4000 different genomes per gram of soil (Torsvik *et al*, 1990), makes the study of soil microbiology a difficult undertaking.

Soil biomass consists of fungi, bacteria and actinomycetes as well as animals such as nematodes, mites, collembola, earthworms and arthropods. A square meter of an organic temperate agricultural soil may contain 1000 species of organisms with population densities in the order of $106/m^2$ for nematodes, $105/m^2$ for micro-arthropods and $104/ m^2$ for other invertebrate groups. One gram of soil may contain over a thousand fungal hyphae (Davies, 1973; Tisdall, 1991) and up to a million or more individual bacterial colonies (Kennedy and Gewin 1997; Kennedy, 1999).

Bacteria are also sensitive to disturbances such as those introduced by agriculture, pollution and other stresses (Elliott and Lynch, 1994). Understanding the effect of disturbance on soil bacterial diversity and functioning may contribute to the understanding of soil quality and the development of sustainable viticultural production systems (Thomas and Kevan, 1993).

The root system and the soil environment, including mineral and organic material, influence bacterial populations and their function in the rhizosphere (the volume of soil under direct influence of the roots). Presence of roots stimulates bacterial activity by providing nutrient-rich root exudates (Rouatt and Katznelson, 1961). Indeed, the makeup of the plant community may have a very significant influence on the heterogeneity of the bacterial community because of the diverse composition of the root exudates (Christensen, 1989). Changes in the soil's physical and chemical properties induced by cover crops alter the matrix supporting bacterial growth. The diversity of the latter varies with soil depth, with the greatest bacterial activity being located near the soil surface.

As early as 1927, Waksman concluded that soil properties, climatic factors, as well as cropping history and soil management contributed to soil microbial behaviour. This confounded efforts to use microbial criteria as indicators of soil fertility. Furthermore, Somerville and Greaves (1987) observed that changes in soil water content, temperature, pH, soil structure, soil aeration and nutrient levels might also produce fluctuations ranging from 50-100% in the activity and size of microbial populations. This makes it almost impossible to use microbiological populations and processes as direct indicators of soil health. However, diversity indices can be used to monitor the effect of soil disturbance. More importantly, changes in diversity with management may be more informative of the status of a soil bacterial community.

As discussed previously, populations of various functional groups of soil organism, including fungi, fluctuate greatly in response to various abiotic and biotic soil factors (Lee and Pankhurst, 1992; Pankhurst and Lynch, 1995). Numerically, soil fungi are less abundant than bacteria though they constitute the major contributor (70%) to soil biomass (Lee and Pankhurst, 1992). Soil fungi may be free living or in mychorrizal association with plant roots. Most are opportunistic, becoming active when environmental conditions are favourable. Fungi are active in the decomposition of cellulose and are the principal agents for the decomposition of lignin produced by plants. Fungal hyphae, especially those of vesicular

arbuscular mycorrhizal (VAM) fungi and saprophytic fungi, along with fibrous roots, bind micro-aggregates of soil (<0.25 mm diameter) into stable macro-aggregates (>0.25 mm) (Tisdall, 1991). The breakdown products of plant residues from the actions of saprophytic microbes and other soil biota are also important in contributing to the creation of soil aggregates and general improvement of soil structure.

In most agricultural systems there are clearly identifiable seasonal patterns of organic residue inputs to soils. This rhythm of introduced organic residues induces corresponding waves of decomposition with their associated microbial successional processes (Pankhurst *et al*, 1995).

Soil microfauna (e.g., protozoa and nematodes) feed primarily on fungi and bacteria, though predatory and parasitic forms are also abundant (Lee and Foster, 1991). These organisms mainly occupy water-filled soil pores and water films in the soil (Anderson, 1987). Their direct effects on cycling of minerals occur principally through their feeding on and assimilation of microbial tissue and the excretion of mineral nutrients. Due to their high consumption levels, short generation times and fast turnover rates they tend to track the dynamics of bacterial and fungal populations.

Though many micro arthropods are fungivorous, others are bacterivorous or predatory, feeding on a number of micro- and meso-faunal groups. However, there is little evidence to suggest that the feeding activities of mesofauna significantly affect the abundance and distribution of bacteria and fungi in agricultural farming systems. Populations of Collembola and mites are strongly dependent on soil type and texture, as both need pore space for their activities since neither has good capacity to dig. Therefore, population levels tend to be higher in light soils where most of the macropores tend to be air-filled. Other abiotic conditions that favour both organisms include temperatures of around 15^{o}C and soil moisture levels of about 15%.

Ground surface cover by vegetation or loose debris has an immediate impact on surface-dwelling predators because of its direct influence on temperature and moisture. Moreover, these conditions also tend to favour prey species. Because of their slender life-form, the activity of rove beetles tends to be less affected in habitats with high environmental resistance. Being surface dwellers, this insect taxon is less dependent on soil macropores. In fact, clay soils tend to be preferred. This preference may be attributed to the combined effect

of higher vegetation cover, higher moisture, lower temperatures and therefore, higher availability of prey.

Generally speaking, pesticides differ considerably in their impact on predatory arthropods and the latter differ in their susceptibility to insecticides. But, it is generally agreed that insecticide impact > herbicide impact > fungicide impact on Carabid, or ground beetles (suborder Adephaga, family Carabidae), another well-known polyphagous predatory insect. Carabids are generally classified as macro arthropods. Other macro arthropod specimens commonly caught in small numbers in pitfall traps are species of the order Araneae – the spiders.

1.8 Diversity Indices

The sustainability of any farming enterprise can be assessed only by comparison with other similar units that are under different management. Although it is difficult to allocate absolute values of sustainability to a given process, comparisons with other practices can indicate compatible practices. In most cases, the small organisms residing in a habitat may be used as indicators, or as the practical tools to assess the sustainability of a farm.

The purpose of measuring vineyard diversity is to judge its relationship either to other vineyard properties, such as productivity and stability, and to the environmental conditions that the vineyard is exposed to. However, the challenge is to find a reliable measure of biodiversity, and before this can be measured, it is often necessary to define precisely the collection of organisms that coexist in the vineyard before implementing practice change.

The goal of monitoring is, therefore, to identify appropriate techniques to enable viticulturists to decide if the health of their viticultural production system is declining, stable or improving as a consequence of existing farming practices. Diversity indices assume that the more abundant a species is, the more important it is in the soil-plant system. Obviously not all species should count equally toward an estimate of species diversity because their functional roles in the community vary in proportion to their overall abundances. But the more abundant species are not necessarily the most important or the most influential. Such diversity indices can be used to provide a measure for treatment comparison of vineyard ecosystems.

Maintenance of biodiversity is a major factor contributing to nutrient turnover, and the control of harmful organisms in soils. Options for achieving sustainable management of soil and

water resources will include strategies that maintain or enhance high populations and taxonomic diversity of the soil biota. Therefore, alternative viticultural practices must be carefully adapted to the biological, physical and climatic conditions of the region. They require research and extension to achieve an appropriate balance of conventional and alternative methods.

1.9 Preliminary and Previous Research

Previous (see GWRDC projects SEE 93/1, DAV 95/1, CRS 95/1) and current (see CRV 99/13) research examined important aspects of sustainability in isolation rather than in an integrated way. European experience, in particular the Swiss IP (Wädenswil) production system, suggests that weed control has to address the entire vineyard system and integrate with other practices, such as plant nutrition, irrigation, and pest and disease management. This model stresses high biodiversity, closed nutrient cycles, sustained soil fertility, optimal growing conditions and minimal unintended environmental side effects, while maintaining profitability through improved fruit quality and reduced inputs.

Adoption by the Swiss wine industry of the IP approach to wine grape growing has shown dramatic effects: +270% in biodiversity, -18% in pesticide use, -15% in nitrogen fertiliser use, and phosphorus fertiliser use has fallen below levels used in the 1950's. Consequently, use of site-adapted plant species for cover cropping is now seen as the leading edge of botanical diversification in European and American vineyards (Bugg and Hoenisch 2000). We propose to adapt this model to Australian conditions, using native and introduced plant species. Adoption by the wine industry would improve its clean-green image on both national and international levels and enhance the industry's competitive advantage.

The major risk faced with application of the Swiss IP model approach is that it may not be adaptable to suit Australian conditions, although international experience suggests that this is unlikely. If not managed properly, floor covers may compete for resources with grapevines, decreasing water and nitrogen availability to vines. This could reduce vine growth and yields, and lead to stuck fermentations and reduced wine quality (Maigre et al. 1995, Bugg and Van Horn 1997). The exacerbation of spring-frost problems is also a concern.

Thus, the move toward sustainable viticultural practices will not occur without some difficulty. The process of converting from conventional to sustainable practices does not

merely involve low-input farming (Ingels 1992). In fact, considerable management and non-chemical inputs are required for successful grape production in a sustainable system.

The major barrier to adoption of sustainable vineyard management practices is the lack of credible scientific information under Australian conditions. More research on biological, cultural, and chemical alternatives to currently available synthetic agrochemicals is needed to assure that productivity is maintained during the transition period (Striegler et al. 1997). Also, industry may perceive that the short-term losses might outweigh the long-term gains.

In Australian vineyards, weeds have traditionally been controlled using repeated cultivation in combination with herbicides. However, high herbicide use in cultural systems can affect soil biodiversity in negative ways (Somerville and Greaves, 1987). Long-term problems with herbicide use include accumulation in the soil, which can damage vine roots, contamination of irrigation dams due to surface runoff and leaching into the ground water (Itoh and Manabe 1997, Lennartz et al. 1997, Williams 1999). Many Australian soils are particularly prone to these problems because of their relatively low water-holding capacity, low water infiltration rate and low organic matter content (Geeves et al. 1994). Moreover, the build-up of herbicide resistance in target weeds is a threat to weed control. Glyphosate-resistant *Lolium rigidum* has already been found in Australian vineyards. Glyphosate (e.g. Roundup^{TM}) is one of the most widely used herbicides in Australia and is also suspected to kill beneficial insects such as parasitic wasps and lacewings (Anonymous 1999).

Weed-free vineyards may thus suffer greater insect pest problems (Robinson 1987), since they are basically monocultures with high input and output. Such 'agricultural ecosystems' are characterised by a lack of stability due to their inherent ecological simplicity (Tedders 1983). There are few ecological niches, and the crop is susceptible to pests, pathogens and weed competition, requiring external regulation to ensure stability of production.

Natural ecosystems, on the other hand, are characterised by high biological diversity. Mass multiplication of any one organism is impossible due to competition, predators and parasites. Disturbances and balance shifts are self-regulated internally. Maintaining such complex ecosystems requires the adoption and optimisation of sustainable production techniques and cultural practices.

The reduction of chemical inputs, particularly pesticides and fertilisers, is an essential first step, which is linked to Integrated Pest and Disease Management (IPDM), closed nutrient cycles and management of stable and diverse agro ecosystems (Boller and Remund 1986). Hence, vineyard soil or floor management is the most important component of the Swiss IP model.

Appropriate soil management practices, such as minimal, shallow tillage, infrequent or alternate mowing and optimal nitrogen fertilisation can enhance botanical diversity (Perret et al. 1993, Gut 1997, Keller 1997). This ensures a constant supply of flowering plants providing a habitat and continuing food supply for predatory mites and other beneficial arthropods (Remund et al. 1989, Debach and Rosen 1991), which generally increase with greater plant diversity. Long-term Swiss studies have demonstrated that a botanically diverse vineyard can be home to up to 3000 arthropod species. Some 25% of these are potentially beneficial (predators and parasitoids) and 70% are indifferent (i.e. neither beneficial nor damaging), while pest populations fluctuate at a very low level (Remund et al. 1989, Boller et al. 1997).

A survey of vineyard fauna in California's hot Central Valley also revealed that cover crops reduced insect pest populations and increased beneficial arthropod populations compared to clean cultivation (Altieri and Schmidt 1985, Mayse et al. 1995).

Soil management according to the Swiss IP model, aims to synchronise water and nutrient supply with vine demand and to ensure long-term soil fertility. Annual nitrogen input and output in a typical European vineyard (from Keller 1997) is shown in Figure 1.1 as an open system.

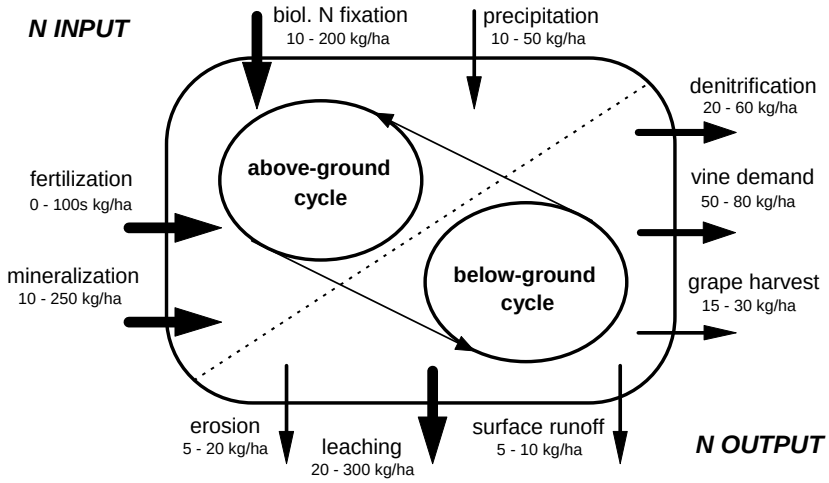


Figure 1.1. Nitrogen cycling typically observed in European vineyards

Individual figures may vary under Australian conditions, but the system and principles remain the same.

Soil fertility can only be sustained if nutrients removed with harvest products and other potential losses are replaced on a regular basis. To achieve this, a strategy termed Adaptive Nitrogen Management was developed as part of the Swiss IP model (Perret et al. 1993). Its aim is to regulate the soil's potential for nitrogen storage and mobilisation by managing site-adapted and botanically diverse ground covers. This is achieved through soil cultivation, mulching or mowing at critical vine growth stages to mobilise organically bound nitrogen, rather than applying fertilisers and herbicides (Perret et al. 1993, Keller 1997). This leads to relatively slow rates of soil nitrate accumulation, but nitrate is available for longer periods of time. During periods of low vine demand the growing floor cover ties up soil nitrogen. The continuous plant cover also improves soil nutrient storage capacity and the balance between individual nutrients such as N, K, P and Mg (Berthold 1991).

Research conducted in California has demonstrated that floor covers can also improve water infiltration in poorly structured soils (Gulick et al. 1994, Bugg and Van Horn 1997). The better soil structure, higher soil organic matter and higher biological activity increase the soil's water holding capacity (Pinamonti et al. 1996) and reduce herbicide persistence and leaching. The strategy has been tested for a variety of soils and climates across Europe, including sandy soils in low-rainfall regions (as low as 500 mm per annum, less than 300 mm

during the growing season). Even under these unfavourable conditions, which are similar to many Australian vineyard sites, permanent ground covers have proved highly successful if implemented carefully. Grape quality was improved even in the low summer-rainfall area of Montalcino, Italy (Ferrini et al. 1996). This has direct implications for vineyard management. To capture these benefits and avoid the environmental problems that characterise current production systems, all viticultural practices should aim to improve and maintain the vineyard as a diverse and stable ecosystem.

1.10 Proposed R & D Program

The world trend towards environmental management systems and integrated fruit production, and increased problems with chemical resistance, will force the Australian wine grape industry to become more environmentally sustainable in addition to maintaining economic viability. There is a paucity of information on the effect of various inputs used in the viticulture production system (herbicides, pesticides, fungicides and fertilisers) on the biological component of the soil. Research is needed into weed / pest / disease control strategies and the influence of such management practices on soil biological resilience.

This project set out to investigate the relative performance of vineyard floor management treatments on vine performance and their impact on vineyard biodiversity and sustainability. The work was carried out at the National Wine & Grape Industry Centre (NWGIC) in Wagga Wagga. The NWGIC is a joint venture of Charles Sturt University (CSU), the NSW Department of Primary Industries (DPI), the NSW Wine Industry Association (WIA) and Deakin University. Several large wine companies expressed interest in and support for this project. They include Southcorp, BRL Hardy, Orlando Wyndham and Yalumba Wine Company. All of them stressed the importance of developing sustainable vineyard management systems for the Australian wine industry.

1.11 Objectives

1. To develop sustainable vineyard floor management systems suitable for Australian conditions, using the Swiss IP model as a basis
2. To investigate the suitability of Australian native plant species as components of sustainable vineyard production systems
3. To determine effects of improved floor management on vineyard input (nutrients, water, pesticides, fuel), environmental impact (biodiversity, nutrient leaching, water

loss, soil stability), vine productivity (vigour, yield, disease incidence), and grape and wine quality (sugar, acid, pH, colour, sensory properties)

4. To reduce the reliance on agrochemicals (pesticides, herbicides, fertilisers) and maintain cost-effectiveness and product quality without compromising the environment in the long term.

The main aim of this project is to adapt the Swiss IP model to suit local Australian conditions. However, the transition to sustainable vineyard management practices requires a long-term approach. We propose to conduct a pilot feasibility study in two climatically different regions (hot/dry and cool/wet) for three years. Future trials will be based on the outcomes of this study along with industry consultation/participation. On-farm trials will then be conducted as part of the CRCV's *Viticare* program and by industry collaborators (BRL Hardy, Southcorp, Yalumba).

A literature review of the Swiss model and other IP approaches overseas (Europe, California, Oregon, New Zealand) was conducted as part of this application. The project was also submitted to industry stakeholders for feedback and comments showed that knowledge on IP (particularly biodiversity and interrelationships with grape production) is required, but doubts were raised that it may not be applicable to all Australian conditions. We have established links with CRCV Project 5.1 (*Viticare*) through the collaboration of Mr S. Hackett (NSW DPI, NSW Viticare Program Coordinator) to ensure ready adoption by industry. Adoption will also be encouraged by providing research results to NSW DPI extension officers who will develop a technical training manual that combines elements of IOBC/WPRS (European IP guidelines) and ISO14001 with project outcomes. This will ensure that claims to a 'clean and green' product can be substantiated through documentation and auditing.

Benefits to industry (based on overseas experience) will be a substantial reduction in the use of agrochemicals (pesticides, herbicides, fertilisers) and more sustainable viticultural practices with associated benefits for consumers and the environment. The enhanced 'clean and green' image on both national and international markets will ensure Australia's competitive advantage in the future.

The development of sound technical information is required so that growers can effectively make the transition to sustainable practices. This transition does not occur overnight.

Restoring more natural vineyard ecosystems is a long-term exercise. This is also true for the current proposal. The challenge is to provide an adequate long-term research effort that will examine the feasibility of sustainable viticulture practices in the Australian context. A comprehensive long-term, multi-disciplinary approach is needed to achieve this goal. More information in this area would benefit growers, consumers and the environment.

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2. General Materials and Methods (Site description, treatments, trial design, management operations and measurements)

Ron Hutton

2.1 Vineyard sites

Two drip-irrigated *Vitis vinifera* L. cv. Chardonnay vineyards located in climatically distinct grape-growing regions (Table 2.1) in New South Wales were selected for the trial. The CSU Winery vineyard at Wagga Wagga (147°20'57"E; -35°03'06"S; elevation 239 m) site was in a hot and semi-arid area (mean January temperature 24.0ºC, 2050 growing degree-days >10°C and 304 mm rainfall over the October-April season). The other site was a commercial vineyard at Tumbarumba (148°00'44"E; -35°46'41"S; elevation 645 m) with a mild and semi-humid climate (20.1ºC, 1318 growing degree-days and 492 mm rainfall from October to April). Frost is often experienced in the early part of the growing season in cooler climates such as Tumbarumba.

The CSU vineyard was planted to own-rooted Chardonnay vines in 1997 and the Tumbarumba vineyard was planted similarly in 1989, with 3 m between rows and 2 m between vines. Row direction was E-W at the Wagga Wagga site and NE-SW at Tumbarumba. At both sites vines were cordon-trained and spur-pruned (approximately 25 buds/vine) by hand. Canopy management used a simple single cordon wire and one foliage wire at both sites. However, excessive vine vigour can be a problem in the cooler climate production areas and canopy management often relies on split canopy systems. A cover crop of cocksfoot and subterranean clover mix was sown in June 2002 but severe rainfall deficiencies during winter and spring resulted in poor establishment, so that the non-herbicided plots contained a diversity of plant species with a mixture of grasses such as *Cynodon, Stellaria, Erogrostis, Digataria and Panicum*, and other herbaceous species.

Table 2.1. Mean climatic conditions at the comparatively hotter and drier climate of Wagga Wagga and cooler and wetter climate of Tumbarumba (The Australian Bureau of Meteorology, periods: 1912-2001 for Wagga Wagga and 1885-2001 for Tumbarumba).

Month	Wagga			Tumbarumba		
	Min temp. (ºC)	Max temp. (ºC)	Rainfall (mm)	Min temp. (ºC)	Max temp. (ºC)	Rainfall (mm)
January	16.6	31.4	39.6	12.0	28.2	64.0
February	16.6	30.5	42.2	11.7	28.0	52.1
March	14.2	27.7	41.0	8.6	24.8	67.0
April	10.2	22.4	42.9	4.3	19.6	67.1
May	6.5	16.7	43.8	2.5	15.1	86.0
June	4.2	13.8	49.8	0.1	11.4	104.0
July	3.4	12.6	46.0	-0.2	10.5	105.9
August	4.2	13.9	50.6	0.9	12.2	106.8
September	5.5	17.4	45.0	3.0	15.1	91.7
October	8.5	20.3	55.1	5.3	19.2	99.2
November	10.2	24.8	42.1	7.1	22.1	72.0
December	13.8	29.2	41.5	9.5	25.9	70.6

Seasonal weather conditions varied over the experimental period. The 2002/03 season, with less than a third of normal rainfall over the October-April period, stands out as extremely dry and hot.

The soil type at Wagga Wagga was a Basic Paralithic Orthic Tenosol overlaying coarse granite (BPOT; ASC[1]) in the southeast and northern part of the site and Haplic Red Kandosol overlaying coarse granite (HRK; ASC) in the south western corner (AMG Grid Reference 532853E, 6120170N; longitude 147.360290, Latitude -35.060544; Wagga Wagga, 8327). In 2002, before the treatments were applied, average inter-row soil pH was 7.0 (1:5, 0.01 M of $CaCl_2$); $NaHCO_3$-extractable phosphate (available P) was 36 mg kg^{-1} (Colwell 1963) and total soil organic C (OC) (0-10 cm soil depth, dichromate oxidation method) was 0.81% in the under-vine and 0.92% in the inter-row soil.

[1] ASC = Australian Soil Classification.

The soil at Tumbarumba was a brown clay-loam with a shallow A horizon of silty clay loam over a deeper (up to 90 cm) B horizon of light clay. $NaHCO_3$-extractable P was 20 mg/kg soil in the inter-row (Colwell, 1963). Soil pH (1:5, 0.01 M of $CaCl_2$) was 5.9 and oxidisable organic carbon (dichromate oxidation method) was 1.7 %.

The vines in each vineyard were irrigated with the same amount of water across all treatments and fertilized according to the standard practice applied by respective vineyard managers. Water meters were installed at the Wagga Wagga trial site, and they recorded a seasonal (October-April) irrigation amount of 1.73, 1.65, and 1.93 ML/ha for the 2002/03, 2003/04 and 2004/05 seasons, respectively. Water meters were installed at Tumbarumba only in the 2004/05 season. Vineyards in this area are normally not as dependent on irrigation as those in the warmer areas like Wagga, and the recorded seasonal amount of irrigation was only 0.46 ML/ha. The irrigation strategy was determined by the respective vineyard managers at each site and the information driving these decisions was not made available.

2.2 Floor management treatments

Three distinct experimental vineyard floor management treatments were established and maintained at each vineyard, representing our best effort to simulate different common approaches to grape production.

(1) ***Unvegetated***: herbicide sprayout of undervine and inter-row vegetation.
(2) ***Partially Vegetated***: Undervine herbicide strip with permanent resident vegetation between rows.
(3) ***Vegetated (No herbicide)***: Complete permanent resident vegetation managed by alternate mowing regime and no herbicide applications.

These treatments were applied in consecutive growing seasons from 2001/02 through to 2004/05. In 2001/02, treatments were applied only at Wagga Wagga, while for the remaining three seasons both sites received the same treatments.

An EM38 soil survey was performed at the CSU Vineyard at Wagga Wagga prior to establishing the trial site. This, in conjunction with Hyperspectral images of vine vigour (courtesy, Dr David Lamb; CRCV project 1.1.1) was used to characterise an area of maximum uniformity within the CSU vineyard, based on vine vigour and historical yield data recorded in previous seasons prior to treatment application.

The original trial design established in the 2001/02 season at the Wagga Wagga site used a randomised block design with four 20 m replicate plots of 198 vines, each consisting of six adjacent mid-rows. This was subsequently amended from the start of the 2002/03 season by reducing the plot size and increasing the level of replication to give greater experimental precision.

Experimental treatments were arranged in a randomized block design with 12 replicate plots, each of 27 vines comprising three panels of three vines per panel. The new trial design was superimposed over the original layout at Wagga Wagga and this design was mirrored in a new site that was selected at Tumbarumba such that both trial sites were identical. Floor vegetation treatments were applied on 8 m plots of four adjacent mid-rows, using the vines in the centre row for data collection. Twelve plots existed for each treatment, with a total number of experimental plots being 36 at each site.

Single vine-row corridors between the three rows of randomised plots within each experimental block were used to ensure that a continuous natural ecosystem existed adjacent to all treatments. At WaggaWagga, the entire vineyard was over-sown with a perennial grass mix of cocksfoot and sub clover that was direct drilled into the natural site-adapted grass sward present in autumn and spring. At Tumbarumba, the naturally occurring grasses were well adapted and there was no need to modify the species mix present in the mid-rows.

On 20 October 2001, frost severely damaged the trial site in Tumbarumba and the trial at this location was aborted. Drought in 2002/03 and 2003/04 severely affected the establishment of the over-sown perennial grasses and they had to be repeatedly direct drilled into the natural site-adapted grass sward each autumn. It was originally envisaged that the cocksfoot/sub clover grasses would actively grow, flower, seed and self sow during spring before haying off during summer before germinating in the following autumn/winter period.

2.3 Herbicide applications

Herbicide applications in the unvegetated and partially vegetated treatment plots at the Wagga Wagga trial site used a diquat and paraquat mixture applied at the appropriate label recommended rates (2.78L/ha) in April, September, October and November of 2002 and in June, November and December of 2003. A mixture of carfentrazone-ethyl and glyphosate (1.85L/ha) was applied in March and October of 2003.

At the Tumbarumba trial site, glyphosate (1.85L/ha) was applied to the appropriate treatment plots in July 2002. A diquat and paraquat mixture (2.78L/ha) was subsequently applied in October and November 2002, January, June, November and December 2003 and in January 2004. A mixture of carfentrazone-ethyl and glyphosate herbicide was also applied in September and October 2003.

2.4 Soil water measurements

Soil water content was monitored in 2003/04 and 2004/05, using neutron probes in each plot in four different positions (underneath the irrigation drip emitter, immediately adjacent to the vine, at approximately 50 cm from the vine row into the alley and in the centre of the alley). These neutron probe access tubes enabled measurements of volumetric soil moisture content at the following depths: 20 cm, 30 cm, 40 cm, 50 cm, 70 cm, 90 cm and 110 cm. Gravimetric soil moisture content in winter (July 2004) was determined from soil samples collected from 10-15 cm depth from selected plots. The samples were dried in an oven at 100 °C until constant weight.

Soil physical and chemical properties including soil water and plant-available nutrients were monitored at key vine-growth stages during the season. Soil moisture tension (kPa) was monitored using gypsum blocks and Watermark sensors connected to a G Bug logging system (Measurement Engineering Australia, Magill, South Australia). Gypsum blocks and Watermark sensors measure soil moisture tension which is a direct measure of suction required for vines to extract water from the soil. Four sensors were positioned around the in-line irrigation dripper nearest the vine in the vine-line at depths of 20 cm, 50 cm, 70 cm and 100 cm. A set of sensors were also placed from the vine-line dripper into the mid-row. Two sensors near the dripper were located near the vine at 50 cm and 100 cm depth and a further two were placed at approximately 50 cm from the vine row into the alley and in the centre of the alley at depths of 50 cm respectively. This set-up was replicated 12 times across the trial site at Wagga Wagga (with a total of four replicates in each of the three treatments) and 9 times at Tumbarumba (having three replicates of each treatment). A simpler set-up was located at Tumbarumba from October 2002 to March 2004, having only one replicate per treatment.

Irrigations were scheduled when tensions exceeded 80-100 kPa at 50cm root zone soil depth. Neutron probe access tubes were also installed at both sites and volumetric moisture content was recorded in train with the tension measurements each season. Irrigation volumes were also recorded and seasonal water use was computed at the end of each season.

2.5 Soil Analyses

Soil samples were collected from selected plots, both from under-vine and mid-row positions, from the 0-10 cm layer in July 2002, August 2003 and December 2004. Samples were collected from the 0-10 cm layer, as the floor cover treatments were expected to show the greatest effect over time in the topsoil. In December 2004, soil samples were also collected from the 40-50 cm layer.

Soil samples were sent to the Pivotec Laboratory (Werribee, Victoria) for analysis of major nutrients. Measurements were made of organic carbon, pH, available N, P and K and CEC from under vine and inter row. Organic Carbon was determined by dichromate oxidation and titration. Also determined were: CEC total, Al, Ca, Na, Mg, K (0.1M NH_4Cl/ 0.1M $BaCl_2$); Zn, Mn and Fe extracted in DTPA, $CaCl_2.2H_20$, triehanolamine, ICP-AES); K (1 M HNO_3 at 100 °C, ICP-AES); Mn (DTPA, $CaCl_2.2H_2O$, triehanolamine, ICP-AES); total N (Kjeldahl digestion); nitrate (1M KCl); total P (Kjeldahl digestion); available phosphate (Colwell); pH (water); pH ($CaCl_2$) and available S (0.01M $CaHPO_4$). Soil analyses at both sites were undertaken in three successive seasons from 2002/03.

2.6 Vine performance measurements

During each growing season, weekly measurements of shoot length were made from flowering until harvest and canopy measurements using a septometer were taken at veraison. To determine plant nutrient status, 25 petioles were collected from each experimental plot (with a total of 36 samples per site) from nodes opposite an inflorescence or bunch at flowering (2003/04 and 2004/05) and veraison (2002/03 and 2003/04). They were analysed at the Waite Analytical Services (Adelaide, South Australia) for macro- and micro-nutrients by Inductively Coupled Plasma Atomic Emission Spectrometry. Leaf petiole samples were taken at the same time for assessing foliar nutrient levels.

Viticultural performance of Chardonnay grapevines was assessed by measuring grape yield and bunch number per vine at harvest (all treatments were hand harvested on the same date). Average berry weight was determined at veraison, mid-maturity and at harvest using a sample of 50 berries randomly collected from each plot. Vine vegetative growth was assessed by measuring length of ten shoots per selected plot on a weekly basis. The weight of winter prunings was measured for each plot. The canopy point quadrat method (Smart 1988) was used at veraison to assess canopy architecture on selected plots in the 2001/02, 2002/03 and 2003/04 seasons. In the 2004/05 season, three key phenological stages (budburst, flowering and veraison) were also monitored as described in Tesic et al. (2002), on two vines per selected plot. Phenological and shoot growth data were used to calculate average early-season vigour (daily shoot growth rate during the budburst-flowering period). Overall vine performance was assessed by correlating yield and pruning weights (vigour, vine balance) whilst grape and wine composition was measured (standard analyses) together with wine sensory evaluation following small-scale winemaking.

At harvest, measurements of berry size, bunch number, TA, Baume, pH, and yield were recorded. Fresh berries were analysed for total soluble solids (TSS) by refractometer. Titratable acidity (TA) and pH of the juice were determined from frozen grape samples using TitraLab 80 (Radiometer Copenhagen, Willich-Schiefbahn, Germany). Grape composition was determined at harvest in all seasons and at veraison, mid-maturity and harvest in 2004/05. Grapes harvested from selected plots were used for small-lot vinification in 2002/03, 2003/04 and 2004/05 to evaluate the impact of management inputs on wine quality.

2.7 Soil Microbial Analyses

Microbial diversity in the soil was assessed in soil samples on relative population levels (dilution plate method), relative acidity levels (dehydrogenase activity) and a qualitative test for actinomycete population levels. Soil-P solubilising microbes were also monitored.

2.8 Arthropod Analyses

Arthropod diversity was monitored using pitfall traps and sticky window traps.

2.9 Botanical Analyses

Botanical analyses of the vineyards were conducted in March and October in Wagga and in October in Tumbarumba in 2002/03 to establish a baseline species diversity reference point. From this time until October 2005, botanical analyses were undertaken each October and March to monitor changes in species mix at both sites. Seed bank trials were undertaken in spring 2002 and spring 2005 to identify the impact of vineyard floor management treatments on species abundance at both Wagga and Tumbarumba sites. Botanical diversity and population dynamics, and potential weed invasion was assessed (species number and abundance, vegetative cover) throughout the year using ground evaluation.

2.10 Statistical Analyses

Statistical analysis of data was conducted using *Statistica* 7.1 software package (StatSoft, Tulsa, OK, USA), Genstat for Windows, 8th edition (ANOVA, ASREML) and Principal Component Analysis (PCA) depending on the nature of the data. Correlation and regression analysis were used to determine the relationship between selected variables, and ANOVA and LSD 1-way and 2-way tests were used to determine significance of differences between treatments. Unless otherwise indicated, results with $p<0.05$ were considered to be statistically significant in this experiment.

3. Vineyard floor management practices affect grapevine vegetative growth, yield and fruit composition

Dejan Tescic, Ron Hutton, Emily Rouse

3.1 Abstract

The viticultural effects of sward competition with vines for water and nutrients, indirectly resulting from reduced herbicide use under a sustainable production system, are well established in cooler, more humid areas, but are less well understood in warm and dry areas. Three floor management treatments were applied in two Chardonnay vineyards at Wagga Wagga and Tumbarumba. The three floor management treatments were: (1) unvegetated (complete herbicide spray), (2) partially vegetated (under-vine strip sprays), and (3) vegetated (mowed with no herbicide). Increased floor vegetation decreased early-season soil moisture and petiole nutrient status, and strongly reduced vine vegetative growth. After three experimental years, grape yield also became limited. Large treatment differences in vegetative growth, canopy structure and yield contributed to differences in berry weight and composition. Vine response to floor vegetation was less pronounced at Tumbarumba under mild climatic conditions compared to the hot and dry conditions at Wagga. Total or partial floor vegetation is a powerful tool for controlling vegetative growth of grapevines. However, under hot and dry conditions, competition for water and nutrients, particularly at sensitive development stages (eg. flowering and berry set) can lead to a substantial decrease in vine capacity.

3.2 Introduction

In Australian vineyards, weeds have traditionally been controlled by using repeated cultivation in combination with herbicides. However, long-term problems with herbicide use include accumulation in the soil, which can damage vine roots, contamination of irrigation dams through surface runoff, and leaching into the ground water (Lennartz et al. 1997). Many Australian soils are prone to these problems because of their relatively low water-holding capacity, low water infiltration rate and low organic matter content (Geeves et al. 1994). Moreover, the appearance of herbicide resistance in target weeds is a threat to weed control. For example, glyphosate-resistant *Lolium rigidum* has already been found in Australian vineyards and orchards (Powles et al. 1998).

Weed-free vineyards may lead to increased insect pest problems (Robinson 1987), since they are essentially high-input monocultures. Such 'agricultural ecosystems' are characterised by a lack of stability due to their inherent ecological simplicity (Tedders 1983). Maintaining complex ecosystems requires adopting and optimising sustainable production techniques and cultural practices that form a part of an integrated management system. Reducing chemical inputs is an essential first step, which is linked to integrated pest and disease management, closed nutrient cycles and management of stable and diverse agroecosystems (Boller and Remund 1986).

To bring vineyards closer to natural conditions, the Swiss model of integrated production (IP), developed at the Federal Research Station in Wädenswil, stresses the desirability of high biodiversity, sustained soil fertility, optimal growing conditions and minimal unintended environmental side effects while maintaining cost-effectiveness. Vineyard floor management is an integral component of IP, various versions of which are being implemented across Europe, North America, South Africa and New Zealand.

The IP model was designed primarily for environmental reasons, but maintaining vegetation under vines has produced conflicting results when it comes to vine behaviour. Research in California has demonstrated that floor vegetation can improve water infiltration in poorly structured soils (Gulick et al. 1994, Bugg and Van Horn 1997). Improved soil structure, higher soil organic matter and higher biological activity also increase the soil's water holding capacity (Pinamonti et al. 1996) and reduce herbicide persistence and leaching. Permanent vineyard cover crops or swards have been examined on a variety of soils and climates across Europe, including light-textured soils in dry regions. A reduction in vine vigour was observed in Bordeaux vineyards when comparing various swards with traditional soil cultivation, although the reduced vigour was not necessarily associated with reduced yield (Coulon 2002). Malbec vines grown on poorly structured soils with low organic matter in Argentina had canopies that were less dense under a variety of cover crops than under bare soils maintained with herbicides (Uliarte et al. 2004). Sward-vine competition reduced vine vigour and yield in cool dry parts of Germany so much that, in the 1950s, cover crops were abandoned in dryland vineyards as unsustainable (Homrighausen 1990, cited in Schultz and Löhnertz 2002). Similarly, in South Africa, van Huyssteen and Weber (1980a) found the permanent grass cover detrimental owing to severe transpiration losses in Chenin Blanc vines. Grape quality was improved by using a permanent floor cover in the dry summers of Montalcino, Italy

(Ferrini et al. 1996). Conversely, cover crops were associated with an off-flavour development in white wines in Germany, presumably via a lack of nitrogen and water arising from sward-vine competition (Schultz and Löhnertz 2002).

Thus, creating an environmentally sustainable viticultural production system raises the issue of sward-vine interaction, which is an indirect result of reducing herbicide use and soil cultivation. Appropriate floor management practices are vital for successful implementation of sustainable production systems (Pimentel et al. 1992). There is ample experience in switching from conventional to sustainable floor management practices in mild and humid climatic conditions, but less so in warm and dry conditions commonly found in Australia. This chapter examines sward-vine interactions on irrigated Chardonnay grapevines. We explored how these treatments compare between hot dry and mild semi-humid climatic conditions and show that a permanent vineyard sward causes a striking decrease in Chardonnay vigour and yield in the hot and dry climate in comparison with a mild and semi-humid climate.

3.3 Materials and Methods

The three floor cover treatments represented different approaches to grape production:

(1) Unvegetated: completely bare soil maintained by repeated application of herbicides.

(2) Partially vegetated: herbicide strips under vines and permanent resident vegetation between rows with a regular mowing regime. The sward was mowed about 3-4 times per season (mostly during spring), based on visual inspection of sward growth. Most of the resident vegetation was summer-dormant, particularly in Wagga Wagga. A 100-cm wide strip under vines was kept weed-free by herbicide application;

(3) Vegetated: complete permanent resident vegetation with a regular mowing regime (as above) and no herbicide application. The area under vines was mown using a hand-operated lawn trimmer.

These treatments were applied in the growing seasons 2001/02 through to 2004/05. In 2001/02 treatments were applied only at Wagga Wagga, while the remaining three seasons included both sites.

Soil water content was monitored in 2003/04 and 2004/05 using neutron probes in each plot in four different positions (underneath the irrigation drip emitter, immediately adjacent to the

vine, at approximately 50 cm from the vine row into the alley and in the centre of the alley). These neutron probe access tubes enabled measurements of volumetric soil moisture content at depths of 20 cm, 30 cm, 40 cm, 50 cm, 70 cm, 90 cm and 110 cm. Gravimetric soil moisture content in winter (July 2004) was determined from soil samples collected from 10-15 cm depth from selected plots. The samples were dried in an oven at 100 °C until constant weight.

Soil moisture tension was recorded using gypsum blocks (G-Bug System) as described in General Methods (section 2.4).

Soil samples were collected from selected plots, both from under-vine and mid-row positions, from the 0-10 cm layer in July 2002, August 2003 and December 2004. Samples were collected from the 0-10 cm layer, as the floor cover treatments were expected to show the greatest effect over time in the topsoil. In December 2004, soil samples were also collected from the 40-50 cm layer.

Soil samples were analysed at the Pivotec Laboratory (Werribee, Victoria) for major nutrients. To determine plant nutrient status, 25 petioles were collected from each experimental plot (with a total of 36 samples per site) from nodes opposite an inflorescence or bunch at flowering (2003/04 and 2004/05) and veraison (2002/03 and 2003/04). They were analysed at the Waite Analytical Services (Adelaide, South Australia) for macro- and micro-nutrients by Inductively Coupled Plasma Atomic Emission Spectrometry.

Viticultural performance of Chardonnay grapevines was assessed by measuring grape yield and bunch number per vine at harvest (all treatments were hand harvested on the same date). Average berry weight was determined at veraison, mid-maturity and at harvest using a sample of 50 berries randomly collected from each plot. Vine vegetative growth was assessed by measuring the length of ten shoots per selected plot on a weekly basis. In the 2004/05 season, three key phenological stages (budburst, flowering and veraison) were also monitored as described in Tesic et al. (2002), on two vines per selected plot. Shoot growth data recorded at specific growth stages in the phenological growth cycle were used to calculate average early-season vigour (daily shoot growth rate during the budburst-flowering period).

Fresh berries were analysed for total soluble solids (TSS) by refractometer. Titratable acidity (TA) and pH of the juice were determined from frozen grape samples using TitraLab 80 (Radiometer Copenhagen, Willich-Schiefbahn, Germany). Grapes harvested from selected plots were used for small-lot vinification in 2002/03, 2003/04 and 2004/05, detailed methods and results of which will be reported in a separate publication.

Statistical analysis of data was conducted using *Statistica* 7.1 software package (StatSoft, Tulsa, OK, USA). Correlation and regression analysis were used to determine the relationship between selected variables, and ANOVA and LSD tests were used to determine significance of differences between treatments. Unless otherwise indicated, results with $p<0.05$ were considered to be statistically significant in this experiment.

3.4 Results

3.4.1 Soil moisture

Increasing floor vegetation led to lower soil moisture content in the 2003/04 and 2004/05 seasons. These measurements showed some extremely low values of moisture content, particularly at 30 cm soil depth at Wagga Wagga (Fig. 3.1a). This can be related to texture of the topsoil at this site, coarse sand having a very low field capacity. The corresponding value at Tumbarumba was 20.4%. Soil moisture content at Wagga Wagga, measured at 30 cm, showed a lot of variability, particularly when monitored under irrigation drippers and near vines. This is less obvious in the corresponding Tumbarumba measurements, which can be related to the less frequent irrigation events at the latter site. A similar observation can be made when comparing the 30 cm and 90 cm soil moisture readings – they generally fluctuated less at Tumbarumba than at Wagga Wagga, again probably because of the effect of irrigation.

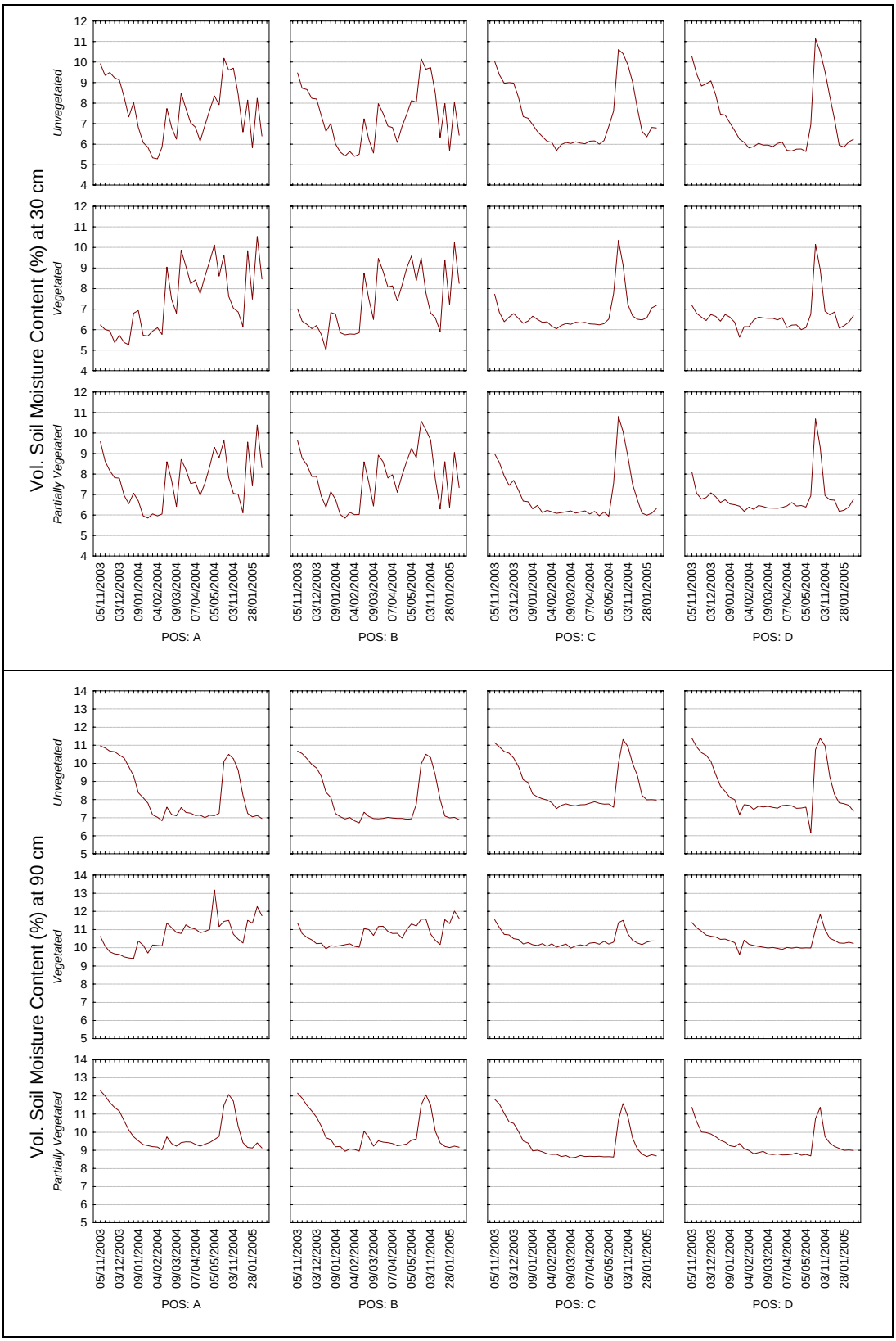


Figure 3.1a. Volumetric soil moisture content at Wagga Wagga, measured at 30 cm (top) and 90 cm depth (bottom). Neutron probe access tubes were located under drippers (A) vine (B), at the wheel track (C) and mid-row (D).

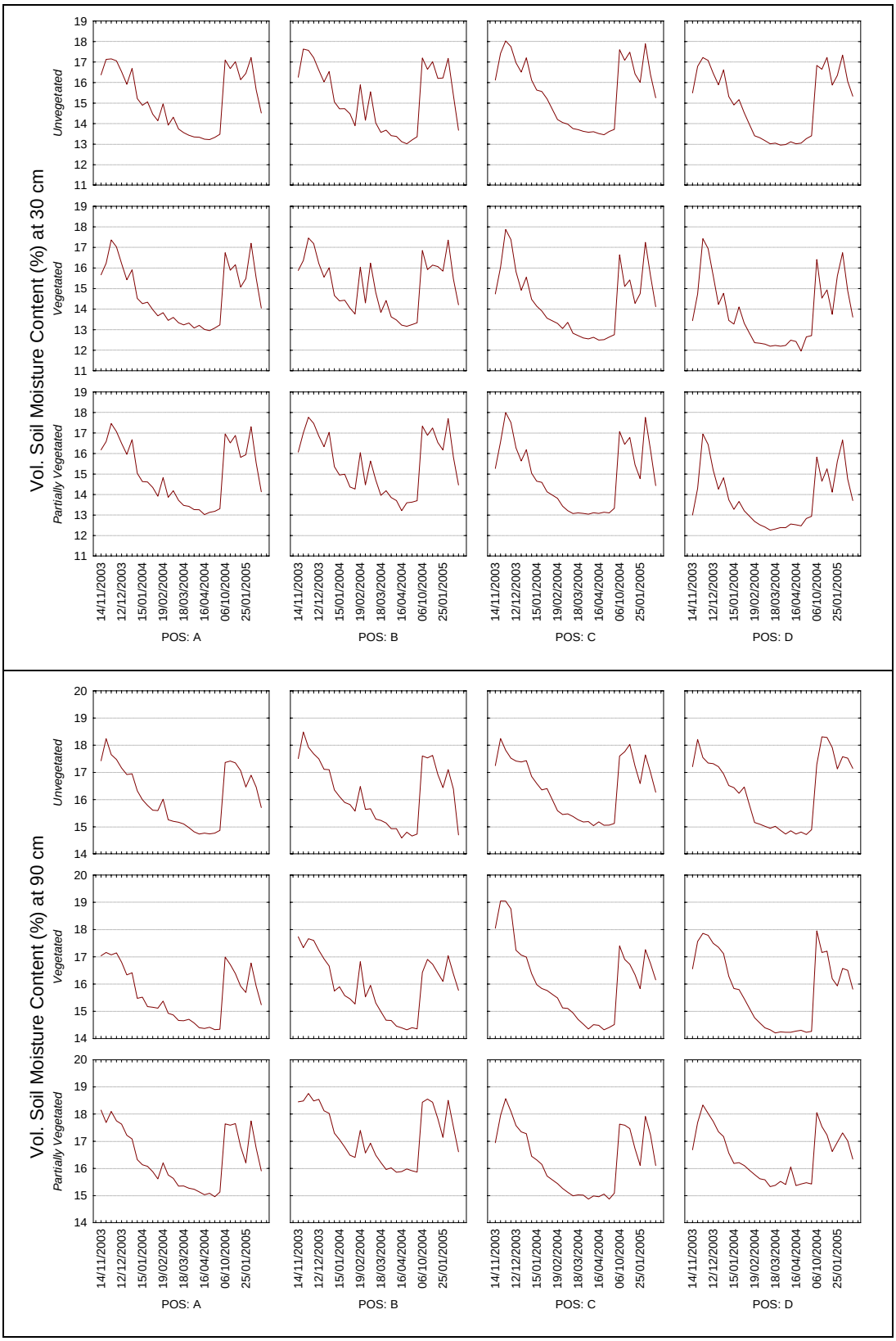


Figure 3.1b. Volumetric soil moisture content at Tumbarumba, measured at 30 cm (top) and 90 cm depth (bottom). Neutron probe access tubes were located under drippers (A) vine (B), at the wheel track (C) and mid-row (D).

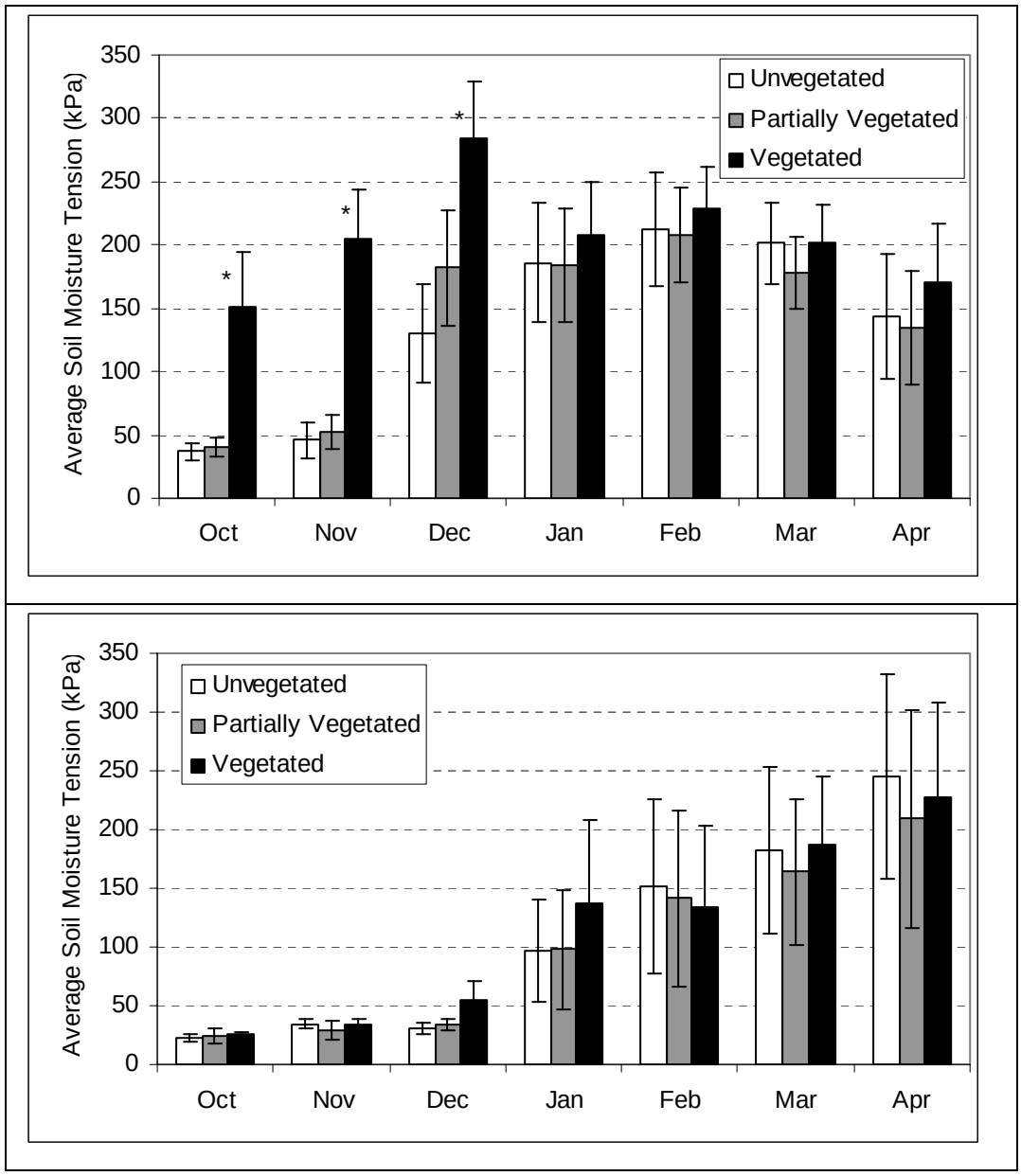


Figure 3.2. Mean monthly soil moisture tension measured at 20-100 cm under vines at Wagga Wagga (top) and Tumbarumba (bottom). Values represent averages for the 2002/03, 2003/04 and 2004/05 seasons. Vertical bars denote one standard deviation. Asterisks mark significant differences between treatments at $p<0.05$. In each season over the experimental period, irrigation commenced early November at Wagga Wagga, and late December at Tumbarumba.

The effect of floor management on soil moisture tension (average for the 2002/03, 2003/04 and 2004/05 seasons) was very strong at Wagga Wagga (Fig. 3.2). Measurements for the *vegetated* treatment at Wagga Wagga in spring and early summer indicate exceptionally dry soil conditions. Differences in mean monthly soil water tension at Tumbarumba were not significant, however at both sites there was a large variability in soil moisture tension, probably related to variable rainfall over years (Fig. 3.3), as well as to the natural soil variability.

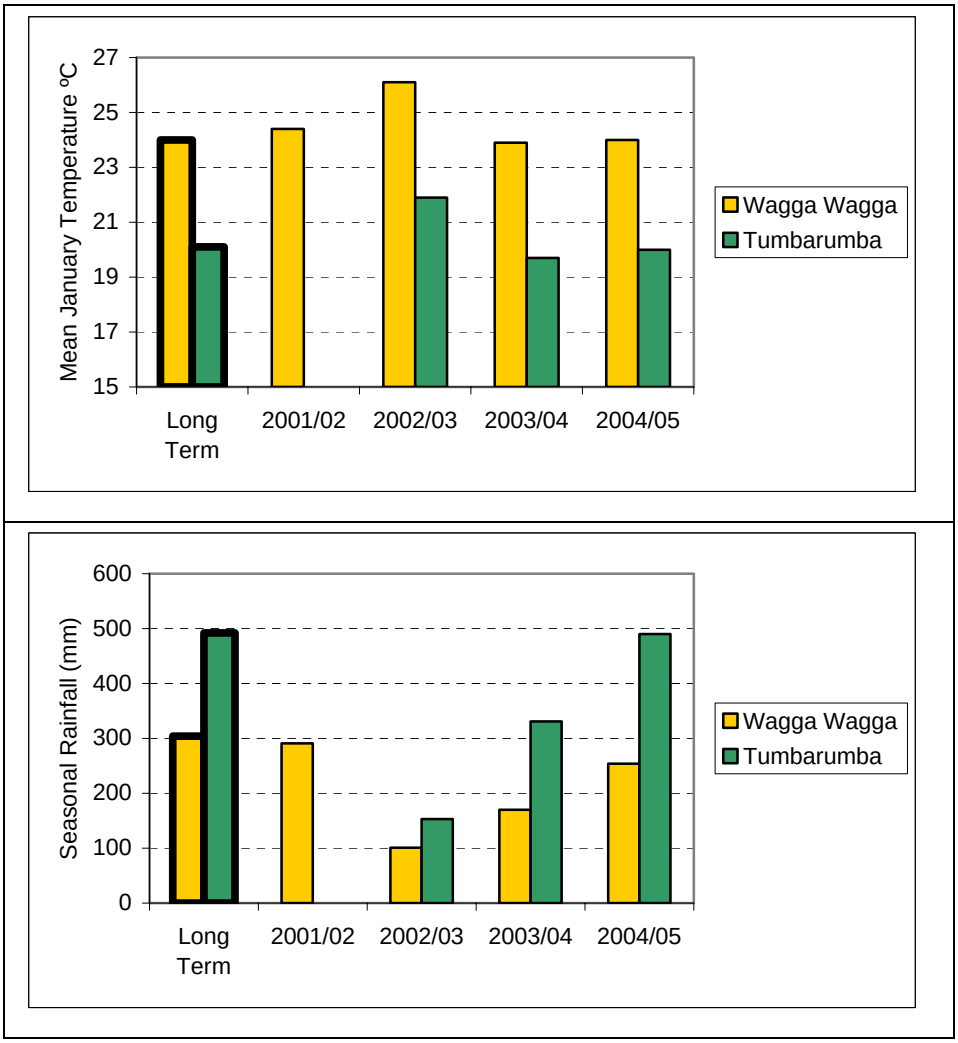


Figure 3.3. Mean January temperature (top) and seasonal (October-April) rainfall (bottom) at Wagga Wagga and Tumbarumba, shown long term and over the experimental period. (The Australian Bureau of Meteorology; long-term data based on periods: 1912-2001 for Wagga Wagga and 1885-2001 for Tumbarumba).

3.4.2 Soil composition

After three experimental years at Wagga Wagga, and two at Tumbarumba, there were few treatment differences in soil composition at 40-50 cm soil depth (Table 3.1). More Phosphorus was determined in the *vegetated treatment* plots than in the other two treatments at Tumbarumba, and at the same site, the soil pH was less acidic in *unvegetated* than in the other two treatments. Soil nitrate contents were extremely low and did not permit statistical data analysis. No differences among treatments were found for any other soil properties investigated (Table 3.1).

Table 3.1. Soil composition at 40-50 cm under vines in December 2004 as affected by vineyard floor cover at both vineyards.

	Wagga Wagga			Tumbarumba		
	Unvegetated	*Partially vegetated*	*Vegetated*	*Unvegetated*	*Partially vegetated*	*Vegetated*
Nitrate N (mg/kg)	1.4	1.1	1.1	2.6	<1	<1
P - Colwell (mg/kg)	33.0	12.0	32.8	12.3 **b**	7.5 **b**	20.8 **a**
K available (mg/kg)	88.8	99.0	104.3	176.0	168.3	144.0
S available (mg/kg)	1.8	2.7	2.5	35.0	43.0	46.5
Electrical conductivity (dS/m)	0.04	0.04	0.04	0.04	0.03	0.04
Organic carbon (%)	0.22	0.27	0.22	0.35	0.31	0.33
pH H_2O	7.70	7.60	7.45	5.58 **a**	5.43 **b**	5.35 **b**
pH $CaCl_2$	6.75	6.60	6.48	4.73 **a**	4.58 **b**	4.55 **b**
Total Cation EC (meq/100g)	5.40	5.22	5.15	7.01	6.67	6.83
Al EC (meq/100g)	nd	Nd	nd	0.62	0.94	1.00
Ca EC (meq/100g)	3.78	3.41	3.43	4.78	4.28	4.31
Mg EC (meq/100g)	1.23	1.36	1.25	1.06	0.93	1.06
Na EC (meq/100g)	0.17	0.20	0.21	0.11	0.09	0.09
K EC (meq/100g)	0.23	0.25	0.27	0.45	0.43	0.37

Different letters within rows denote values different at LSD<0.05. All values are expressed on a dry soil basis; nd – not done; EC – exchange capacity.

In agreement with the climatic differences between the two sites (Figure 3.3), the Tumbarumba soil had more organic carbon (1.5%) than the Wagga Wagga soil (0.8%). Although organic carbon content in the 0-10 cm soil layer (Table 3.2) was not affected by the floor management treatments, there was more organic C in the mid-row (mean 1.3%) than under vines (mean 1%), regardless of site, treatment or year. Interaction of site and year was observed at Tumbarumba, where the 2002 and 2004 means were different (1.5 % and 1.6%, respectively). There was also an interaction of treatment with year, as overall mean for *partially vegetated* in 2002 (1%) was less than in 2004 (1.2%).

Table 3.2. Organic Carbon (%) in soil samples collected from 0-10 cm as affected by vineyard floor cover at both vineyards.

	Wagga Wagga					
	Mid-row position			Under-vine position		
	Jul-02	Aug-03	Dec-04	Jul-02	Aug-03	Dec-04
Unvegetated	1.0	0.8	0.8	0.9	0.6	0.6
Partially vegetated	0.9	0.8	0.9	0.7	0.7	0.7
Vegetated	0.9	0.7	0.8	0.8	0.6	0.8
	Tumbarumba					
	Mid-row position			Under-vine position		
	Jul-02	Aug-03	Dec-04	Jul-02	Aug-03	Dec-04
Unvegetated	1.8	1.7	1.7	1.2	1.4	1.3
Partially vegetated	1.5	1.8	2.1	1.1	1.2	1.2
Vegetated	1.8	1.8	1.9	1.4	1.3	1.3

3.4.3 Petiole nutrient content

Nutrient content in petioles (Table 3.3) indicates that there was some effect of floor management treatments on vine nutrient uptake. In the 2003/04 and 2004/05 seasons, N at flowering was significantly less in *vegetated* than in *unvegetated* (and in some cases *partially vegetated*) treatments at both sites. This difference was also found in Wagga Wagga petioles collected at veraison in the 2003/04 and 2004/05 seasons, and at Tumbarumba in 2004/05.

Table 3.3. Petiole nutrient content at flowering as affected by vineyard floor cover at Wagga Wagga and Tumbarumba.

		Wagga Wagga					
		Season 2003/04			Season 2004/05		
		Unvegetated	*Partially vegetated*	*Vegetated*	*Unvegetated*	*Partially vegetated*	*Vegetated*
Total N	(%)	0.96 **a**	0.71 **a**	0.65 **b**	1.39 **a**	1.05 **a**	0.83 **b**
P	g/kg	2.6 **b**	4.8 **a**	2.9 **a**	2.4	2.8	2.0
K	g/kg	36.7 **a**	33.2 **b**	35.8 **a**	27.3 **a**	24.3 **b**	29.3 **a**
Ca	g/kg	13.2	13.1	12.6	11.8	11.6	11.6
Mg	g/kg	3.9 **a**	3.8 **a**	3.4 **b**	5.0 **a**	4.8 **a**	3.8 **b**
S	mg/kg	847 **b**	1060 **a**	947 **b**	927	956	1025
Fe	mg/kg	18.8	16.7	18.2	17.6	17.4	15.5
Mn	mg/kg	78.3	57.2	63.0	53.4	46.7	61.5
Zn	mg/kg	43.1	41.9	44.9	39.9	39.2	42.4
Cu	mg/kg	6.2 **a**	6.6 **a**	4.8 **b**	14.2	14.2	14.6
B	mg/kg	140	132	151	105	107	122
Mo	mg/kg	<0.9	<0.9	<0.9	<0.5	<0.5	<0.5
Na	mg/kg	149.0	152.1	158.4	140.6 **b**	138.4 **b**	157.4 **a**
Ni	mg/kg	<1	<1	<1	0.6	0.7	0.7
Cd	mg/kg	<0.4	<0.4	<0.4	<0.1	<0.1	<0.1
Co	mg/kg	<0.9	<0.9	<0.9	<0.3	<0.3	<0.3
Al	mg/kg	6.9	6.7	11.9	3.4	3.5	3.6
		Tumbarumba					
		Season 2003/04			Season 2004/05		
		Unvegetated	*Partially vegetated*	*Vegetated*	*Unvegetated*	*Partially vegetated*	*Vegetated*
Total N	(%)	1.79 **a**	1.65 **b**	1.46 **c**	1.45 **a**	1.35 **a**	1.10 **b**
P	g/kg	6.4	6.9	6.1	4.9	5.0	4.9
K	g/kg	34.0 **a**	32.2 **a**	26.0 **b**	33.8	32.3	33.3
Ca	g/kg	10.1	9.7	10.2	10.3	10.0	10.0
Mg	g/kg	6.3 **a**	5.1 **b**	5.6 **b**	5.5	5.5	5.0
S	mg/kg	1875 **b**	2450 **a**	2240 **a**	1583 **b**	1906 **a**	1653 **b**
Fe	mg/kg	23.2	24.7	25.0	21.4	22.2	21.1
Mn	mg/kg	171	185	186	144	142	108
Zn	mg/kg	82.8	96.4	88.5	71.3	80.3	82.6
Cu	mg/kg	32.6 **b**	36.4 **a**	32.5 **b**	46.1	45.8	45.6
B	mg/kg	179	186	184	145	147	140
Mo	mg/kg	<0.9	<0.9	<0.9	<0.5	<0.5	<0.5
Na	mg/kg	145	150	151	193	195	190
Ni	mg/kg	1.4	1.9	1.9	1.1	1.7	1.4
Cd	mg/kg	<0.4	<0.4	<0.4	<0.1	<0.1	<0.1
Co	mg/kg	<0.9	<0.9	<0.9	0.4	0.6	0.5
Al	mg/kg	<6	<6	<6	3.8	3.6	3.9

Different letters within rows and seasons denote values different at LSD<0.05.

In 2003/04, Cu at flowering was higher in the *partially vegetated* treatment than in the other treatments at both sites. Mg was increased in the *unvegetated* treatment in both seasons at Wagga Wagga, and in 2003/04 at Tumbarumba. Na was increased in the *vegetated* treatment at Wagga Wagga in 2004/05. Potassium at flowering was lower in vines from the *vegetated* treatment than in the *unvegetated* treatment at Tumbarumba in 2003/04, however it was

higher in the same treatment compared to the other two at Wagga Wagga in 2004/05. In 2003/04 P was higher in *unvegetated* than in *partially vegetated* treatments. Sulphur was generally lower in *unvegetated* than *partially vegetated* treatments. This was found in the Wagga Wagga petioles collected at flowering in 2003/04, and at Tumbarumba in petioles from flowering in 2003/04 and 2004/05, and those collected at veraison in 2003/04 (not shown).

3.4.4 Vegetative growth and canopy architecture

In 2004/05, flowering occurred earlier in the *unvegetated* treatment at Tumbarumba, while at Wagga Wagga veraison was delayed by 3-4 days in the *vegetated* treatment in comparison to the other treatments (Table 3.4). A strong effect of the floor management treatments on shoot growth was observed in the 2003/04 and 2004/05 seasons, particularly in Wagga Wagga. At that site, shoot vigour of vines from the *vegetated* treatment was 1.1 cm/d over the budburst-flowering period, whereas shoots from *unvegetated* and *partially vegetated* treatments grew considerably faster (1.6 cm/d and 1.5 cm/d, respectively, $p<0.05$). However, early-season vigour was similar for all treatments in Tumbarumba (1.0, 1.2 and 1.1 cm/d respectively for *vegetated*, *unvegetated* and *partially vegetated*).

As a consequence of the reduced vigour, final shoot length generally decreased with increasing extent of floor vegetation cover (Fig. 3.4), and this response was also reflected in the pruning weight (Fig. 3.5). From these results, it appears that there was a tendency for treatment differences in vegetative growth to increase over time at Wagga Wagga. Yield to pruning weight ratio (not shown) remained relatively constant over four experimental seasons.

Table 3.4. Phenological stages in the 2004/05 season as affected by vineyard floor management treatment at both vineyards.

	Budburst	**Flowering**	**Veraison**
Wagga Wagga			
Unvegetated	4 Sep	8 Nov	14 Jan **b**
Partially vegetated	5 Sep	8 Nov	15 Jan **b**
Vegetated	5 Sep	8 Nov	18 Jan **a**
Tumbarumba			
Unvegetated	22 Oct	17 Dec **b**	27 Feb
Partially vegetated	25 Oct	26 Dec **a**	27 Feb
Vegetated	24 Oct	23 Dec **a**	28 Feb

Different letters denote values different by LSD test at $p<0.05$

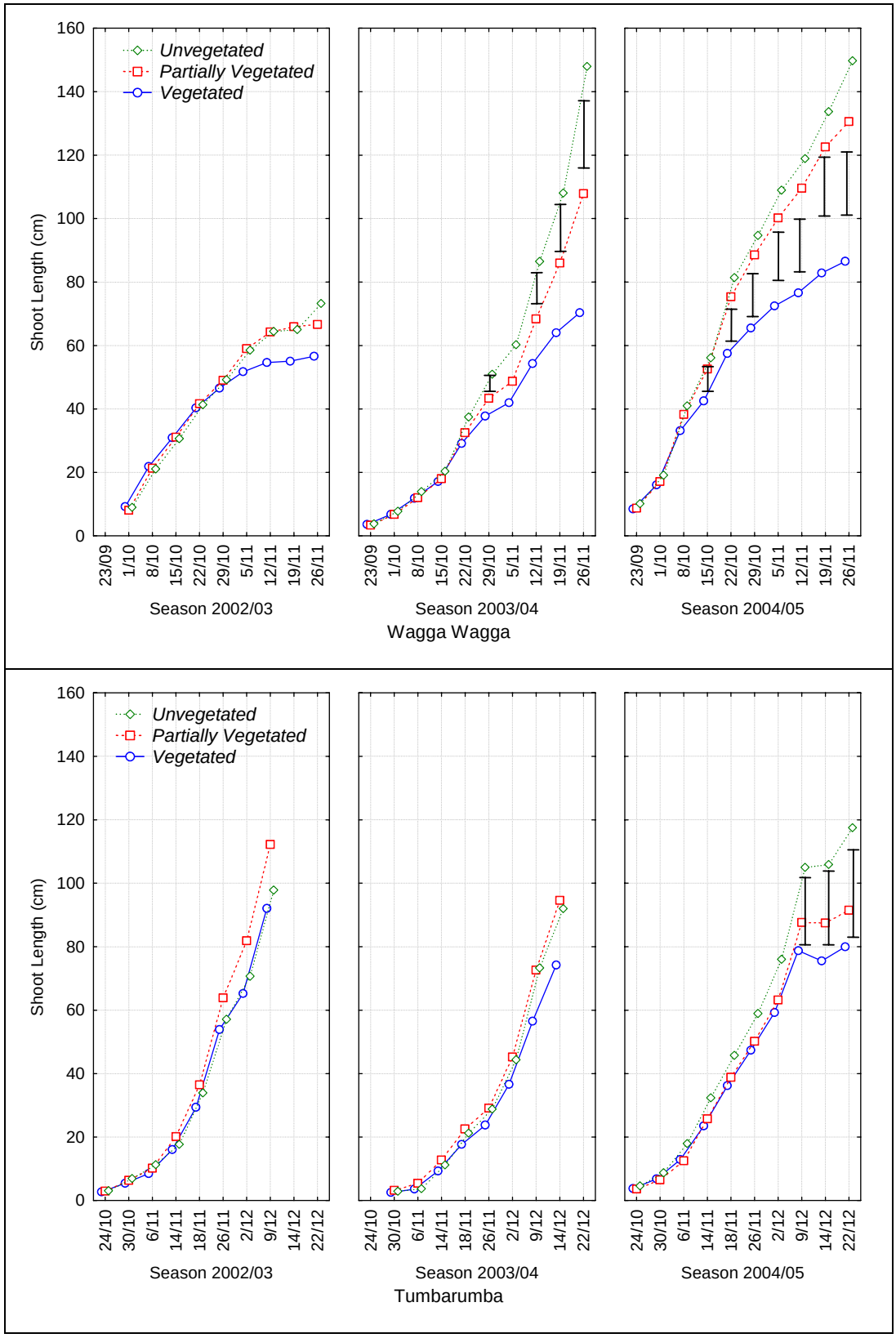


Figure 3.4. Shoot growth at Wagga Wagga (top) and Tumbarumba (bottom) over three growing seasons. Vertical bars denote LSD at p=0.05 (shown where F test significant at p<0.05).

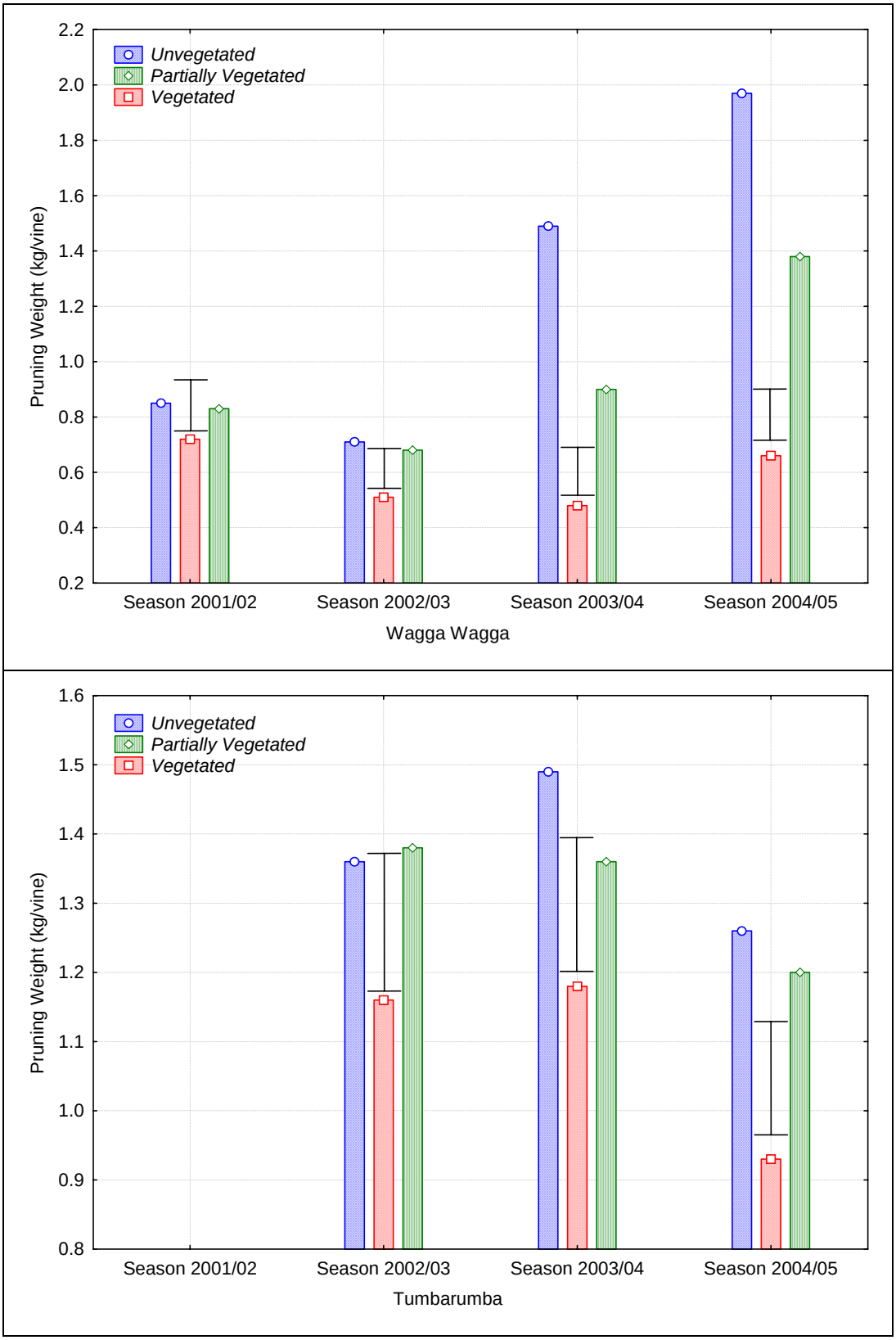


Figure 3.5. Changes in pruning weight over the experimental period at Wagga Wagga (top) and Tumbarumba (bottom). Vertical bars denote LSD at p=0.05.

Table 3.5. Canopy point quadrat measurements as affected by vineyard floor cover at both vineyards.

	Gaps (%)	Leaf Layer Number	Internal Bunches (%)	Internal Leaves (%)
Wagga Wagga				
2001/02				
Unvegetated	3.8	3.2	55	56
Partially vegetated	2.8	3.5	56	54
Vegetated	4.8	2.9	52	54
2002/03				
Unvegetated	4.0	2.0	46	20
Partially vegetated	3.0	2.0	35	20
Vegetated	4.0	1.8	36	15
2003/04				
Unvegetated	0.0 b	3.6 **a**	92 **a**	45 **a**
Partially vegetated	0.0 b	2.8 **b**	65 **b**	37 **a**
Vegetated	5.5 a	1.9 **c**	50 **c**	19 **b**
Tumbarumba				
2002/03				
Unvegetated	2.0	3.7	89	46
Partially vegetated	3.0	3.7	84	49
Vegetated	4.0	4.0	82	52
2003/04				
Unvegetated	1.0	4.6 **a**	100 **a**	57
Partially vegetated	0.0	4.6 **a**	98 **a**	57
Vegetated	3.0	3.8 **b**	85 **b**	49

Different letters within columns denote values different by LSD test at $p<0.05$

Initially, no treatment differences in canopy characteristics were evident, but by the 2003/04 season most observed attributes differed between treatments (Table 3.5). This was particularly the case at Wagga Wagga, where vines in the *vegetated* treatment were different in all canopy attributes: percent gaps, leaf layer number (LLN), percent internal bunches and percent internal leaves, compared to the other two treatments. Vines from the *vegetated* treatment had the fewest leaf layers, internal leaves and bunches, and the most canopy gaps, whereas vines from the *unvegetated* treatment appeared to have the densest canopies. There were also some differences between *partially vegetated* and *unvegetated* treatments, with vines from *unvegetated* having a higher LLN and percent internal bunches than vines from the *partially*

vegetated treatment. Vines from the *vegetated* treatment were also lower in LLN and percent internal bunches than the other two treatments at Tumbarumba.

Table 3.6. Yield components as affected by vineyard floor cover at both vineyards.

	Yield (kg per vine)	Bunch number per vine	Bunch weight (g)	Berry number per bunch	Berry weight (g)
Wagga Wagga					
2001/02 (11/02/02)					
Unvegetated	5.50	52	105	96	1.09
Partially vegetated	4.29	44	97	87	1.11
Vegetated	4.21	44	97	88	1.09
2002/03 (31/01/03)					
Unvegetated	3.85	47	82 **a**	81	1.00
Partially vegetated	3.97	48	82 **a**	85	0.97
Vegetated	3.10	46	68 **b**	72	0.94
2003/04 (11/02/04)					
Unvegetated	6.71 **a**	57 **a**	117 **a**	160	0.73 **a**
Partially vegetated	4.76 **b**	46 **b**	103 **b**	159	0.64 **b**
Vegetated	2.76 **c**	43 **b**	64 **c**	129	0.50 **c**
2004/05 (14/02/05)					
Unvegetated	10.99 **a**	83 **a**	132 **a**	124 **a**	1.06 **a**
Partially vegetated	8.60 **b**	70 **b**	123 **a**	126 **a**	0.97 **b**
Vegetated	4.60 **c**	56 **c**	82 **b**	93 **b**	0.88 **c**
Tumbarumba					
2002/03 (25/03/03)					
Unvegetated	1.80	34	54 **b**	43	1.26
Partially vegetated	2.19	34	64 **a**	48	1.35
Vegetated	1.77	31	57 **b**	44	1.29
2003/04 (05/04/04)					
Unvegetated	5.77	62	93 **b**	70	1.32 **b**
Partially vegetated	6.20	65	95 **ab**	69	1.38 **a**
Vegetated	6.29	60	106 **a**	77	1.36 **a**
2004/05 (21/04/05)					
Unvegetated	1.82 **a**	36 **a**	50	36	1.40
Partially vegetated	1.65 **a**	34 **a**	49	34	1.42
Vegetated	1.25 **b**	25 **b**	50	36	1.38

Dates in parentheses indicate harvest dates
Different letters within columns denote values different by LSD test at $p<0.01$
Reduced yield in the 2002/03 and 2004/05 seasons in Tumbarumba is due to spring frosts

3.4.5 Yield and yield components

Significant treatment effects were observed in grape yield at harvest, as well as in the number of bunches per vine (Table 3.6). In the first two seasons (2001/02 and 2002/03) no differences were observed at Wagga Wagga, however yield and bunch numbers were strongly affected by the applied floor management treatments in the third and fourth experimental season at this site. In these seasons, yield and bunch numbers were higher in *unvegetated* than in the *vegetated* treatment, with the *partially vegetated* treatment in between. (There were no differences between *partially vegetated* and *vegetated* treatments in bunch numbers in 2003/04). Similarly to Wagga Wagga, over the first two experimental seasons at Tumbarumba there were no treatment differences, but in 2004/05 vines in the *vegetated* treatment had a decreased yield and bunch number compared to the other treatments. The low number of bunches and a relatively low yield at Tumbarumba in the 2002/03 and 2004/05 seasons can be related to damages incurred by frosts that occurred in this region in the springs of 2002 and 2004.

The increasing floor vegetation reduced berry weight (Fig. 3.6). This was particularly noticeable at Wagga Wagga, where all differences between treatments observed at veraison, mid-maturity and harvest were significant ($p<0.01$). The fact that these differences were already present at veraison suggests that the impact of the treatments was most pronounced on early berry growth. The final berry weight at Tumbarumba in 2003/04 was lower in the *unvegetated* treatment compared to the other two treatments ($p<0.01$). In 2004/05 berry weight was higher in the *unvegetated* treatment compared to the other two treatments at veraison, and mid-maturity ($p<0.01$), with no differences at harvest.

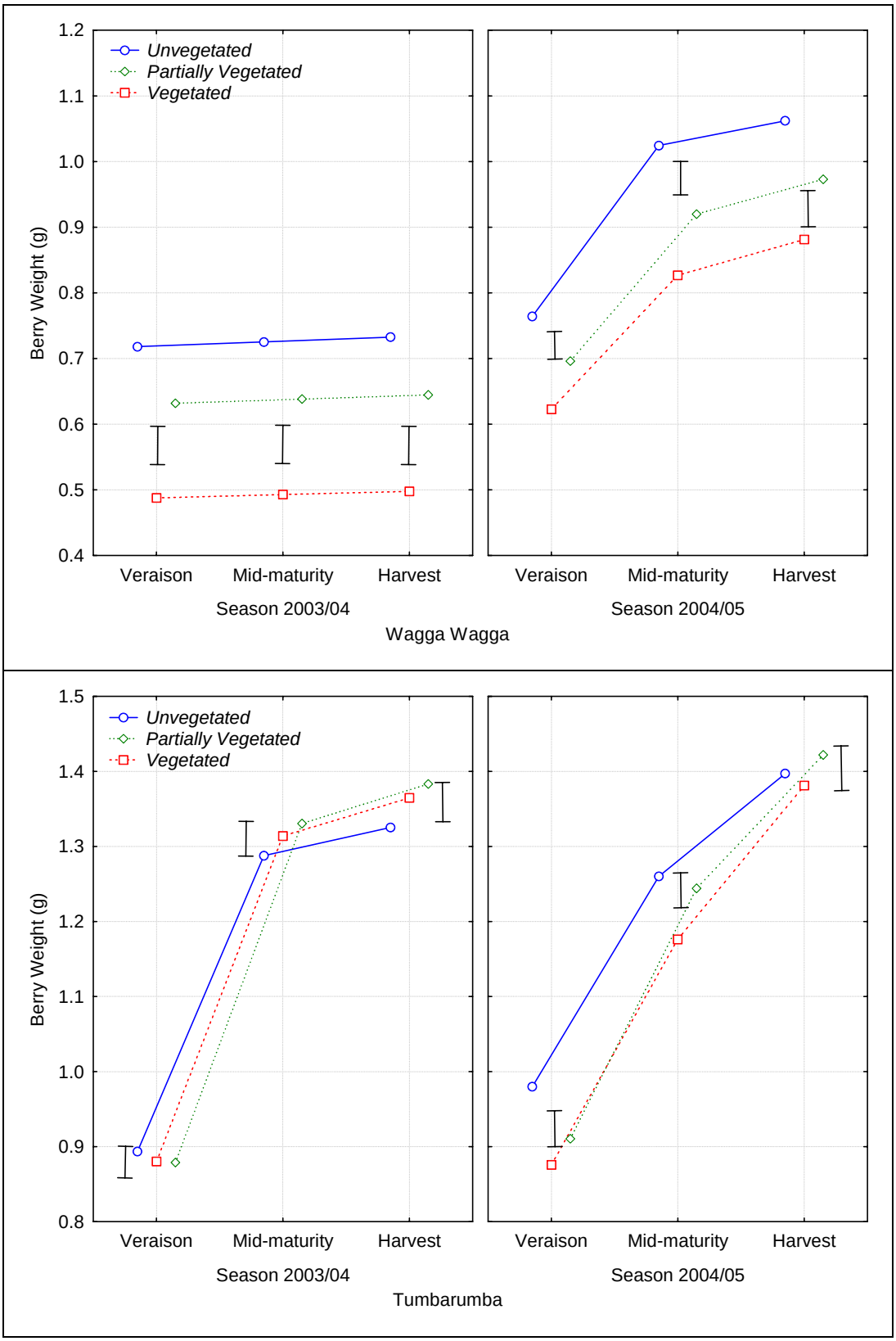


Figure 3.6. Berry weight at Wagga Wagga (top) and Tumbarumba (bottom). Vertical bars denote LSD at p=0.05.

3.4.6 Fruit composition

At Wagga Wagga in 2003/04, TSS differed between treatments at veraison, however there were no differences between treatments at mid-maturity and at harvest (data not shown). In 2004/05, treatments at this site were different at all examined stages of fruit ripening, with fruit from the *vegetated* treatment having a higher TSS than two other treatments. Floor covers did not affect TSS at any stage of fruit ripening at Tumbarumba.

At Wagga Wagga in 2003/04, the TA values differed between treatments at mid-maturity, being lower in the *vegetated* treatment than in the other two treatments (data not shown). In 2004/05 berries differed in TA at this site at all three sampling stages, with the *unvegetated* treatment being higher than the *vegetated* treatment, and *partially vegetated* in between. The pH values at Wagga Wagga in 2003/04 differed only at mid-maturity, with fruit from the *partially vegetated* treatment being lower than the other two treatments (data not shown). In 2004/05 the pH values were higher in the *vegetated* treatment than the other two treatments at Wagga Wagga throughout the ripening period. At Tumbarumba, fruit from the *unvegetated* treatment was higher in pH than from the other two treatments at harvest in 2003/04. In 2004/05 there were no differences at this site in pH at harvest, however, a higher pH was recorded at veraison and mid-maturity in the *unvegetated* treatment.

In Wagga Wagga, TA was lower in the *unvegetated* treatment in 2002/03, but higher in 2004/05, compared to the other treatments (Table 3.7). In 2004/05 the *partially vegetated* treatment was also higher than the *vegetated* treatment in this respect. The pH values also varied accordingly, the order being *unvegetated* > *vegetated* > *partially vegetated* in 2002/03, and higher in the *vegetated* treatment than the other two treatments in 2004/05. In 2004/05 at Wagga Wagga, TSS was markedly higher in the *vegetated* treatment than in the *partially vegetated* treatment, which was higher than in the *unvegetated* treatment. At Tumbarumba TA in the *partially vegetated* treatment was higher than the other two treatments in 2002/03, but in 2004/05 the order was: *unvegetated* > *partially vegetated* > *vegetated*. The pH values also differed at Tumbarumba in 2003/04, with the *vegetated* treatment recording lower values than the other two treatments.

Table 3.7. Fruit composition at harvest.

	TSS (ºBrix)	TA (g/L)	pH
Wagga Wagga			
2001/02 (11/02/02)			
Unvegetated	23.3	8.4	3.72
Partially vegetated	23.2	8.4	3.73
Vegetated	23.8	8.2	3.75
2002/03 (31/01/03)			
Unvegetated	22.0	4.8 **a**	3.62 **a**
Partially vegetated	22.1	6.0 **b**	3.41 **c**
Vegetated	21.7	5.9 **b**	3.53 **b**
2003/04 (11/02/04)			
Unvegetated	24.9	4.7	4.02
Partially vegetated	25.0	4.1	4.02
Vegetated	25.4	4.5	4.00
2004/05 (14/02/05)			
Unvegetated	21.2 **a**	5.7 **a**	3.54 **a**
Partially vegetated	22.1 **c**	5.1 **c**	3.54 **a**
Vegetated	23.4 **b**	4.7 **b**	3.66 **b**
Tumbarumba			
2002/03 (25/03/03)			
Unvegetated	22.8	9.3 **b**	3.44
Partially vegetated	22.6	10.0 **a**	3.41
Vegetated	22.8	9.2 **b**	3.44
2003/04 (05/04/04)			
Unvegetated	21.8	6.0	3.87 **a**
Partially vegetated	21.7	5.9	3.83 **a**
Vegetated	21.9	6.1	3.75 **b**
2004/05 (21/04/05)			
Unvegetated	21.7	9.5 **a**	3.45
Partially vegetated	21.6	9.0 **c**	3.41
Vegetated	21.6	8.6 **b**	3.41

Dates in parentheses indicate harvest dates

Different letters within columns denote statistical differences by LSD test for $p<0.05$

3.5 Discussion

The increased floor cover reduced the soil moisture content and increased the soil moisture tension (Figs 3.1 and 3.2). This effect varied with time of season, vineyard site, measurement position and depth. At Wagga Wagga, mid-row position at 30 cm depth in the *vegetated*

treatment was drier in spring compared to the *unvegetated* treatment. Positions under vine at this depth had higher moisture content due to drip irrigation. In deeper layers of soil (ie. 90 cm) these differences between positions are less compared to shallower layers. At Wagga Wagga, the effect of treatment at 90 cm is almost opposite to that at 30 cm, as the *vegetated* treatment recorded higher moisture content than the *unvegetated* treatment. During March 2004, at Tumbarumba, the treatment differences at 90 cm were a lot less than at Wagga Wagga. The treatment differences were also opposite in direction – i.e. the *vegetated* treatment was lower in moisture content at both analysed depths (30 cm and 90 cm) compared to the other treatments. This difference between sites can be explained by the fact that vines at Tumbarumba were (and normally are) much less dependent on irrigation than those at Wagga Wagga. Tumbarumba receives about 60% more seasonal rainfall and is several degrees cooler than Wagga Wagga, which would greatly reduce evaporative demand in addition to the extra moisture input. The increased depletion of moisture under the *vegetated* treatment at Tumbarumba could therefore indicate increased root activity in these deeper soil layers, to compensate for competition for water with cover crop plants growing under vines. The general lack of difference between *unvegetated* and *partially vegetated* treatments in this respect (both treatments having no vegetation growing under vines), also points to the same conclusion. Root growth of vines competing with grass has been found to decrease (Müller et al. 1984), and to be shifted to deeper soil layers (Reimers et al. 1994) or to areas (such as undervine) free of grass root (Morlat and Jacquet 2003). On the other hand, the increased vegetative growth at Wagga Wagga in the *unvegetated* treatment apparently led to increased soil moisture uptake later in the season.

The effect of floor vegetation on soil composition at the 40-50 cm depth was less obvious. Tumbarumba soil pH decreased slightly under the floor covers and was correlated with petiole N ($r=0.77$) and Mg ($r=0.72$) at veraison. Although the floor vegetation had little effect on available plant nutrients in the soil, they did generally lead to decreased petiole nutrient status, an effect that was most pronounced for N and Mg and, somewhat less consistently, K. These results indicate that the lower nutrient status of vines growing in competition with floor vegetation was mostly due to decreased water availability, and consequently decreased nutrient uptake, especially early in the season. Tan and Crabtree (1990) reported a similar decrease in Chardonnay leaf blade N due to floor cover, but found no change in P and K. Reduced petiole N, Ca and Mg due to floor vegetation has also been reported for Merlot (Sicher et al. 1995). A permanent grass sward decreased the amino acid (especially arginine)

concentration in Riesling juice compared with cultivated soil, and this was attributed to reduced soil moisture and nitrate availability (Löhnertz et al. 2000).

At both sites the *vegetated* treatment reduced vine vigour. Shoot length was generally correlated with petiole N content at flowering (r=0.66 at Tumbarumba in 2003/04 and r=0.8 in 2004/05; at Wagga Wagga r=0.86 in 2003/04 and r=0.82 in 2004/05). Final shoot length was also correlated with the mean November soil moisture tension at Wagga Wagga in 2003/04 (r=-0.75) and in 2004/05 (r=-0.87). Müller et al. (1984) reported that sward-vine competition for nutrients was more important in soils with ample water availability, while under drier conditions the soil moisture effect became predominant.

The low soil moisture resulted in a striking decrease of vegetative growth in Chardonnay vines grown with sward at the warm dry Wagga Wagga site. Reduction in vine vegetative growth *via* reduced water availability associated with swards is well-known. Lombard et al. (1988) even described use of the sward-vine competition as a deliberate vine devigoration tool. Longer shoots were also found in Chardonnay grown on bare soil compared to sward by Tan and Crabtree (1990). Ingels et al. (2005) found that a native grass cover crop reduced the pruning weight of drip-irrigated Merlot grown in the hot San Joaquin Valley of California by up to 40% compared to bare soil maintained by cultivation. Nevertheless, we cannot exclude the possibility that the greater influence of floor cover on vine growth in Wagga Wagga was in part due to a vine-age effect and partly due to the shallower soil at that site. Both of these facts may have resulted in a relatively smaller root system, which would have aggravated the effect of the pronounced climatic differences between the two sites.

The remarkable sward-induced inhibition of vine growth in Wagga Wagga was accompanied by a comparable decrease in yield. This is similar to findings with Chenin Blanc in South Africa (van Huyssteen and Weber, 1980b) and with Merlot in Italy's Trentino region (Dorigoni et al. 1991). The reduced number of bunches at Wagga Wagga (Table 3.6) points to inadequate bunch initiation in the *vegetated* treatment and to a lesser extent in the *partially vegetated* (herbicide) treatment. This could be the result of water stress at flowering and berry set. The lower berry number per bunch in the *vegetated* treatment was associated with a markedly higher soil moisture tension in the same treatment (Fig. 3.2) during November, when flowering and berry set occurred at Wagga Wagga (Table 3.4). Accordingly, the Wagga Wagga yield decreased with increasing mean soil moisture tension in November (r=-0.78 and

r=-0.84, respectively for 2003/04 and 2004/05). Moreover, at Wagga Wagga in 2003/04 there was a strong relationship (R^2=0.88, p<0.0001) of berry weight with November soil moisture tension and petiole-N at flowering. In 2004/05, berry weight at Wagga Wagga was more closely related to December soil moisture tension and petiole-N at flowering (R^2=0.594, p<0.02). Petiole N at flowering also correlated with bunch weight (r=0.80) in Tumbarumba 2004/05. This emphasises the need for careful management of floor vegetation, so that excessive competition can be eliminated during critical periods, such as flowering, berry set and the cell division stage.

At veraison in the 2003/04 season at Wagga Wagga, the first occurrence of advanced fruit maturity (smaller berries with higher solute concentration) was observed presumably as an effect of the increased floor cover. The 2004/05 results confirmed this effect at all observed stages of ripening. No such difference was observed at Tumbarumba, where treatments were imposed one year later than in Wagga Wagga. Dorigoni et al. (1991) and Egger et al. (1995) found a similar effect of floor treatment on TSS in two of three experimental years. The increases in TSS with increased floor cover in later years of this experiment can be in part explained through the TSS response to previously mentioned changes in yield and possibly berry size. Correlation coefficients between yield and TSS at harvest at Wagga Wagga were r=-0.4 in 2003/04 and r=-0.69 in 2004/05. However, there was no such correlation *within* floor management treatments due to the treatment effect on both these variables. Also at Tumbarumba there was a correlation between TSS and yield in 2003/04 (r=-0.34) and in 2004/05 (r=-0.4). In addition, denser canopies at Tumbarumba were associated with lower TSS: in 2002/03 LLN and percent internal leaves were correlated with TSS at harvest (r=-0.69 and r=-0.70, respectively).

The decreased cost of not using herbicides, and probably of the reduced use of pesticides, less erosion and dust, all associated with complete floor vegetation cover, would likely not offset the decrease in grape yield in a hot/dry climate. This would hold even when the gain in fruit maturity is taken into account, although this would be dependent on the end use of grapes and the pricing regime. The relative cost of complete floor vegetation may be different in a cooler, more humid climate. In hot and arid environments, regardless of the present results, it would be too simplistic to recommend maintaining bare soil with herbicides as a sustainable option, as there could be other unintended negative effects associated with the use of herbicides. As a part of the same research study reported in this paper, a negative effect of herbicides on the

presence of soil micro-organisms was observed by Whitelaw-Weckert et al (2004) (see Chapter 4).

A number of approaches exist to overcome a reduction in grape yield resulting from the transition from a clean vineyard floor to using partial or total floor cover. Mowing, for example, generally decreases water use by cover crops (Skrotch and Shribbs 1986). Species that are not characterised by intensive spring growth might be preferred as cover crops (Skrotch and Shribbs 1986), as well as summer dormant species. The choice of floor covers can be further expanded by using mulches, as they provide the highest soil moisture conservation of all floor covers (van Huyssteen and Weber, 1980a; Skrotch and Shribbs 1986). Another possibility for reducing unwanted effects of the sward-vine competition is in using drought tolerant grapevine rootstocks. Moisture depletion under vines grown with a sward and vines under bare soil was demonstrated to differ according to rootstock (Goulet 2004). Rootstocks have also been found to vary in their ability to take up and use soil nutrients in vines growing with a permanent complete floor cover (Keller et al. 2001b), which led to differences in yield and fruit composition (Keller et al. 2001a). Of course, changes in irrigation management also could mitigate some of the perceived negative aspects of the use of floor covers while preserving the positive facets. For instance, irrigation could be initiated earlier in the season, or irrigation water amounts increased during critical stages of development (e.g. flowering/fruitset).

In our experiment, there was little effect of treatment on the content of organic carbon in the topsoil over three years (Table 3.2). The ability to increase soil organic matter content is vital for a successful implementation of herbicide-free viticulture (Perret & Koblet 1985). Over a 15-year period, a sward increased organic matter in vineyards of the Loire Valley in France (Morlat and Jacquet 2003) and (after three years) the Adige valley in Italy (Pinamonti et al. 1996). An increase in soil organic matter was also achieved in the semi-arid Brazilian Sao Francisco River Valley by using green manure over a six-year period (Faria et al 2004).This emphasizes the need to study long-term effects of vineyard soil management systems. For the systems approach to work, enough time is required to achieve ecological balance (Ingels 1992).

3.6 Conclusions

Water and nutrient availability to the vines were decreased by the increased floor vegetation cover in this study. That reduction in soil moisture was associated with a considerably diminished nutrient, and particularly nitrogen, availability. The extent of this effect was site-dependent, whereby sward-vine competition for water was more severe in the dry hot Wagga Wagga climate compared to the milder Tumbarumba climate. Floor vegetation altered canopy architecture, reduced vine vigour and yield at both sites, but only after treatments had been imposed for two or three years. Prior to the fourth experimental season at Wagga Wagga, treatment effects on fruit composition were minor compared with those on growth and yield formation; in that season, however, fruit ripeness was improved with increasing floor vegetation. A number of vineyard floor management strategies are available to reduce the unwanted effects of sward-vine competition in dry warm areas, particularly during the most sensitive stages for yield formation. Floor covers can provide a viable option for accomplishing long-term environmental sustainability, while reducing chemical inputs and achieving economic yields and favourable fruit composition.

3.7 References

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4. Permanent swards increase soil microbial counts in Australian vineyards

Melanie Whitelaw-Weckert, Loothfar Rahman, Ron Hutton and Neil Coombes

4.1 Abstract

This study examined the effect of vegetated and unvegetated floors (by repeated herbicide treatment) on soil microbial counts in two Australian vineyards at Wagga Wagga and Tumbarumba. Within three years of allowing swards to develop under the vine, hot water extractable C (HWC) was increased by 73%; whereas three years of herbicide treatment in the inter-row resulted in 78% lower HWC in the unvegetated treatment at Tumbarumba. Most of the bacterial and fungal counts were greatly decreased by the unvegetated treatment and principal components analysis was able to clearly discriminate between microbial populations from the vegetated and unvegetated areas. In both the inter-row and the under-vine soil, HWC was positively correlated with fungal counts and with cellulolytic, pseudomonad, copiotrophic and oligotrophic bacterial counts. HWC was also negatively correlated with soil bulk density.

The grapevine rhizosphere bacterial population was dominated by cellulolytic bacteria in both vinyeards. Many rhizosphere cellulolytic bacteria were slow growing (SCB), requiring up to 84 days of laboratory incubation. At Tumbarumba, the rhizosphere SCB count was positively correlated with the SCB count in the bulk soil. At both sites, soil cellulolytic bacteria were positively correlated with soil HWC and were significantly increased by the continuous plant cover.

4.2 Introduction

Conventional vineyard floor management systems in Australia maintain bare weed-free soil under the vine and, in some districts, between the vine rows. However, as organic matter from crop residues is minimal in viticulture, bare soil may become depleted of organic matter. Continuous plant cover from a permanent sward can therefore be an important source of soil organic matter. Living plant roots produce exudate containing soluble organic compounds such as sugars, amino acids and organic acids. These relatively labile substances can contribute from 0.1 to 2.8 t C ha^{-1} to the soil microbial community (Rees et al., 2005). Mown sward plant residues are also gradually degraded by cellulolytic soil microorganisms, providing easily mineralised organic matter.

Hot water extractable C (HWC), a biodegradable hydrophilic fraction of the total soil dissolved organic C pool, can be used as a sensitive indicator of changes in soil organic matter and soil quality (Haynes and Francis, 1993; Ghani et al., 2003; Haynes, 2005). HWC reportedly consists of carbohydrates from root exudates or extracellular polysaccharides from microorganisms and is highly available to soil microorganisms (Fischer, 1993).

The effect of continuous plant cover on soil organic C and microbial populations was the focus of this study. As pure cultures were needed for future experimentation, the traditional dilution plate counting technique was used to estimate the size of the microbial populations. Although there have been many reports of discrepancies between the number of bacterial colonies formed on solid agar and the total number of bacterial cells present in the soil, recent literature has shown that these discrepancies are made much smaller when long incubations and dilute nutrient agar are used (Janssen et al., 2002; Joseph et al., 2003).

This chapter reports on the impact of vineyard floor vegetation on soil organic C and populations of fungi, cellulolytic bacteria, copiotrophic pseudomonads, copiotrophic bacteria and oligotrophic bacteria. These microbial groups were monitored for three years and population differences in 2004 are reported here.

4.3 Materials and methods

4.3.1 Vineyard field trial

There were three floor management treatments, representing some of the main floor management techniques currently being utilised in Australian viticulture. One treatment consisted of a completely bare unvegetated vineyard floor maintained by regular post-emergent herbicide application both under-vine and between the vine rows (i.e. inter-rows); another maintained a completely vegetated site adapted permanent sward with no herbicides applied; and the third used post-emergent herbicide under-vine only with the inter-row vegetation mowed. Prior to the commencement of the trial the vineyards had been maintained for a decade with bare weed-free soil under-vine and volunteer grasses in the inter-rows. For soil microbiological testing purposes the treatments were: under-vine unvegetated soil; under-vine vegetated soil; inter-row unvegetated soil; and inter-row vegetated soil.

Four replicate experimental plots, randomly selected from 12 field trial replicate plots within a randomised block design, were sampled for soil microbiological testing purposes. The plots were 3 panels long and 3 vine rows wide with a buffer row between each plot. The vine rows were 3 m apart and each panel contained three grapevines (*Vitis vinifera* cv. Chardonnay) spaced 2 m apart. The inter-row permanent swards were mowed regularly and the under-vine permanent sward was kept short with a 'whipper-snipper'.

Soil at the Wagga Wagga site was shallow (approximately 30 cm topsoil, which was quite variable across the vineyard), and consisted of coarse sandy loam overlaying hard-to-penetrate subsoil of granite saprolite. In 2002, before the treatments were applied, average inter-row soil pH was 7.0 (1:5, 0.01 M of $CaCl_2$); $NaHCO_3$-extractable phosphate (available P) was 36 mg kg^{-1} (Colwell 1963) and total soil organic C (OC) (0-10 cm soil depth, dichromate oxidation method) was 0.81% in the under-vine and 0.92% in the inter-row soil.

The soil at Tumbarumba was a brown clay-loam and $NaHCO_3$-extractable P was 20 mg/kg soil in the inter-row (Colwell, 1963). Soil pH (1:5, 0.01 M of $CaCl_2$) was 5.9 and oxidisable organic carbon (dichromate oxidation method) was 1.7 %. Vine rows were 3m apart and each panel contained 8 grapevines spaced 1m apart. The experimental plots were 2 panels long and 4 mid-rows wide with a buffer row between each plot.

4.3.2 Hot water extractable C (HWC) (0 – 2 cm soil depth)

In 2004 only, hot water extractable C (HWC) was analysed by a modified method of Ghani et al. (2003) (from method of Haynes and Francis, 1993). Five soil cores (0-2 cm depth) from each plot were bulked and sieved (10 mm). Representative 4.0 g (field moist weight) soil samples were ground by mortar and pestle until fine enough to pass a 0.5 mm screen, inverted three times and vortex mixed for 10 s in 30 ml deionised water, capped and incubated for 16 h in a 80°C water bath. Tubes were then shaken for 10 s, centrifuged for 20 min at 3500 rpm and the supernatant was filtered through a moist washed 25 mm 0.45 μm Nucleopore polycarbonate membrane filter. A modified method of Burford and Bremner (1975) and Heanes (1984) was used for total C content of the soil extract. The soil extracts (5 ml) were placed in 50 ml pyrex tubes, 5 ml 1N $K_2Cr_2O_7$, concentrated H_2SO_4 (5 ml) was gradually added and the tubes were capped loosely and agitated for 30 s before placing in boiling water bath for 30 min. Absorbance at 600 nm was determined after dilution with 35 ml deionised water.

4.3.3 Isolation of microorganisms from soil

Composite samples from six soil cores (depth 10 cm, diameter 60 mm, collected in May 2002, 2003 and 2004) were obtained from the vine row and inter-row (50 cm from the grapevine trunk) of 12 replicate plots. Gravimetric soil moisture (oven dried at 105°C for 24 h) was determined for each composite soil sample. The soil was sieved (0.5cm) and 10 g (moist weight) representative samples vortex mixed with 90 ml phosphate buffered saline (pH 7.2) (PBS) for 10 s, sonicated at 260 W cm^{-2} for 15 s and orbitally shaken at 290 rev min^{-1} for 30 min on ice. Grapevine roots retrieved from each soil sample were washed under tap water, blotted dry and 1g (fw) was vortex mixed with 9 ml PBS for 10 s, sonicated at 260 W cm^{-2} for 15 s and shaken at 290 rev min^{-1} for 30 min on ice. Aliquots (0.1 ml) were spread onto solid media and incubated in darkness at 25°C.

4.3.4 Microbial counts

Copiotrophic pseudomonads (PS) were selectively cultured on Pseudomonas agar CCF (Oxoid) containing antibiotics Cetrimide, Fucidin and Cephaloridine. Cellulolytic bacteria were cultured on Cellulose Bacterial Agar (CBA) (Tuitert et al., 1998) containing carboxy methyl cellulose as the sole source of C plus the antibiotic cycloheximide. Colonies were counted after 4 d (fast growing cellulolytic bacteria, FCB). In 2004 only, colonies were also counted after 84 d (total cellulolytic bacteria, TCB). The slow growing cellulolytic bacterial count (SCB) was calculated from TCB – FCB. Nutrient Benomyl Agar (NBA) (Oxoid Nutrient agar 30 μg ml^{-1} benomyl fungicide) was used to isolate copiotrophic bacteria (CB) which are able to grow quickly (4 d) on a high C medium containing high salt concentrations. Dilute Nutrient Benomyl Agar (DNBA) (100-fold diluted Oxoid Nutrient Agar with 30 μg ml^{-1} benomyl) was used to isolate bacteria able to grow on a low C medium (Hattori and Hattori, 2000). Colonies were counted after 4 d (fast growing low nutrient bacteria, FLNB) and 84 d (total low nutrient bacteria, TLNB). As some copiotrophic bacteria grow on DNBA (Hattori and Hattori, 2000) those that grew on DNBA but not on NBA were considered to be oligotrophic bacteria (OB) (Mitsui et al., 1997). The OB count was calculated from TLNB - CB.

DRBC fungi were isolated on Dichloran Rose Bengal Chloramphenicol (DRBC) agar, a general mycology isolation medium which inhibits bacteria and colony size of rapidly growing fungi. Cellulolytic fungi were isolated on Cellulose Czapek Chloramphenicol agar

(CCC) which was modified from Cellulose Czapek agar (Omar and Abdel-Sater, 2000) with chloramphenicol (100 μg ml^{-1}) instead of ampicillin.

4.3.5 Bulk density, pH, OC, nitrate and available P

Bulk density (BD) was determined for each replicate plot using the core method (Graecen et al., 1981). Metal cores of 6.1-cm length and 7.6-cm diameter were used for collecting soil core samples at 6- to 16.1-cm soil depth. The soil was weighed and dried at 105°C for 48 h, and BD was determined by the ratio between soil dry weight and the ring volume. Soil chemical analyses for total organic C (OC) (dichromate oxidation and titration), pH (water), nitrate (1M KCL) and available P (Colwell P) were performed by Pivot Limited, Werribee, Victoria.

4.3.6 Statistical analysis

Data were subjected to analysis of variance (ANOVA) test (1 way) using Genstat for Windows, 8th Edition. In the under-vine, the unvegetated plots were combined from the unvegetated and partially vegetated treatments and the vegetated plots were from the vegetated treatment. In the inter-row, the unvegetated plots were from the unvegetated treatment and the vegetated plots combined those from the vegetated and partially vegetated treatments. Least significant differences (l.s.d.) and linear correlations were calculated using Genstat for Windows, 8th edition. Principal Component Analysis (PCA) was performed by Genstat for Windows, 8th edition.

4.4 Results

4.4.1 Organic C

Soil organic C was significantly increased by the vegetated treatment as compared to the unvegetated (herbicided) treatment. Within three years of allowing a sward to develop under the vine, hot water extractable C (HWC) (0-2cm) was increased by 73% at Wagga Wagga and Tumbarumba; whereas three years of inter-row herbicide treatment at Tumbarumba resulted in 78% lower HWC in the unvegetated soil (Table 4.1). Organic C was also positively correlated with many soil microbial groups. HWC was positively correlated with TCB in both the under-vine and inter-row soil at Wagga Wagga and Tumbarumba (Fig. 4.1). HWC in the inter-row soil was also positively correlated with FCB, TCB and PS at Wagga Wagga; and with FCB, TCB, CB, FLNB, TLNB, PS, cellulolytic fungi and DRBC at Tumbarumba. HWC in the under-vine soil was also positively correlated with FCB, TCB, CB, TLNB, PS, cellulolytic fungi and DRBC at Wagga Wagga and with FCB and TCB at Tumbarumba. Soil

OC in the inter-row was also positively correlated with DRBC fungi at Wagga Wagga and with TLNB at Tumbarumba ($P < 0.05$, Table 4.3).

4.4.2 Soil microbial populations

The bacterial and fungal counts from the vegetated and unvegetated under-vine soil were not significantly different in 2002 but in 2003 the CB count was 50% higher in the vegetated inter-row at Tumbarumba (data not shown). By 2004 (3 years after the commencement of the trial) the presence of a permanent sward had increased the counts of all soil bacterial groups. At Wagga Wagga, the counts for PS, SCB and FCB were 125%, 64% and 50% greater respectively in the vegetated inter-row soil; and those for PS, FCB, CB, SCB, FLNB and OB were 267%, 265%, 181%, 106%, 86% and 83% higher in the vegetated under-vine soil (Table 4.1). At Tumbarumba the inter-row soil PS, CB, FCB and FLNB counts were increased by 258%, 102%, 86% and 86% respectively. The Tumbarumba under-vine oligotrophic bacteria (OB) and FCB counts were also increased by 414% and 87% respectively (Table 4.1). Principal components analysis (PCA) was able to clearly discriminate between microbial populations from the vegetated and unvegetated soil.

Table 4.1. Microbial counts, organic carbon and bulk density in under-vine and inter-row vineyard soil, Wagga Wagga and Tumbarumba, May 2004.

	FCB[1]	SCB[2]	CB[3]	FLNB[4]	OB[5]	PS [6]	Cellulo-lytic fungi [7]	DRBC fungi [8]	HWC [9]	Bulk density [10]
	(10^5 cfu cm $^{-3}$ ds)						(10^3 cfu cm $^{-3}$ ds)		(mg C cm^{-3} ds)	(g cm $^{-3}$ ds)
Under-vine, Wagga Wagga										
Vegetated [11]	452a[13]	274a	382a	385a	628a	30.5a	62	129	2.6a	1.24
Unvegetated [12]	124b	133b	136b	207b	344b	8.3b	28	84	1.5b	1.20
Under-vine, Tumbarumba										
Vegetated [11]	506a	91	295	396	216a	11	189	194	3.8a	1.21
Unvegetated [12]	270b	33	287	302	42b	4	159	182	2.2b	1.23
Inter-row, Wagga Wagga										
Vegetated [11]	318a	166a	200	392	409	3.6a	111	177	2.0	1.46
Unvegetated [12]	212b	101b	197	359	350	1.6b	112	140	1.6	1.40
Inter-row, Tumbarumba										
Vegetated [11]	564a	97	442a	562a	238	14.3a	237	266	8.1a	1.10a
Unvegetated[12]	303b	102	219b	302b	251	4.0b	174	199	1.8b	1.17b

[1] FCB = fast growing cellulolytic bacteria, colonies on CBA after 4 days; [2] SCB = slow cellulolytic bacteria, calculated from total cellulolytic bacteria, colonies on CBA after 84 d (TCB) - FCB; [3] CB = copiotrophic bacteria, colonies on NBA after 4 days; [4] FLNB = fast growing low nutrient bacteria, colonies on DNBA after 4 days; [5] OB = oligotrophic bacteria , calculated from total low nutrient bacteria, colonies on DNBA after 84 d (TLNB) – CB; [6] PS = copiotrophic pseudomonads, colonies on Pseudomonas Agar CCF after 4 days; [7] Fungal colonies on CCC after 7 days; [8] Fungal colonies on DRBC agar after 7 days; [9] Soil hot water extractable C, 0-2cm depth; [10] Soil bulk density 0-10 cm depth; [11] sward = grassed, nil herbicide treatment; [12] bare = herbicide treatment; [13] values within a column followed by the same letter are not significantly different based on l.s.d. (P = 0.05); cfu = colony forming units; ds = dry soil.

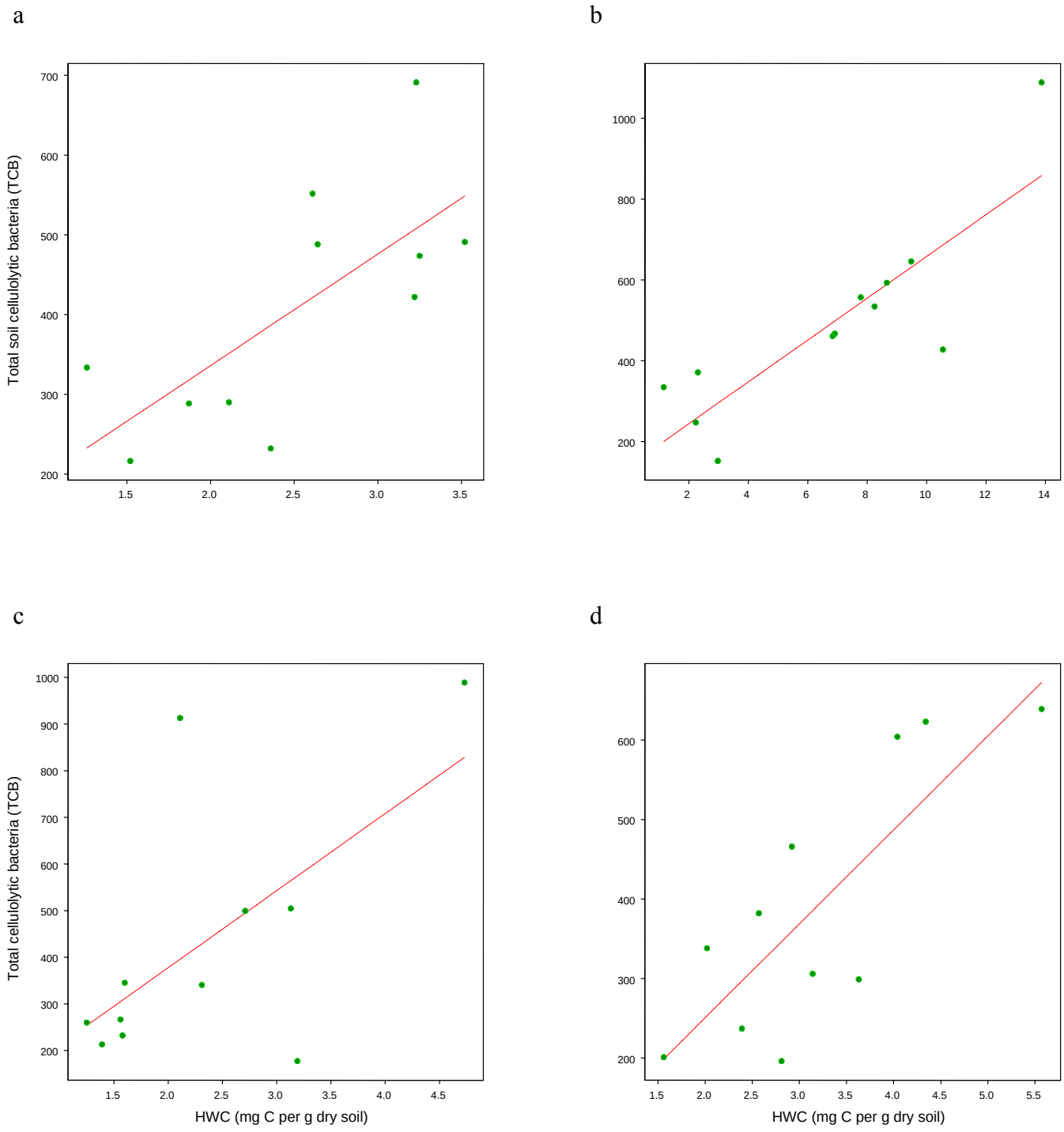


Figure 4.1. Simple linear regression equations for soil organic C (HWC, 2 cm depth) and total cellulolytic bacteria (TCB): (a) Wagga Wagga inter-row soil (Y = 57 + 140X), n = 12, r = 0.68, *P* = 0.013; (b) Tumbarumba inter-row soil (Y = 141 + 52X), n = 12, r = 0.83, *P* < 0.001; (c) Wagga Wagga under-vine soil (Y = 47 + 165X), n = 12, r = 0.57, *P* = 0.040; and (d) Tumbarumba under-vine soil (Y = 14 + 118X), n = 12, r = 0.78, *P* = 0.003.

4.4.3 Grapevine rhizosphere microbial populations

By 2004 the Tumbarumba grapevine rhizosphere SCB count was increased by 314% by the presence of a permanent sward. At Wagga Wagga the vegetated treatment had not yet significantly increased any of the grapevine rhizosphere microbial counts, although there was a non-significant trend towards a higher FLNB count. Interestingly, a high proportion of the fast growing bacterial count in the grapevine rhizosphere were cellulolytic: FCB counts were only 23% and 15% lower than FLNB counts at Wagga Wagga and Tumbarumba respectively. Similarly, at Wagga Wagga a high proportion of the slow growing rhizosphere bacterial count was also cellulolytic. A high proportion of rhizosphere fungi were also cellulolytic (Table 4.2).

Table 4.2. Grapevine rhizosphere microbial counts for vineyards at Wagga Wagga and Tumbarumba, May 2004.

	FCB [1]	SCB [2]	CB [3]	FLNB [4]	OB [5]	PS [6]	Cellulo-lytic fungi [7]	DRBC fungi [8]
	(10^5 cfu g^{-1} rfw)						(10^3 cfu g^{-1} rfw)	
Wagga Wagga								
Vegetated [9]	1178	1334	761	1566 [11]	1423	132	124	89
Unvegetated [10]	1085	1650	624	1388	1372	166	110	67
Tumbarumba								
Vegetated [9]	2325	708a[12]	1850	2770	1625	58	152	188
Unvegetated [10]	2250	171b	1088	2616	1871	82	131	147

[1] FCB = fast growing cellulolytic bacteria, colonies on CBA after 4 days; [2] SCB = slow cellulolytic bacteria, calculated from total cellulolytic bacteria, colonies on CBA after 84 d (TCB) - FCB; [3] CB = copiotrophic bacteria, colonies on NBA after 4 days; [4] FLNB = fast growing low nutrient bacteria, colonies on DNBA after 4 days; [5] OB = oligotrophic bacteria , calculated from total low nutrient bacteria, colonies on DNBA after 84 d (TLNB) – CB; [6] PS = copiotrophic pseudomonads, colonies on Pseudomonas Agar CCF after 4 days; [7] Fungal colonies on CCC after 7 days; [8] Fungal colonies on DRBC agar after 7 days; [9] sward = grassed, nil herbicide treatment; [10] bare = herbicided treatment; [11] non-significant trend towards higher count for sward, $P = 0.054$; [12] values within a column followed by the same letter are not significantly different based on l.s.d. ($P = 0.05$); cfu = colony forming units; rfw = root fresh weight.

All microbial counts were greater in the grapevine rhizosphere than in the under-vine bulk soil. At Wagga Wagga, the populations of PS, SCB, TCB, FLNB, FCB, OB, TLNB, CB and cellulolytic fungi were 668%, 633%, 434%, 399%, 293%, 188%, 181%, 167%, 160% and 160% respectively higher in the rhizosphere than in the under-vine bulk soil. At Tumbarumba, the populations of OB, PS, TLNB, FLNB, SCB, TCB, FCB and CB were 1181%, 833%, 712%, 672%, 609%, 504%, 490% and 405% respectively higher in the rhizosphere than in the

under-vine bulk soil ($P < 0.001$, Tables 4.1 and 4.2). Two grapevine rhizosphere microbial groups were positively correlated with their populations in the under-vine bulk soil: DRBC fungi at Wagga Wagga (r = 0.72) and SCB at Tumbarumba (r = 0.57) (Table 4.3).

Table 4.3. Simple linear regression correlation coefficients between soil organic C, soil pH, and soil or rhizosphere microbial populations[a].

	Wagga Wagga		**Tumbarumba**	
	r[b]	***P***	**r**	***P***
Inter-row soil				
HWC *vs* FCB	0.63	0.030	0.83	<0.001
HWC *vs* TCB	0.66	0.016	0.82	<0.001
HWC *vs* CB	NC	NC	0.78	0.0021
HWC *vs* FLNB	NC	NC	0.80	0.001
HWC *vs* TLNB	NC	NC	0.75	0.005
HWC *vs* PS	0.60	0.030	0.83	<0.001
HWC *vs* cellulolytic fungi	NC	NC	0.64	0.015
HWC *vs* DRBC	NC	NC	0.69	0.012
HWC *vs* OC	NC	NC	0.51	0.050
HWC *vs* bulk density	NC	NC	-0.89	<0.001
OC *vs* TLNB	NC	NC	0.58	0.035
OC *vs* DRBC	0.68	0.009	NC	NC
OC *vs* bulk density	-0.58	0.027	NC	NC
pH (water) *vs* SCB	NC	NC	0.53	0.045
pH (water) *vs* TLNB	NC	NC	0.68	0.013
Under-vine soil				
HWC *vs* FCB	0.61	0.028	0.74	0.006
HWC *vs* TCB	0.54	0.049	0.73	0.006
HWC *vs* CB	0.55	0.047	NC	NC
HWC *vs* FLNB	NC	NC	NC	NC
HWC *vs* TLNB	0.55	0.045	NC	NC
HWC *vs* PS	0.67	0.014	NC	NC
HWC *vs* cellulolytic fungi	0.67	0.014	NC	NC
HWC *vs* DRBC	0.91	<0.001	NC	NC
HWC *vs* OC	NC	NC	NC	NC
HWC *vs* bulk density	NC	NC	NC	NC
OC *vs* bulk density	NC	NC	NC	NC
pH (water) *vs* DRBC fungi	NC	NC	-0.52	0.049
pH (water) *vs* cellulolytic fungi	NC	NC	-0.80	0.001
Rhizosphere soil				
HWC *vs* SCB	NC	NC	0.65	0.018
HWC *vs* CB	NC	NC	0.58	0.037
HWC *vs* DRBC	0.63	0.023	NC	NC
pH (water) *vs* PS	NC	NC	0.74	0.003
Soil SCB *vs* rhizosphere SCB	NC	NC	0.57	0.031
Soil DRBC *vs* rhizosphere DRBC	0.72	0.005	NC	NC

[a] n = 12, $P = 0.05$; [b] r = linear correlation coefficient; NC = not correlated, $P < 0.05$.

4.4.4 Soil pH

Soil pH ($CaCl_2$) was not correlated with any microbial group but pH (water) was positively correlated with SCB (r = 0.53*) and TLNB (r = 0.68) in the Wagga Wagga inter-row soil and with PS in the grapevine rhizosphere (r = 0.74). Soil pH (water) was also negatively correlated with cellulolytic fungi (r = -0.80) and DRBC fungi (r = -0.52) in the Wagga Wagga under-vine (Table 4.3).

4.4.5 Bulk density

In 2004, after 3 years of herbicide treatment, soil BD was 6.4% higher for the unvegetated than for the vegetated inter-row soil at Tumbarumba (Table 4.1). Inter-row soil BD was negatively correlated with HWC at Tumbarumba (r = -0.89) and with OC at Wagga Wagga (r = -0.58) (Table 4.3).

4.5 Discussion

4.5.1 Organic C

After three years, permanent swards had significantly increased organic C and microbial populations in the vineyard soil. This supports the findings of Morlat and Jacquet (2003) who showed that permanent grass cover resulted in higher organic C levels in vineyard inter-row soil. Many non-viticultural studies also support these findings (Voets et al., 1974; Gorlach-Lira et al., 1997; Murata and Goh, 1997).

HWC (0-2 cm) responded to the vegetated treatment quickly whereas OC (0-10 cm) was still not significantly higher in the vegetated plots after 3 years. In addition most soil microbial populations were positively correlated with HWC whereas only two were correlated with OC. This is in agreement with Ghani et al. (2003) who reported that HWC was a more sensitive and consistent indicator for differentiating treatment and land-use effects. However, the lack of response in OC may also be explained in part by the different soil sample depths used for the two methods because accumulated C originating from plant litter is likely to be close to the soil surface. Purnomo et al. (2000) reported that, on a similar Red Kandosol cropping soil situated close to the vineyard site, the organic C content in the 0-2 cm depth was 24% higher than the average for the 0-10 cm depth. Most of the net N mineralised in the Purnomo et al. (2000) study originated from the top 2 cm, indicating that much of the microbial activity also occurs at this depth.

4.5.2 Soil microbial counts

After 3 years, the permanent sward (consisting primarily of grasses of low to intermediate fertility) had caused significant increases in nearly all bacterial counts, consistent with the tendency of soil bacteria to act as early indicators of the effects of soil treatments (Wardle et al., 1999; Powlson et al., 1987). The separation of the microbial response profiles by PCA is probably attributable to differences in soil organic C levels. These findings are in agreement with the results of Reuter et al. (2000) who reported that long-term use of herbicides resulted in impoverishment of soil organic nutrient sources and decreased microbial biomass in a vineyard in Burgundy, France. Similarly, Bardgett et al. (1999) showed that the total active microbial biomass (as estimated by PLFA) was increased by grass species of semi-natural grasslands or grasslands of intermediate fertility. The positive correlations between organic C (HWC and OC) and soil microbial populations are in agreement with the strong positive correlations between organic C and microbial biomass in grasslands reported by Haynes (1999) and Ghani et al. (2003).

In agreement with data from a barley study (Højberg et al., 1996) the grapevine rhizosphere contained much larger populations of most microbial groups studied than the surrounding under-vine soil. The fact that the PS population was much larger (668% and 833% for Wagga Wagga and Tumbarumba respectively) in the grapevine rhizosphere than in bulk soil is also consistent with the results from a wheat study by Smit e*t al.* (2001). Plant roots tend to be selective towards members of the *Pseudomonas* genus (Marilley and Aragno, 1999). Cellulolytic bacteria tended to form a large proportion of the grape-vine rhizosphere bacterial count. It is likely that cellulolytic enzymes confer an advantage for colonisation of the grapevine rhizosphere. Compant et al. (2005) report that colonisation of Chardonnay plantlets by a plant growth-promoting and cellulolytic bacterium, *Burkholderia* sp. strain PsJN, appeared to be aided by cell wall-degrading cellulolytic enzymes which would allow the bacterium to gain entry into root internal tissues. The observation that populations of SCB and DRBC fungi in the rhizosphere were positively correlated with their populations in the under-vine bulk soil is consistent with the suggestion by Jjemba and Alexander (1999) that rhizosphere competence of some soil microorganisms may be dependent on their ability to survive in large numbers in soil.

4.5.3 Cellulolytic bacterial counts

The presence of a permanent sward had no significant effect on most rhizosphere microbial counts within the three year time frame of this trial. The only exception was the rhizosphere SCB count which was greatly increased in the vegetated treatment at Tumbarumba (314%) and was positively correlated with HWC. Long incubation periods were used for the isolation of SCB which may be part of the previously 'unculturable' bacterial population and will be the subject of further investigation.

Data obtained soon after the initial herbicide application for this vineyard trial showed that a very high proportion of soil cellulolytic soil microorganisms isolated from the newly herbicided inter-row had *in vitro* suppressive activity against the growth of the grapevine fungal root pathogens (Whitelaw-Weckert, 2004). Increasing soil organic C may thus result in a 'suppressive' soil: one that is able to suppress grapevine fungal pathogens. Soil microbial cellulolytic activity has been found to be positively correlated with suppression of plant pathogens (Workneh and van Bruggen, 1994; Rasmussen et al., 2002).

The grapevine rhizosphere also contained large numbers of OB. These oligotrophic bacteria exploit soil ecological niches with low substrate concentrations and are adapted for low nutrient environments (Ohta and Hattori, 1983). This may seem surprising as roots are often seen as high nutrient copiotrophic environments, but parts of the rhizosphere are oligotrophic, with C concentrations ranging from 10-100 $\mu g\ g^{-1}$ dry soil (Maloney et al., 1997).

4.5.4 pH

The positive correlations between soil pH and SCB or TLNB in the inter-row, and PS in the rhizosphere, are consistent with the inhibition of bacterial growth at low pH, whereas the negative correlations between soil pH and DRBC fungi and cellulolytic fungi in the under-vine soil are consistent with the inhibition of fungal growth at high pH (Alexander, 1977).

4.5.5 Bulk density

After 3 years of vegetation cover, soil BD was significantly lower (6.4%) in the vegetated inter-row plots at Tumbarumba. A French study reported a 24% decrease in BD and from 23% to 54% lower soil strength after 17 years of permanent grass cover (Morlat and Jacquet, 2003). More time may be needed before a decrease in BD is observed at Wagga Wagga.

The negative correlations between organic C and BD at both vineyards indicate that BD may continue to decrease in vegetated plots.

4.5.6 Herbicides

Herbicide toxicity may have contributed to the reduced soil microbial population in the unvegetated soil plots and this possibility should be further investigated. Results of field and laboratory studies of glyphosate have been contradictory. Long-term laboratory studies have reported reductions in soil microbial abundance (Mekwatanakarn and Sivasithamparam, 1987; Gorlach-Lira et al., 1997) but a long term (10 y) pine plantation experiment concluded that glyphosate had minimal effects overall (Busse et al., 2001). In a field cropping study, paraquat increased populations of bacteria, fungi and actinomycetes at normal application rates but at higher application rates was toxic to fungi (Camper et al., 1973). Paraquat also increased soil urease and invertase activity (Sannino and Gianfreda, 2001) whilst diquat and paraquat increased total fungal populations but decreased the population of some fungal antagonists to take-all (Mekwatanakarn and Sivasithamparam, 1987).

4.6 Conclusions

In the vineyard, bare soil in the inter-row and under the grapevine receives few inputs of organic matter, and maintenance of permanent swards can improve the organic C content and thus, the microbial abundance of the soil. After three years, permanent swards increased soil HWC in the inter-row and the under-vine soil of both vineyards. Soil bacteria and fungi were positively correlated with HWC or OC, and soil bacterial counts were markedly higher in the vegetated soil. Further work will investigate individual soil bacteria and fungi isolated in this study, and their role in the soil nutrient cycles and suppression of grapevine fungal pathogens.

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5. Effects of floor vegetation on beneficial and pest nematodes

Loothfar Rahman

5.1 Abstract

All feeding groups of nematodes namely bacterial-feeders, omnivores, fungal-feeders, predators and plant parasites were present in inter-row and under-vine soil in both vineyards. The prevalence of these groups was in order of bacterial-feeders > fungal-feeders > omnivores > predators > plant parasites. Population densities of nematode trophic groups varied between the two sampling positions (inter-row and under-vine), two soil depths (0-10 cm and 11-20 cm) and sampling months in all treatments. The beneficial nematodes, namely bacterial-feeders, omnivores, fungal-feeders and predators, were mostly abundant in the top 0-10 cm soil layer, irrespective of vine position. Among the treatments, the vegetated treatment had comparatively higher population densities of beneficial nematodes than the herbicide treatments. Variation in population abundance was also observed between the sampling months or seasons, irrespective of treatments and sampling positions. The population levels in soils that were collected in November / December (spring / summer) were always higher than the May - July (autumn/ winter) collection. At the termination of the investigation, beneficial nematodes, especially bacterial-feeders and predators, had increased substantially from initial populations, particularly in the vegetated treatment.

In contrast to beneficial nematodes, plant parasitic nematodes were more abundant in the 11-20 cm layer than the top 0 -10 cm layer of soil under the vines. The population density of plant parasitic nematodes decreased substantially in the top 0-10 cm soil layer, which is possibly a consequence of increased densities of predatory and bacterial-feeding nematodes.

5.2 Introduction

Vegetation is grown on vineyard floors to improve physical, chemical and biological properties of soil by adding organic matter. In addition, organic matter in soil enhances biological activities of different soil biota, which is a good indicator of soil health (Pankhurst et al., 1995). Soil biota are involved, directly or indirectly, in the process of organic matter decomposition, nutrient mineralisation, cycling and immobilisation. The dynamics of the microbial biomass (primarily fungi and bacteria) under different vineyard floor management

treatments has been reported (Ingles et al., 2005; Reinecke et al., 2002; Reuter and Kubiak, 2003) but none mention beneficial nematodes. Beneficial nematodes, also known as free-living nematodes, usually dominate in agricultural soils and have received much attention as possible indicators of soil health (Bongers, 1990; Neher, 2001). They are classified as bacterial-feeders, fungal-feeders, omnivores and predators. These nematodes are associated directly or indirectly with the decomposition of organic matter or plant residues (Freckman, 1988; Beare et al., 1992), increased nutrient mineralisation (N, P and S) and cycling (Mishra and Mitchell, 1987; Griffiths, 1989; Dalal, 1998) and increased nutrient uptake by plants (Ingham et al, 1985). Bacterial-feeding nematodes in association with protozoa contribute about 8-19 % N mineralisation in conventional and integrated farming systems (Neher, 2001). Predatory nematodes feed on smaller sized plant parasitic or other free living nematodes and thus contribute as a biological control agents in IPM practices.

Floor vegetation in vineyards is managed by ploughing, discing, mowing or by using herbicide (mainly in under-vine areas). Impact of different agronomic practices and application of synthetic herbicides on the abundance and community structure of beneficial nematodes has been reported in other crops (Bostrom and Sohlenius, 1986; Sohlenius et al. 1987; Yeates and Hughes, 1990, Freckman and Ettema, 1993) but not in grapevines. Management of floor vegetation by mowing or by applying herbicides may influence the population abundance and community structures of beneficial nematodes in vineyards. Therefore, this preliminary investigation was undertaken to determine the impact of different vineyard floor management practices on the abundance of different nematode populations.

5.3 Methods

5.3.1 Treatments

Nematode abundance and community structure were measured at two vineyards at Tumbarumba and Wagga Wagga. Three floor management treatments were conducted at each vineyard:

1. Unvegetated where where herbicide was applied to both inter-row and under-vine areas;
2. Partially vegetated where herbicide was applied only to under-vine areas and the inter-row was left vegetated and managed by mowing; and
3. Vegetated where no herbicide was applied and floor vegetation was managed by mowing.

Each treatment was replicated 12 times. Four vines in each treatment plot were selected and marked for collecting soil samples throughout the trial period.

5.3.2 Soil sampling

Soil samples were collected from inter-row (0 -10 cm depth) and under-vine (0-10 and 11-20 cm depth) positions twice each year in May-July and November-December. Eight soil cores from four selected vines (two cores from each vine) were collected from each treatment plot by using a 59 mm diameter soil auger, bulked, mixed thoroughly and a 1 kg (approx.) sub-sample was taken to the laboratory for assessment of nematodes and soil moisture. Undervine samples were collected at a distance of 350-400 mm from the vine along the vine row while inter-row samples were collected from the centre of the inter-row area in each plot. Samples were kept in a cool room (4°C) until processing for nematodes.

5.3.3 Nematode extraction

Nematodes were extracted from 2x 200 g soil for each sub-sample by using the Whitehead tray method (Whitehead and Hemming, 1965) with 5 day incubation period. The resulting suspensions were passed through a 15 μm sieve and the nematodes were back washed from the sieve into a 75 ml plastic container. Numbers of different groups of nematodes in the supernatant were counted using a Doncaster counting dish (Doncaster, 1962) under a stereomicroscope at 50x magnification. Specimens were also observed under a compound microscope at higher magnifications whenever necessary. Nematodes were identified to either family or genus levels. Then numbers in each group were converted to population densities per square metre using bulk density data for each sampling time. A few nematodes remained unidentified and were not included in the analysis.

5.3.4 Carbon analysis

Percentage of total carbon in the soil under different floor management practices between 2002 and 2004 were analysed by a commercial laboratory.

5.3.5 Statistical analysis

Data on nematode densities m^{-2} were transformed by natural logarithm ($\log_e x + 1$) to meet normality assumptions for the analysis. A linear mixed model including fixed and random effects was fitted for each set of data using the ASREML software (Gilmour et al, 1999). Fixed effects include floor management treatments, sampling months, sampling positions

(inter-row and under vine), sampling depth (0-10 and 11-20 cm) and their interactions while replicates and residual terms were included as random effects.

5.4 Results

5.4.1 Nematode community structure

Nematodes of all feeding groups were recorded from soils of all floor management treatments. The nematode feeding groups were bacterial-feeders, omnivores, fungal-feeders, predators and plant parasites. Bacterial-feeders include members of Rhabditidae (*Rhabditis*, *Mesorhabditis*, *Cephalobus*, *Heterocephalobus*, *Acrobles*), omnivores comprised primarily Dorylaimidae excluding plant parasites and *Aporcelaimellus*, fungal-feeders were primarily Tylenchidae, predators included members of Mononchidae and Dorylaimidae (*Aporcelaimellus* spp.) and plant parasites comprised root lesion (*Pratylenchus* spp.), pin (*Paratylenchus* spp.), ring (*Criconemoid* spp.), spiral (*Helicotylenchus* spp.) and citrus (*Tylenchulus semipenetrans*) nematodes. On average, the order of prevalence were bacterial-feeders (45%) > fungal-feeders (28%) > omnivores (17%) > predators (6%) > plant parasites (4%).

Table 5.1. Summary results of statistical analysis for densities[a] of different nematode feeding groups at 0 -10 cm soil depth in inter-row and under-vine positions at Tumbarumba and Wagga Wagga between 2002 and 2004.

	Tumbarumba				
Source of	P values for different feeding groups of nematodes [b]				
Variation	BF	OV	FF	PD	PP
Treatment	ns	Ns	ns	<0.05	ns
Position	ns	< 0.001	<0.001	<0.001	<0.001
Trt. x Pos.	<0.001	Ns	ns	<0.001	<0.001
Sampling Month	< 0.001	<0.001	<0.001	<0.001	<0.001
Trt. x Month	P=0.053	Ns	ns	<0.01	ns
Pos. x Month	< 0.001	<0.01	<0.01	<0.001	<0.001
Trt. x Pos. x Month	ns	Ns	ns	ns	ns
	Wagga Wagga				
Source of	*P* values for different feeding groups of nematodes [b]				
Variation	BF	OV	FF	PD	PP
Treatment	<0.001	ns	ns	<0.05	ns
Position	<0.001	< 0.001	<0.05	ns	ns
Trt. x Pos.	<0.001	< 0.001	ns	ns	ns
Sampling Month	< 0.001	< 0.001	<0.05	<0.001	<0.001
Trt. x Month	<0.001	<0.05	<0.05	<0.05	<0.05
Pos. x Month	< 0.01	<0.001	ns	<0.001	ns
Trt. x Pos. x Month	<0.05	ns	ns	ns	ns

[a] Analysis on Log $_e$ (nematode numbers + 1) transformed data.
[b] Nematode feeding groups: BF = Baceria feeders, OV = Omnivores, FF = fungi feeders, PD = Predators and PP = Plant parasites

5.4.2 Nematode populations in inter-row and under-vine position (0-10 cm soil depth)

The interaction effects of treatment x positions (inter-row and under-vine) x month of sampling on nematode densities of different feeding groups were not significant at Tumbarumba but only significant (P<0.05) for total bacteria feeders at Wagga Wagga (Table 5.1). The highest level significant interaction effects were treatment x positions for bacteria feeders, predators and plant parasites (P < 0.001), treatment x sampling months for predators

(P < 0.01) and positions x sampling months for all feeding groups (P < 0.001) at Tumbarumba (Table 5.1). At Wagga Wagga, the second highest level significant interaction effects were treatment x sampling position (P<0.001) for omnivores, treatment x sampling months (P<0.05) for all feeding groups and position and sampling months (P<0.05) for omnivores and predators (Table 5.1). These interaction effects on the abundance of different nematode groups are presented here only.

Interaction effects of treatments, sampling position and sampling month on the abundance of nematode densities in soil in vineyards: Population abundance of bacteria feeder nematodes varied significantly between the treatments, sampling position and sampling month at Wagga Wagga (Fig. 5.1). Populations in inter-row soil were comparatively higher than the under-vine soil. No consistent trend on population increase or decrease over sampling period was observed in this vineyard (Fig. 5.1). However, the population densities of bacterial-feeding nematodes in inter-row and under-vine soil were comparatively higher in the vegetated treatment than the others, particularly, during the last sampling month in December, 2004, (Fig. 5.1).

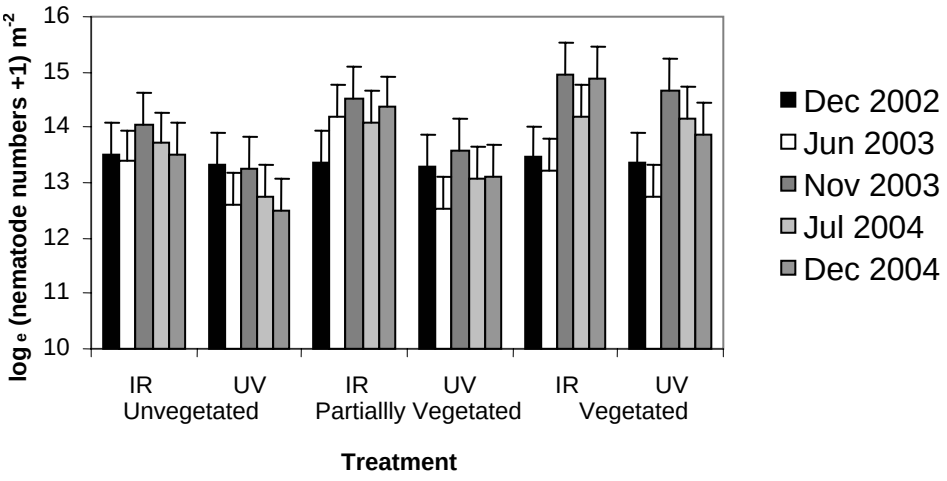


Figure 5.1. Interaction effects of floor management practices, sampling positions (inter-row (IR) or under-vine (UV)) and sampling month on the abundance of bacterial-feeding nematodes (Rhabditidae) in soil, at Wagga Wagga between 2002 and 2004.

Effect of treatments on the nematode population densities in inter-row and under-vine soils (Treatment x sampling position): The population densities of bacterial-feeding nematodes in inter-row soil were significantly (P < 0.001) higher than the under-vine soil at Tumbarumba

(Fig. 5.2). A similar trend was also observed for predatory nematodes (Fig. 5.3) at Tumbarumba and omnivores at Wagga Wagga (Fig. 5.4). At Tumbarumba, the inter-row soil had significantly ($P < 0.001$) higher population levels of predatory nematodes than the under-vine soil irrespective of floor management treatment.

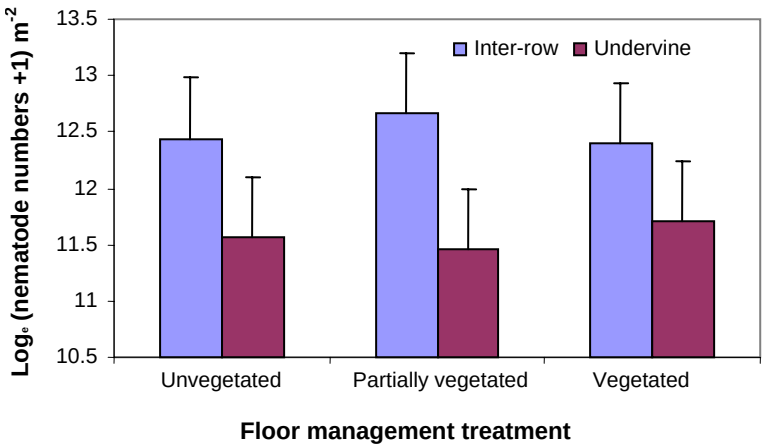


Figure 5.2. Effect of floor management treatment on population densities of bacterial-feeding nematodes (Rhabditidae) in inter-row and under-vine soil at Tumbarumba between 2002 and 2004.

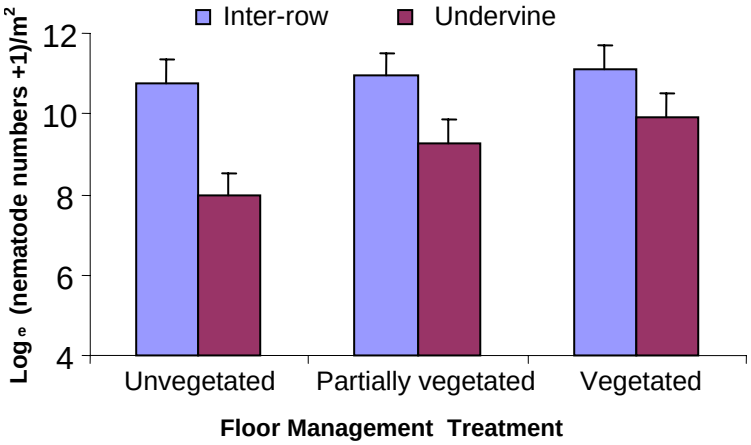


Figure 5.3. Effect of floor management treatment on the population densities of predatory nematodes (Mononchidae and Dorylaimidae) in inter-row and under-vine soil at Tumbarumba between 2002 and 2004.

Population densities of omnivores were also significantly higher in inter-row soil than the under-vine soil in all treatments at Wagga Wagga (Fig. 5.4). However, population densities were similar among the treatments irrespective of sampling position.

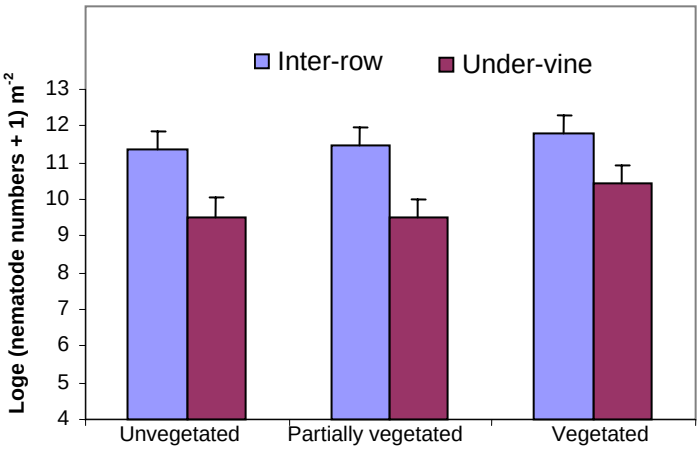


Figure 5.4. Effect of floor management treatment on the population densities of omnivores (Dorylaimidae) in soil of inter-row and under-vine position at Wagga Wagga between 2002 and 2004.

Population densities of plant parasitic nematodes in inter-row and under-vine soil also varied significantly ($P < 0.001$) within each treatment but not between the treatments at Tumbarumba (Fig. 5.5).

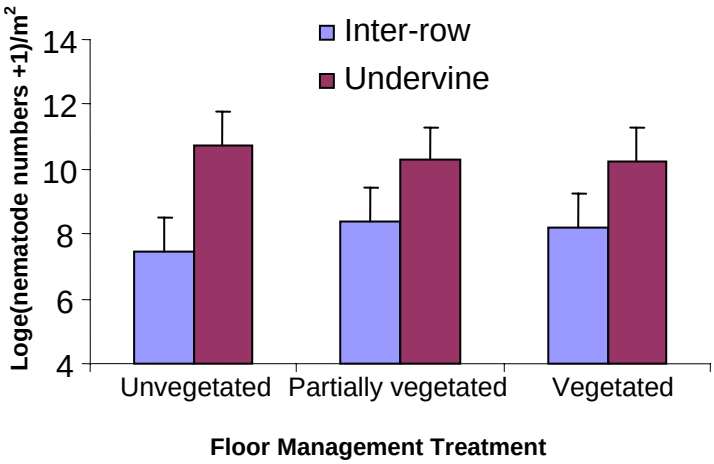


Figure 5.5. Effect of floor management treatment on the population densities of plant parasitic nematodes (Tylenchidae) in inter-row and undervine soil at Tumbarumba between 2002 and 2004.

Seasonal effects on the population abundance of nematode population densities in the inter-row and under-vine soil (Sampling positions x Sampling months): Nematode populations in under-vine and inter-row positions varied with sampling time. Greater population densities of bacterial-feeding nematodes were recorded at Tumbarumba in during November-December than in May-June (Fig. 5.6). The initial population densities in November 2002 were increased by 2.8-fold in inter-row and 1.2-fold in under-vine position in November 2004 in this vineyard (Fig. 5.6). A similar trend was also observed for omnivorous nematodes (Figs 5.7 and 5.8) predatory nematodes (Figs 5.9 and 5.10) and plant parasitic nematodes (Fig. 5.12). At Tumbarumba, fungal-feeding nematodes were recorded in November 2002 and May 2003 samples only (Fig. 5.11). Populations of predatory nematodes consistently increased in inter-row position except in December 2003 while it was inconsistent for under-vine position at Tumbarumba (Fig. 5.9). Similarly, the initial population densities of predatory nematodes in inter-row and under-vine soil increased in spring / summer seasons with a small reduction in winter at Wagga Wagga (Fig. 5.10). However, the final population densities of predatory nematodes were greater than initial population levels in both vineyards. There were 4.95- and 3.23-fold increases in population density in inter-row and under-vine soil respectively at Tumbarumba (Fig. 5.9), and 5,842- and 4-fold increases in inter-row and under-vine soil respectively in CSU vineyard (Fig. 5.10). In contrast to the increase of beneficial nematodes at the termination of the soil sampling, plant parasitic nematodes decreased consistently both in the inter-row and under-vine positions in all sampling months except May 2003 in inter-row position at Tumbarumba (Fig. 5.12).

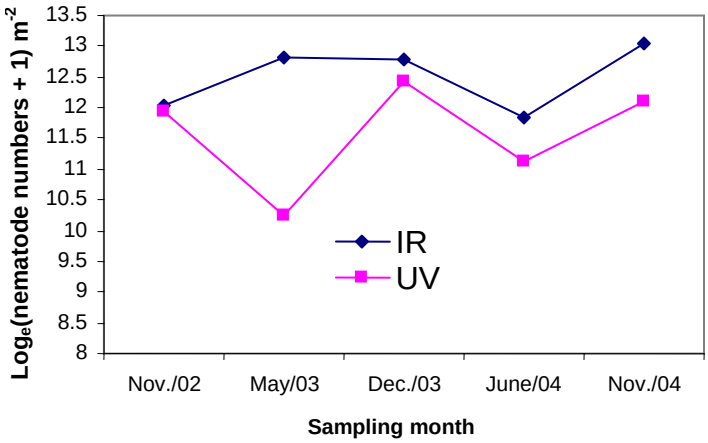


Figure 5.6. Population densities of bacteria feeder nematodes (Rhabditidae) in inter-row and under-vine soil at different sampling months at Tumbarumba between 2002 and 2004.

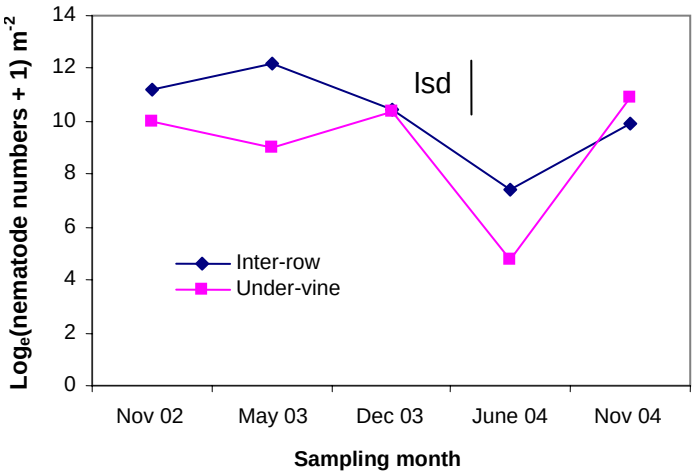


Figure 5.7. Population densities of total omnivores (Dorylaimidae) in inter-row and under-vine soil at different sampling months at Tumbarumba between 2002 and 2004.

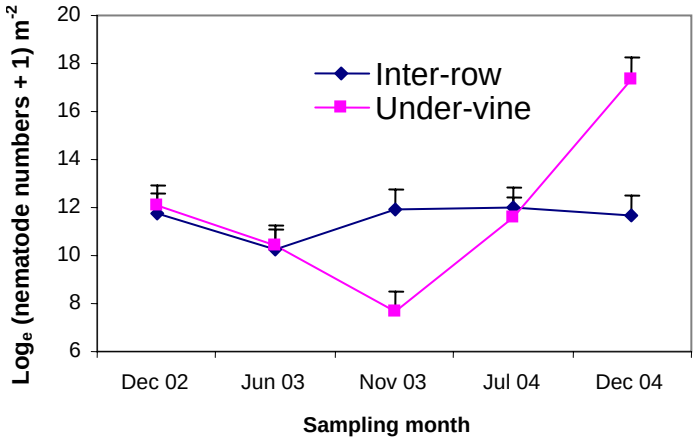


Figure 5.8. Population densities of total omnivores (Dorylaimidae) in inter-row and under-vine soil at different sampling months at Wagga Wagga between 2002 and 2004.

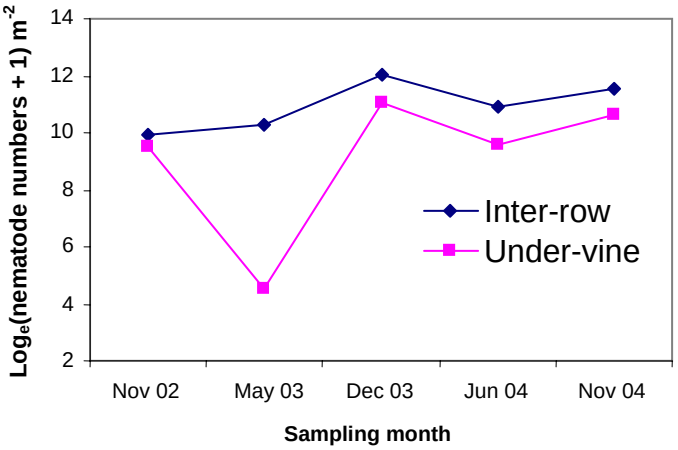


Figure 5.9. Population densities of predatory nematodes (Mononchidae and Dorylaimidae) in inter-row and under-vine soil at different sampling months at Tumbarumba between 2002 and 2004.

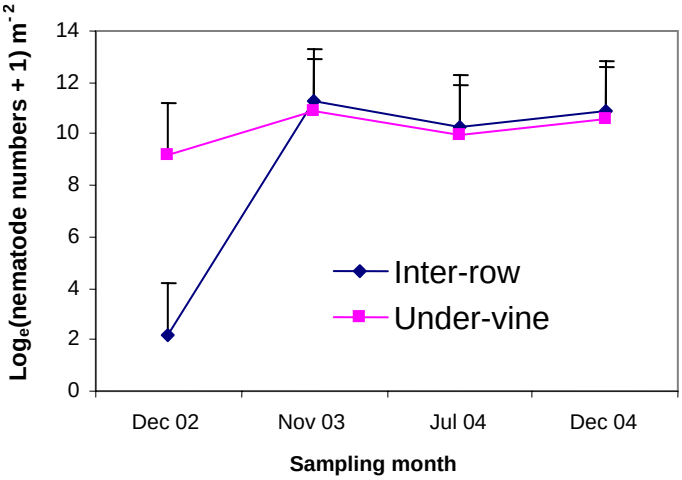


Figure 5.10. Population densities of predatory nematodes (Mononchidae and Dorylaimidae) in inter-row and under-vine soil at different sampling months at Wagga Wagga between 2002 and 2004.

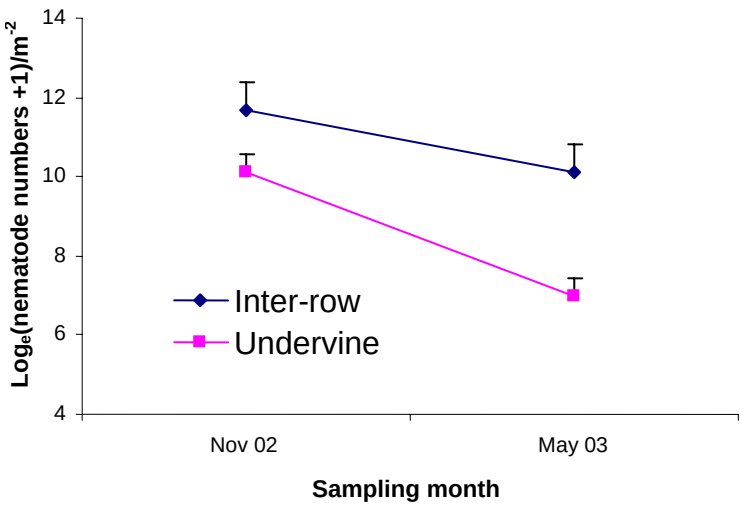


Figure 5.11. Population densities of fungal feeders (Tylenchidae) in inter-row and undervine soil at different months at Tumbarumba between 2002 and 2004.

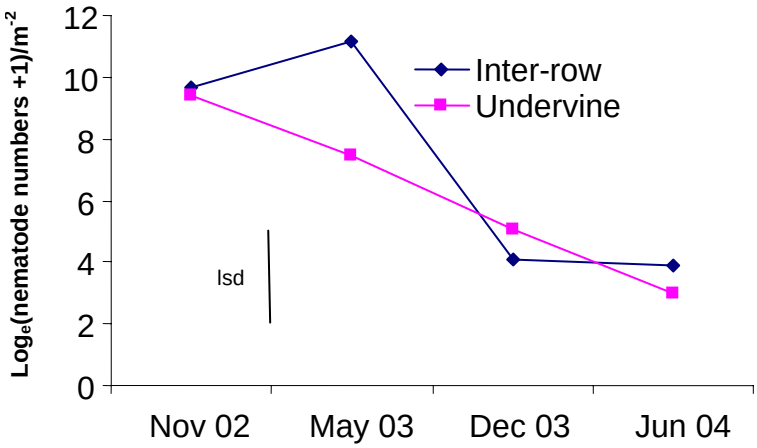


Figure 5.12. Population densities of plant parasites (Tylenchidae) in inter-row and undervine soil on different months at Tumbarumba between 2002 and 2004.

Effects of different treatments on the abundance of nematode populations in soil at different sampling month (Treatment x sampling month): There were seasonal effects on the population densities of bacteria feeders ($P = 0.053$) and predatory nematodes ($P < 0.01$) at Tumbarumba and for all feeding groups at Wagga Wagga ($P < 0.05$). The population densities of bacterial-feeding nematodes in soil varied between the sampling months within a floor management treatment in both vineyards (Figs 5.1 and 5.13). Initial population levels increased 101% and 235% in vegetated and partially vegetated plots respectively at Tumbarumba (Fig. 5.13). At Wagga Wagga, population densities of bacterial-feeding

nematodes also increased considerably in inter-row and under-vine positions in the vegetated treatment compared to the unvegetated treatment during Spring / summer season (Fig. 5.1). A similar trend was also observed for the population densities of predatory nematodes in both vineyards (Figs 5.14 and 5.15). There were 3- to 7-fold increases in population levels in vegetated and partially vegetated plots compared to 2.7-fold increase in unvegetated plots at Tumbarumba (Fig. 5.14). In contrast, the highest population of predatory nematodes were recorded from November 2003 in all treatments at Wagga Wagga (Fig. 5.15). No predatory nematodes were recorded from the June 2003 sample at Wagga Wagga.

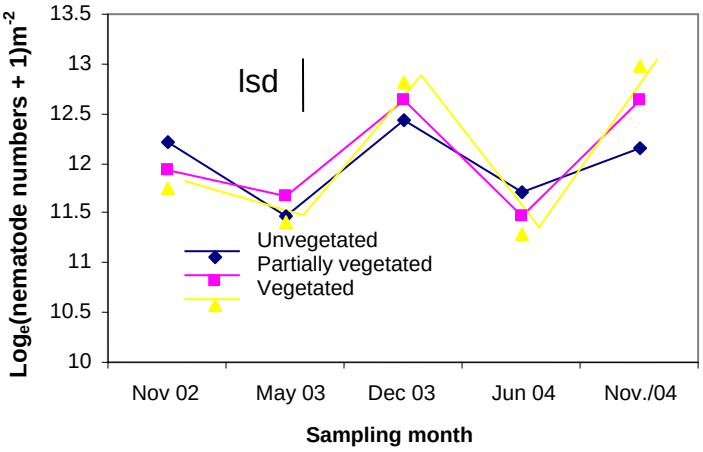


Figure 5.13. Effect of floor management treatments on population densities of bacterial-feeding nematodes (Rhabditidae) in soil on different sampling months at Tumbarumba between 2002 and 2004.

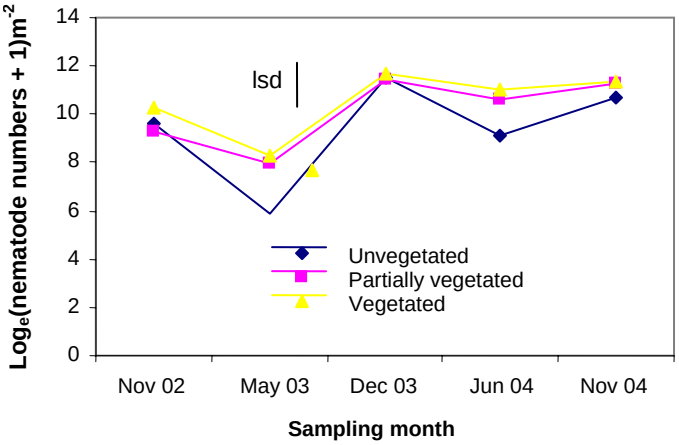


Figure 5.14. Effects of floor management treatments on population densities of predatory nematodes (Monochidae and Dorylaimidae) in soil on different sampling months at Tumbarumba between 2002 and 2004.

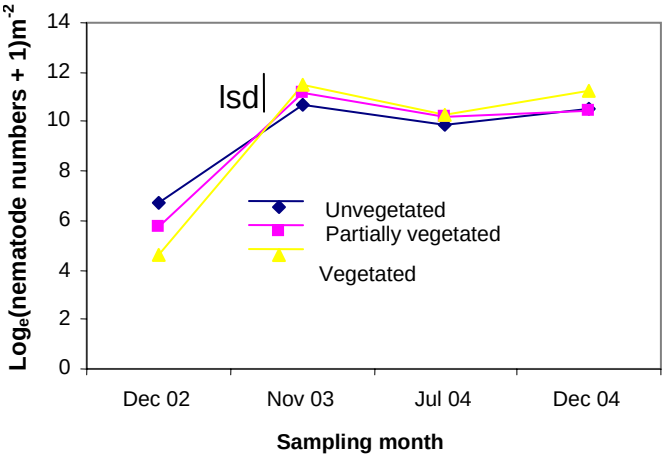


Figure 5.15. Effect of floor management treatment on population densities of predatory nematodes (Monochidae and Dorylaimidae) in soil on different sampling months at Wagga Wagga between 2002 and 2004.

Fungal-feeding nematodes also followed the same pattern in the CSU vineyard (Fig. 5.16) where the population densities were in order of unvegetated < partially vegetated < vegetated treatment during the all sampling periods.

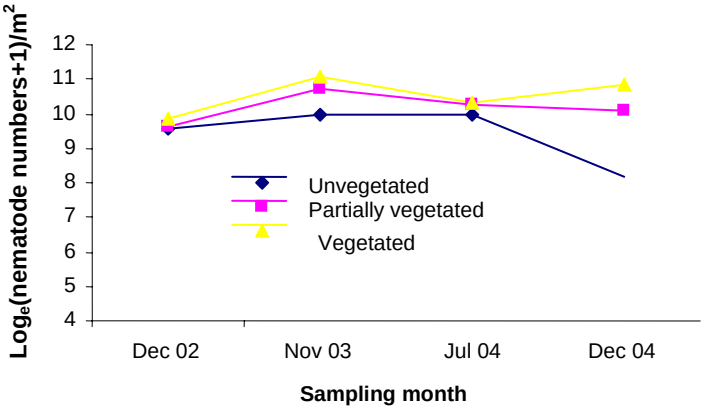


Figure 5.16. Population densities of fungi feeders (Tylenchidae) in different floor management treatments during different sampling months at Wagga Wagga between 2002 and 2004.

No consistent trend was observed for omnivores at Wagga Wagga (Fig. 5.17). At the termination of investigation in December 2004, population densities had decreased in all treatments.

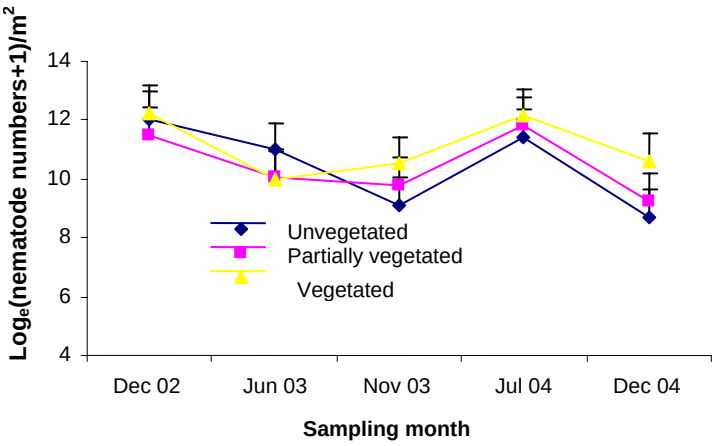


Figure 5.17. Population densities of omnivores (Dorylaimidae) in different floor management treatments for different sampling months at Wagga Wagga between 2002 and 2004.

The population density of plant parasitic nematodes varied significantly between the sampling periods within a treatment at Wagga Wagga (Fig. 5.18). The differences were insignificant between the treatments within a sampling month except during July 2004.

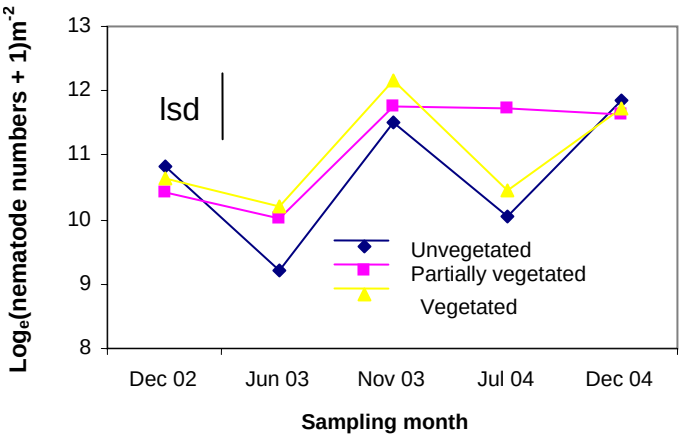


Figure 5.18. Effects of floor management treatment on population densities of plant parasitic nematodes (Tylenchidae) in soil on different sampling months at Wagga Wagga between 2002 and 2004.

5.4.3 Spatial distribution of nematodes in under-vine position

No significant interaction effect of treatment x months of sampling x soil depth was observed for any of the nematode feeding groups in both vineyards (Table 5.2). The highest level of significant interactions were treatment x soil depth, treatment x sampling months, and soil depth x sampling months for both vineyards (Table 5.2).

Table 5.2. Summary results of statistical analysis for densities[a] of different nematode feeding groups at 0-10 cm and 11-20 cm soil depth in under-vine positions at Tumbarumba and Wagga Wagga between 2002 and 2004.

	Tumbarumba				
Source of	Nematode feeding groups[b]				
Variation[c]	BF	OV	FF	PD	PP
Treatment	ns	<0.05	ns	ns	ns
Depth	< 0.001	< 0.001	ns	<0.05	<0.001
Trt. x depth	ns	<0.01	ns	ns	<0.05
Sampling month.	< 0.001	<0.001	-	<0.001	<0.001
Trt. x Month.	ns	ns	-	<0.05	ns
Depth x Month.	< 0.01	<0.05	-	<0.05	<0.01
Trt. x Depth x Month.	ns	ns	-	ns	ns
	Wagga Wagga				
Source of	Nematode feeding groups[b]				
Variation[c]	BF	OV	FF	PD	PP
Treatment	<0.01	<0.05	ns	<0.001	ns
Depth	< 0.001	< 0.001	ns	<0.001	ns
Trt. x depth	<0.01	ns	ns	<0.05	ns
Sampling month.	< 0.001	<0.001	ns	<0.05	<0.05
Trt. x Month.	ns	ns	ns	ns	ns
Depth x Month	< 0.05	<0.05	ns	ns	ns
Trt. x Depth x Month	ns	ns	ns	ns	ns

[a] Analysis on Log $_e$(nematode numbers + 1) transformed data.
[b] Nematode feeding groups: BF = Baceria feeder, OV = Omnivores, FF = fungal feeders, PD = Predators and PP = Plant parasites
- data were not sufficient for analysis

Effects of treatments on the population density of nematodes at different depths of soil in under-vine position (Treatment x depth): Floor management treatments did not have any consistent effect on nematode population density either at 0-10 cm or 11-20 cm soil layer at Tumbarumba. Total plant parasitic nematodes varied significantly between the treatments in the 11 - 20 cm soil layer but not in the 0 -10 cm soil layer (Fig. 5.19). Population levels were

comparatively higher in the 11-20 cm soil layer than the 0-10 cm soil layer except in the unvegetated treatment but the difference was only significant for the vegetated treatment (Fig. 5.19).

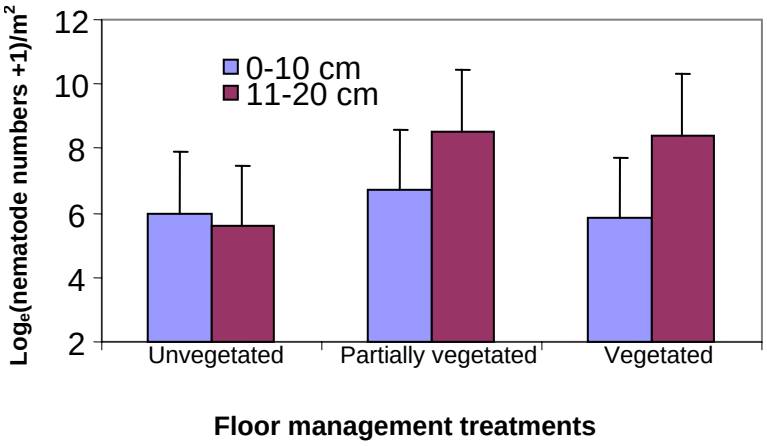


Figure 5.19. Population densities of plant parasites (Tylenchidae) in different cover crop management practices at 0-10 and 11-20 cm depth of soil in undervine position at Wagga Wagga between 2002 and 2004.

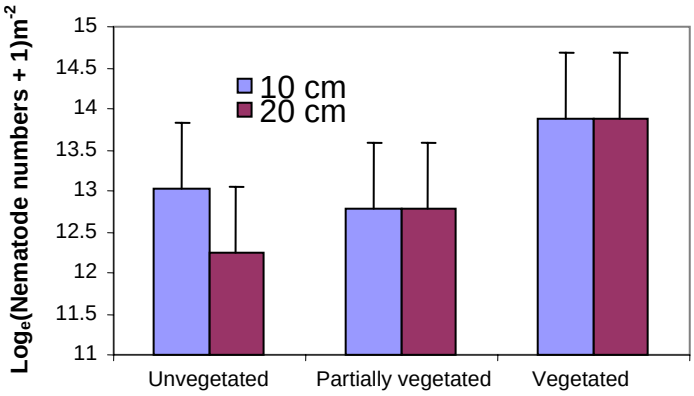


Figure 5.20. Effects of different floor management treatments on population densities of bacterial-feeding nematodes (Rhabditidae) at different soil depths in under-vine position at Wagga Wagga between 2002 and 2004.

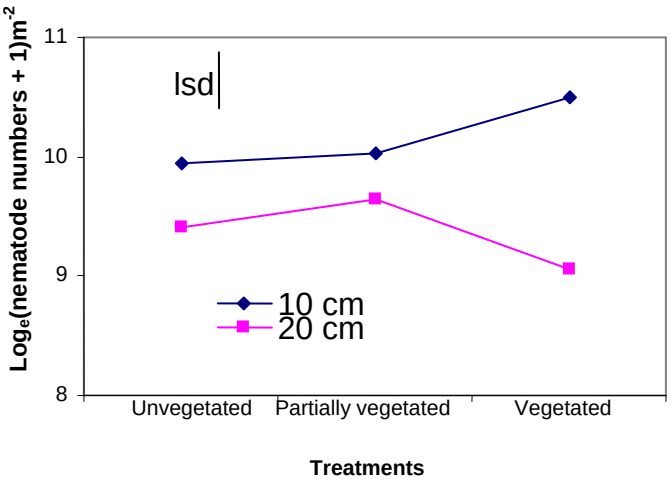


Figure 5.21. Effects of different floor management treatments on population densities of predatory nematodes (Monochidae and Dorylaimidae) at different soil depths in under-vine position at Wagga Wagga between 2002 and 2004.

The interaction effect of treatment and depth was only significant for bacteria feeders ($P < 0.01$) and predators ($P < 0.05$) at Wagga Wagga (Table 5.2). The vegetated treatment had greater population densities of total bacteria feeders than the other treatments irrespective of soil depth (Fig. 5.20). Population densities of predatory nematodes were significantly greater in 0-10 cm soil in the vegetated treatment than the others (Fig. 5.21).

Seasonal effects on the population density of nematodes at different soil depth in under-vine position (Depth x sampling month): The population densities of bacteria feeders (Figs 5.22 and 5.23), omnivores (Figs 5.24 and 5.25) and predators (Fig. 5.26) were comparatively higher in the top 0 -10 cm soil layer than the underlying 11-20 cm soil layer in most cases in both vineyards. Population densities of bacterial-feeders were comparatively higher during spring / summer than in autumn / winter in the both vineyards (Figs 5.22 and 5.23). A similar trend was also observed for omnivores in both vineyards (Figs 5.24 and 5.25).

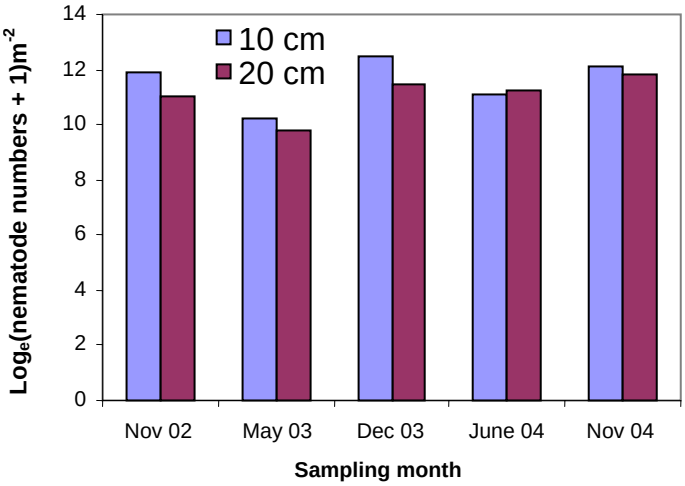


Figure 5.22. Population densities of bacteria feeder nematodes (Rhabditidae) in 0-10 and 11-20 cm soil layers in under-vine position during different sampling months at Tumbarumba between 2002 and 2004.

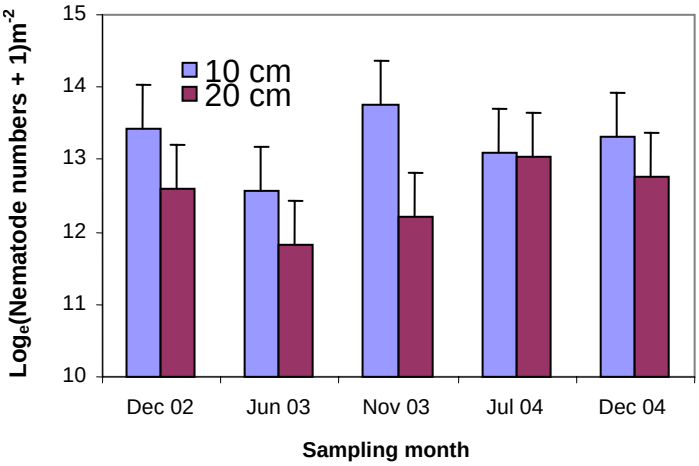


Figure 5.23. Population densities of bacteria feeder nematodes (Rhabditidae) in 0-10 and 11-20 cm soil layers in under-vine position during different sampling months at Wagga Wagga between 2002 and 2004.

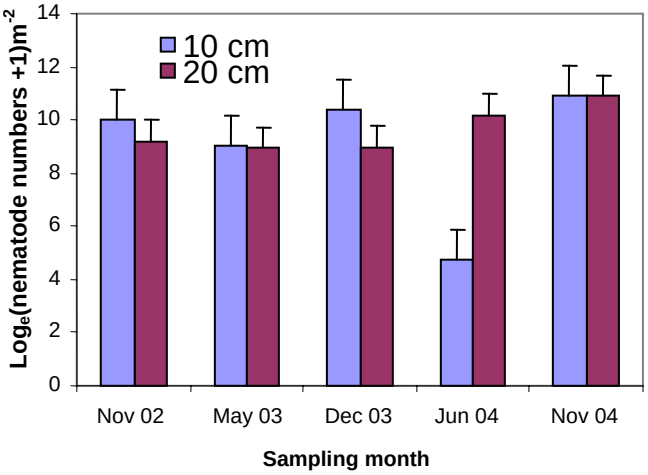


Figure 5.24. Abundance of omnivores (Dorylaimidae) at 0-10 and 11-20 cm soil layers in under-vine position during different sampling months at Tumbarumba between 2002 and 2004.

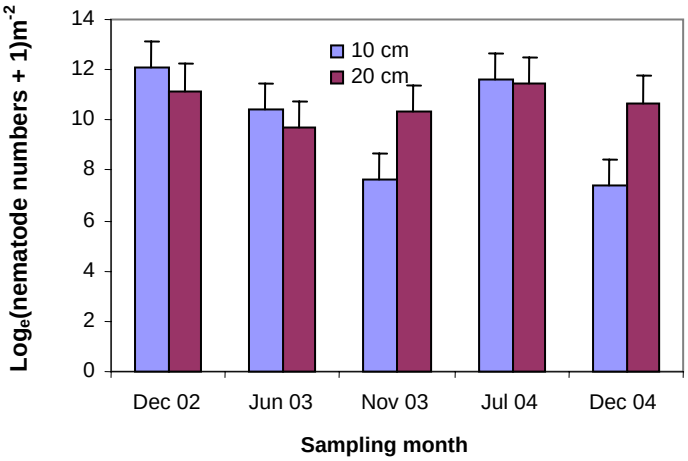


Figure 5.25. Abundance of omnivores (Dorylaimidae) at 0-10 and 11-20 cm soil layers in under-vine position during different sampling months at Wagga Wagga between 2002 and 2004.

Population densities of predatory nematodes did not differ significantly between the soil layers except in the sample collected in May 2003 at Tumbarumba (Fig. 5.26). However, population densities of predatory nematodes were increased by 3.2- and 4.6-fold in the 0 -10 cm and 11 -20 cm soil layers respectively (Fig. 5.26) during the last sampling period in November 2004.

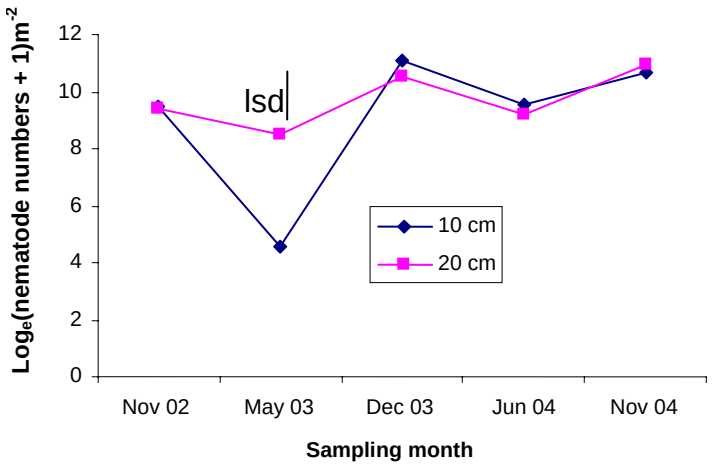


Figure 5.26. Population density of predatory nematodes (Monochidae and Dorylaimidae) at 0-10 cm and 11-20 cm soil layers in under-vine position from different sampling months at Tumbarumba between 2002 and 2004.

In contrast to the beneficial nematodes, plant parasitic nematode densities in the 0 -10 soil layer decreased consistently but was inconsistent in the 11 - 20 cm soil layer at Tumbarumba (Fig. 5.27). Reductions in population densities of plant parasitic nematodes were equivalent to 99.6 % and 89.9 % respectively in the 0 -10 cm and 11 -20 cm soil layers (Fig. 5.27).

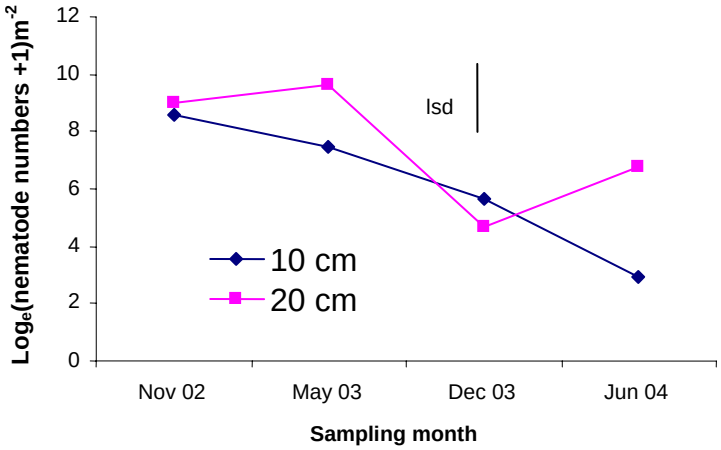


Figure 5.27. Population densities of plant parasitic nematodes (Tylenchidae) in 0-10 and 11-20 cm soil layes in under-vine position from different sampling months at Tumbarumba between 2002 and 2004.

5.4.4 Carbon contents in soil

Percentages of total carbon in soil were comparatively higher at Tumbarumba than at Wagga Wagga (Table 5.3). In both vineyards, inter-row soil had comparatively higher percentage of total carbon than the under-vine areas. No significant change in total carbon over three years was observed in any of the treatments in both vineyards (Table 5.3).

Table 5.3. Percentage of total organic carbon in soil of different cover crop management practices in Tumbarumba and Wagga Wagga vineyards between 2002 and 2004.

Tumbarumba						
Year	Unvegetated		Partially vegetated		Vegetated	
	Inter-row	Under-vine	Inter-row	Under-vine	Inter-row	Under-vine
2002	1.83	1.2	1.45	1.08	1.83	1.35
2003	1.73	1.38	1.8	1.23	1.78	1.25
2004	1.68	1.33	2.1	1.23	1.93	1.33
Wagga Wagga						
2002	1.04	0.92	0.82	0.59	0.75	0.58
2003	0.85	0.89	0.76	0.66	0.92	0.66
2004	0.87	0.83	0.66	0.60	0.78	0.81

5.5 Discussion

Soil from the inter-row had higher densities of beneficial nematodes, particularly bacterial-feeding nematodes, than under-vine soil. Higher populations of beneficial nematodes in inter-row soil may be related to increased organic matter in the soil. Addition of organic matter to soil provides food sources for nematodes (Andren and Lagerlof, 1983). Increased food sources may thus increase beneficial nematodes in soil (Bohlen and Edwards, 1994; Freckman, 1988; Griffiths, et. al., 1994). Higher levels of organic carbon in inter-row soil (Table 5.3) also supported higher population levels of beneficial nematodes in our study. Ruess et al. (2002) observed increased population abundance and density of bacteria feeder nematodes when labile carbon (sugar) along with fertiliser was added in soil. A lower population density of beneficial nematodes in under-vine soil may be related to the use of herbicide in the under-vine position to control weeds. Freckman and Ettema (1993) observed that there were 40% more bacterial-feeding nematodes in plots with no herbicide than plots

with herbicide application. Yardirn and Edwards (1998) also reported adverse effects of herbicide on bacteria- and fungi-feeding nematodes.

This study also demonstrated that beneficial nematodes are more abundant in the top 0 -10 cm soil layer than the underlying 11-20 cm soil layer. This could also be due to higher levels of organic matter in the top layer of soil but this needs further observation.

Plant parasitic nematodes were more prevalent in under-vine soil than inter-row soil. Association of more vulnerable feeder roots in the under-vine position (Loubser and Meyer, 1986) is the most likely reason for such a high abundance of plant parasitic nematodes in this area. A consistent decrease in plant parasitic nematodes in the top 0 -10 cm soil layer over sampling months suggested that natural enemies or antagonists of plant parasitic nematodes may have been enhanced through the addition of organic matter in this study. An overall increase in predatory nematodes both in the 0-10 and 11-20 cm soil layers may also be the reason for decreasing populations of plant parasitic nematodes in this study. Microbes with competitive, predaceous and antagonistic nature may increase after the addition of organic matter or amendments in soil with consequent decrease of plant diseases including pest nematodes (Akhtar and Mahmood, 1996; Clark et. al., 1998).

Results from this study also demonstrate that there was a seasonal effect on the population abundance of beneficial nematodes in soil. The population densities were always higher in spring/summer than in autumn/winter. This suggests that more favourable conditions for nematode development in spring/summer in conjunction with the added organic matter during this period may be the possible reasons for such a higher population during spring/summer.

Results from this preliminary investigation suggested that beneficial nematodes can be increased with a consequent decrease of plant parasitic nematodes after adding organic matter from mid-row ground covers in vineyards. As beneficial nematodes indirectly mineralise, immobilise and recycle nutrients in organic matter enriched soil, vine health can also be improved in vineyards with high population levels of beneficial nematodes. However, it will require more observations over a longer period of time to demonstrate the beneficial nematodes as an indicator of soil health in vineyards. Choice of ground cover is also important as some grasses and cover crops are hosts of plant parasitic nematodes.

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6. Impact of vineyard floor management practices on arthropod biodiversity

Andrew Loch, Joanne Holloway and Mark Stevens

6.1 Abstract

The impacts of commonly used vineyard floor management practices arthropod biodiversity are not known. In this study we employed pitfall trapping to quantify changes in arthropod biodiversity between these treatments, and identified arthropod species and groups that could be useful bioindicators. There was no strong or consistent impact of any of the floor management treatments on overall arthropod species richness, abundance or biodiversity. High levels of variation between and within treatments were recorded for individual orders or species. There was some evidence of increased springtail and ant abundance in unvegetated treatments, and increased abundance of natural enemies like ladybird and rove beetles, lacewings and wasps in vegetated and partially vegetated treatments. Rutherglen bug was consistently more abundant in vegetated than unvegetated treatments at Wagga Wagga. Results suggest that future biodiversity studies in Australian vineyards should concentrate on selected abundant species from a range of arthropod groups rather than quantify changes in the biodiversity of all species or functional groups of arthropods. Future biodiversity studies must also consider plot size and replication because both may have been inadequate in the current study to detect changes in many arthropod species. Plant feeding bugs like Rutherglen bug, springtails, ants and some of the beneficial natural enemies like wasps, predatory beetles and lacewings appear to be the most responsive and abundant bioindicators.

6.2 Introduction

Grape vineyards, although grown as monocultures, have a floor surface that can comprise significant botanical diversity, which in turn can support high levels of arthropod biodiversity. In Australia, three different vineyard floor management treatments are commonly used: (1) vegetated where the floor vegetation is managed by mowing with no herbicide intervention, (2) partially vegetated comprising an under vine herbicide spray and mowed mid-row vegetation, and (3) unvegetated where all floor vegetation is removed through herbicide spraying. However, the impacts that these different treatments have on arthropod biodiversity are not known. This study investigated the impact of these three vineyard floor management practices on arthropod biodiversity at Wagga Wagga and Tumbarumba. The main aims of the

study were to quantify changes in arthropod biodiversity across the different vineyard floor management treatments and identify any species or groups of arthropods that could be useful bioindicators.

6.3 Materials and Methods

Pitfall trapping was conducted twice a year for three years between 2002-2004 at Wagga Wagga and Tumbarumba. Traps were installed during autumn (April-May) and in spring (October-November) (see Table 6.1 for placement dates). Pitfall traps comprised Chinese food containers (ca 17x12x7cm) that were painted yellow to attract flying insects to the trap. Traps were placed in rectangular holes so that the top and sides of the container were flush with the ground surface. Each trap was filled with 300ml polyethylene glycol, 100ml water and a few drops of detergent. On each sampling occasion, one trap was placed in the centre of each of the 10 replicate plots of each of the three treatments. The two plots at the end of each row were excluded in case of any edge effect. The only exception was the first sampling occasion in autumn 2002 when 8 traps per treatment and 16 traps per treatment were placed at Wagga Wagga and Tumbarumba vineyards respectively. Traps were collected 1 week after placement, sealed with a lid, and returned to the laboratory for asessment.

Table 6.1. Pitfall trap placement dates at Wagga Wagga and Tumbarumba.

Sample date	Wagga Wagga	Tumbarumba
Autumn 2002	2 April 2002	15 May 2002
Spring 2002	5 November 2002	14 November 2002
Autumn 2003	19 May 2003	20 May 2003
Spring 2003	10 November 2003	14 November 2003
Autumn 2004	27 April 2004	5 May 2004
Spring 2004	3 November 2004	17 November 2004

In the laboratory each pitfall trap sample was washed with water through a fine sieve and then stored in 70% ethanol.

Each trap sample was studied under a stereomicroscope and the numbers of each morphospecies were recorded. Species richness, the total number of species, was calculated for each pitfall trap sample. Species diversity considers two important aspects: species richness and dominance or evenness (Magurran, 1988). Two commonly used biodiversity

indices in biological science were calculated for each pitfall trap sample: the Shannon-Weaver index and Simpson index. Biodiversity indices were calculated using the formulae below.

$$\text{Shannon-Weaver index} = -\sum p_i \ln(p_i)$$

$$\text{Simpson index} = 1 - \sum p_i^2$$

In both equations p_i is the proportion of each species in the sample, a measure of the relative abundance of each species. The Shannon-Weaver index (Shannon and Weaver 1949) places greater importance on species richness, and thus samples having high species richness and equal species abundance will generate higher index values. The Simpson index (Simpson, 1949) is more concerned with dominance and thus samples with a few dominant species and many rare species will generate lower index values. The Shannon-Weaver index is more sensitive to the presence of rare species in samples, whereas the Simpson index is more a measure of species dominance and is less affected by rare species.

6.4 Results

Results are presented from years 2002-2004 for Tumbarumba and 2002-2003 for Wagga Wagga. Results for 2004 from Wagga Wagga were not finalised at the time of submitting this final report. The three floor management treatments are referred to as: (1) vegetated, (2) partially vegetated (undervine spray and mowed inter-row), and (3) unvegetated (complete herbicide). Five classes of arthropods were collected during surveys: Arachnida (spiders and mites), Chilopoda (centipedes), Diplopoda (millipedes), Malacostraca (slaters) and Insecta (insects) (Table 6.2). Insects were the dominant arthropod collected both in terms of species richness and total abundance, with arachnids also relatively abundant. Nearly twice as many morphospecies were collected at Tumbarumba compared to Wagga Wagga, with Tumbarumba recording greater numbers of species of spiders, wasps, beetles and flies than Wagga Wagga. Cockroaches, termites and millipedes were only recorded at Wagga Wagga.

Table 6.2. Number of morphospecies of different taxonomic groups of arthropods collected at Wagga Wagga between 2002 and 2003 and Tumbarumba between 2002 and 2004.

Taxonomic Class	Taxonomic Order	Common name	Number of morphospecies	
			Wagga Wagga	Tumbarumba
Arachnida	Araneida	Spiders	12	73
	Acarina	Mites, ticks	4	12
Diplopoda		Millipedes	1	0
Chilopoda		Centipedes	1	1
Malacostraca	Isopoda	Slaters	1	0
Insecta	Collembola	Springtails	4	7
	Blattodea	Cockroaches	3	0
	Isoptera	Termites	1	0
	Dermaptera	Earwigs	1	2
	Orthoptera	Grasshoppers	7	4
	Psocoptera	Booklice	2	1
	Hemiptera	Sucking bugs, aphids, mealybugs, scale	45	42
	Thysanoptera	Thrips	10	9
	Neuroptera	Lacewings, antlions	3	3
	Coleoptera	Beetles	66	92
	Strepsiptera	Twisted-winged flies	1	1
	Diptera	Flies	69	144
	Lepidoptera	Butterflies, moths	18	37
	Hymenoptera	Wasps, bees	92	251
	Hymenoptera	Ants	32	19
Total number of morphospecies			373	698

Mean species richness (Fig. 6.1) and arthropod abundance (Fig. 6.2) were higher at Wagga Wagga than Tumbarumba and were also higher in samples collected during Spring at both vineyards. Both measures of biodiversity, the Shannon-Weaver index (Fig. 6.3) and the Simpson index (Fig. 6.4), produced similar results for each vineyard. As expected, biodiversity was higher during Spring and was also generally higher at Wagga Wagga. There was no general consistent trend in species richness, abundance or the two biodiversity indices

across the three floor management treatments. Species richness varied little between the three treatments at the two vineyards (Fig. 6.1). Total arthropod abundance did vary greatly during some sampling dates at both vineyards but there was no consistency of results and large variation was recorded within treatments (Fig. 6.2). At Wagga Wagga each biodiversity index was similar across the three treatments on all four sampling dates (Figs 6.3, 6.4). At Tumbarumba, biodiversity was lowest in the unvegetated treatment during Spring 2002, Spring 2003 and Autumn 2004.

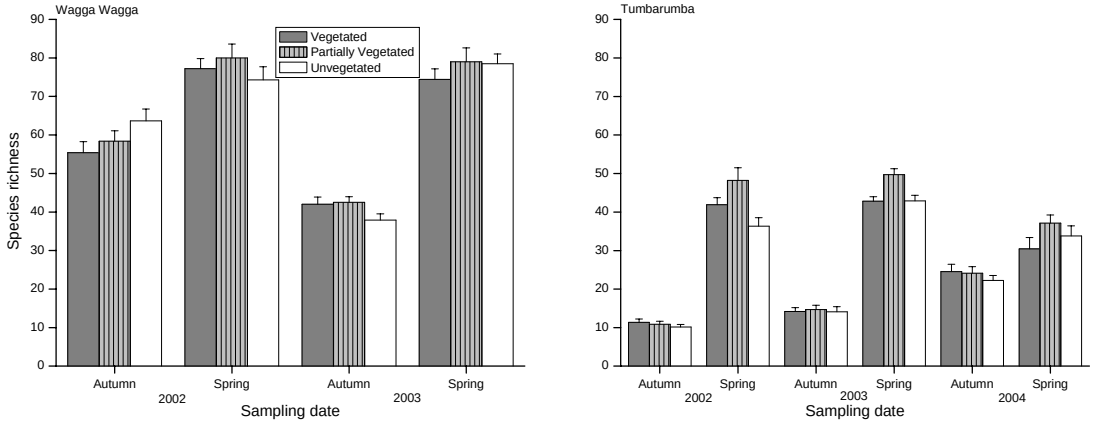


Figure 6.1. Mean ± s.e. species richness at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

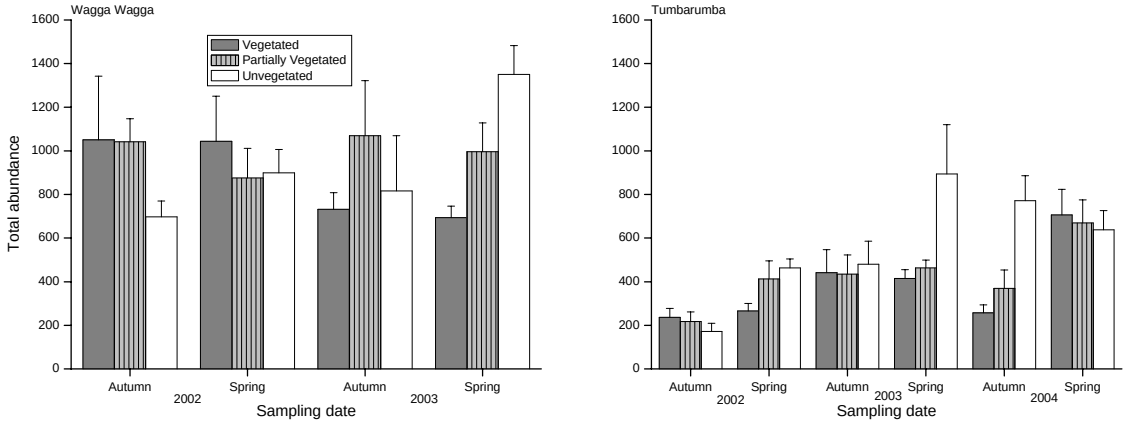


Figure 6.2. Mean ± s.e. arthropod abundance at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

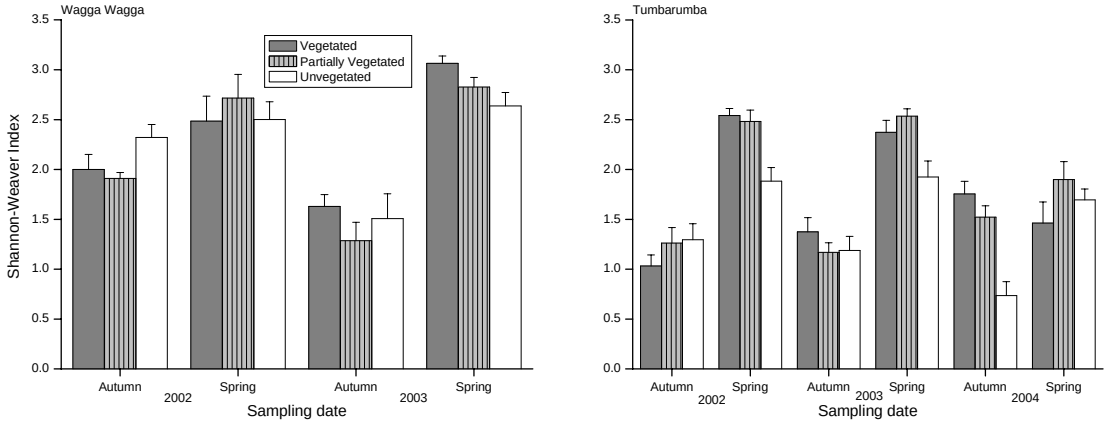


Figure 6.3. Mean ± s.e. Shannon-Weaver Biodiversity Index at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

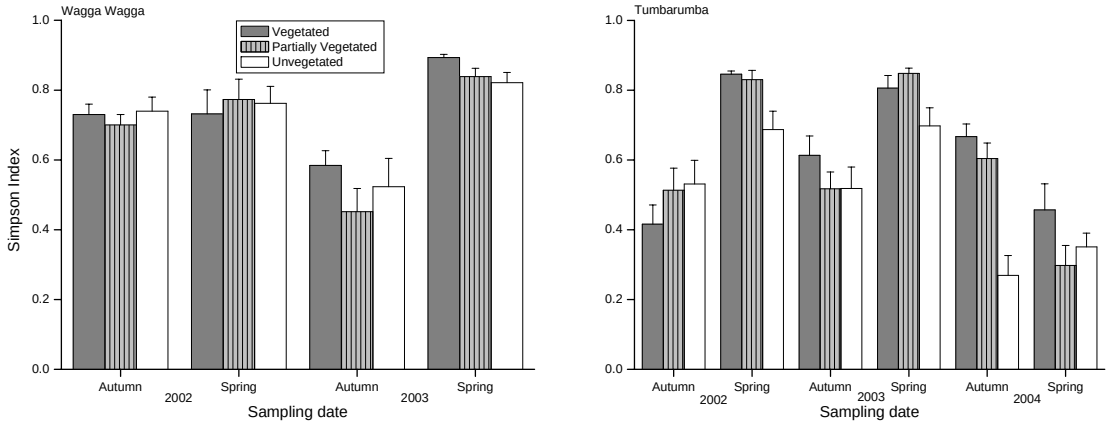


Figure 6.4. Mean ± s.e. Simpson Biodiversity Index at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

The most abundant insect orders recorded in pitfall traps were springtails (Collembola), sucking bugs including true bugs, aphids, mealybugs and scale (Hemiptera), flies (Diptera), beetles (Coleoptera) and wasps, bees and ants (Hymenoptera). When all species from each insect order were grouped together, total abundance of each insect order varied greatly within and between treatments and sampling dates (Figs 6.5-6.10). For each insect group there was little or no evidence of any consistent or strong effect of floor management treatment on insect abundance. Springtails at Tumbarumba were at least two-fold higher in the unvegetated treatment during Spring 2003 and Autumn 2004 but abundance was similar across the three treatments for the other four sampling dates (Fig. 6.5). Sucking bugs were significantly less

abundant in Autumn than in Spring at Tumbarumba but numbers remained more or less even across the seasons at Wagga Wagga (Fig. 6.6). Fly numbers showed no consistent trend across treatment or season with high levels of variation between and within treatments (Fig. 6.7). Beetle numbers seemed unaffected by treatment at Wagga Wagga, whereas at Tumbarumba beetles were more abundant in vegetated and partially vegetated treatments than unvegetated treatments on several sampling occasions (Fig. 6.8). Beetles were also less abundant in Autumn at Tumbarumba. Both ants and wasps tended to be more abundant in Spring than Autumn at both Wagga Wagga and Tumbarumba (Figs 6.9, 6.10). Ants tended to be more abundant in the unvegetated treatment, particularly at Tumbarumba (Fig. 6.9). In contrast, wasps were generally less abundant in the unvegetated treatment (Fig. 6.10).

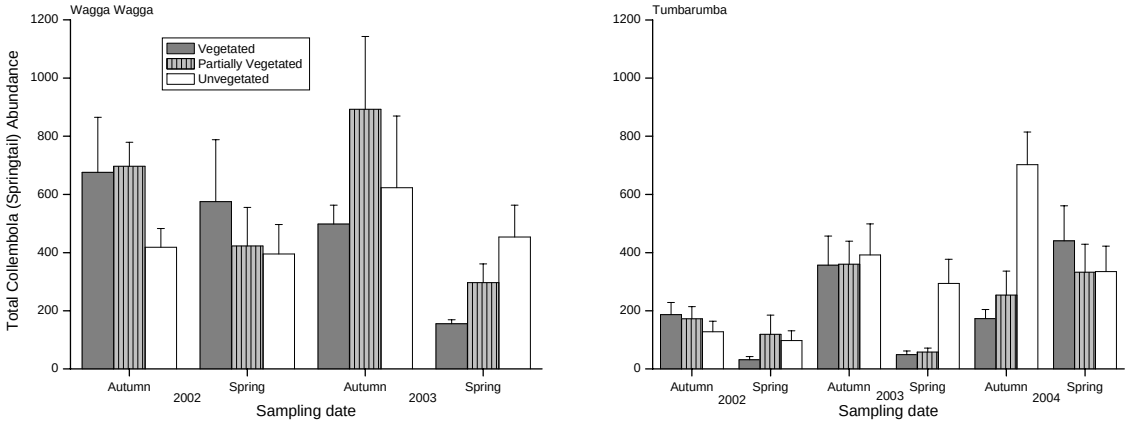


Figure 6.5. Mean ± s.e. abundance of springtails at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

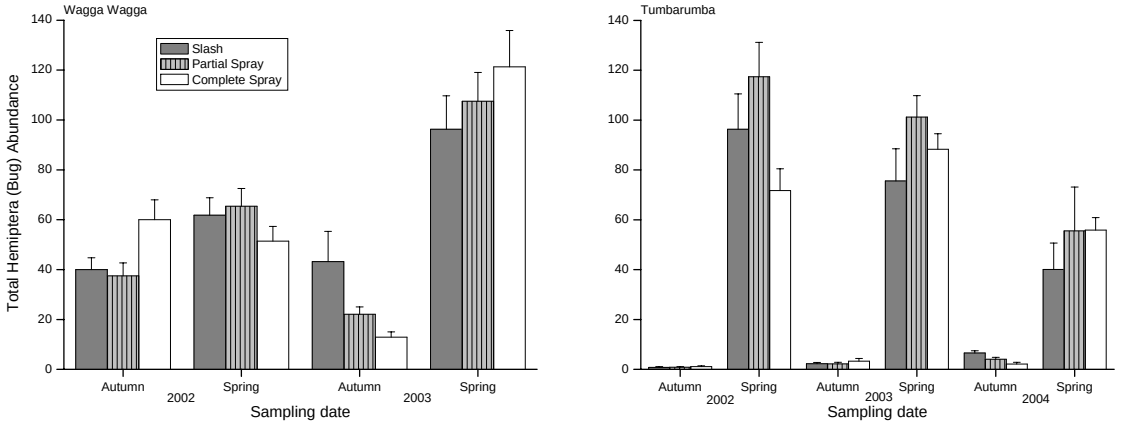


Figure 6.6. Mean ± s.e. abundance of sucking bugs at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

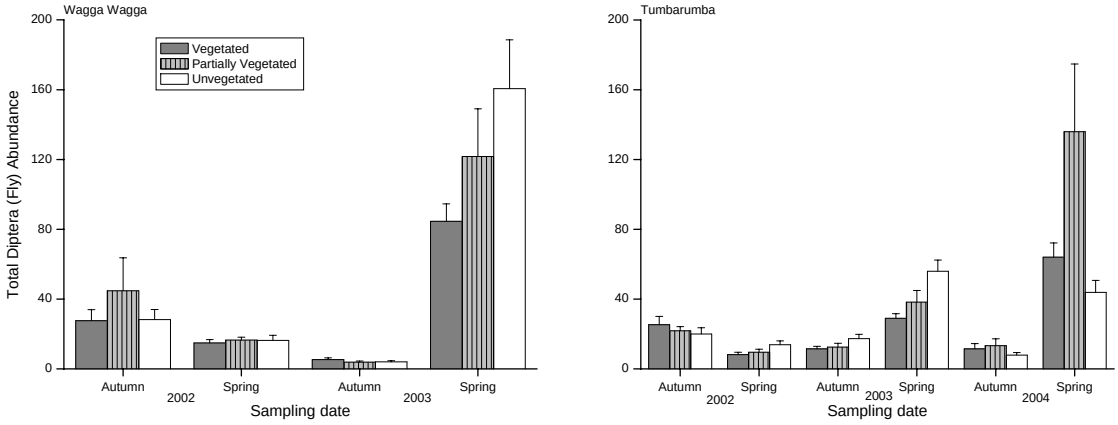


Figure 6.7. Mean ± s.e. abundance of flies at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

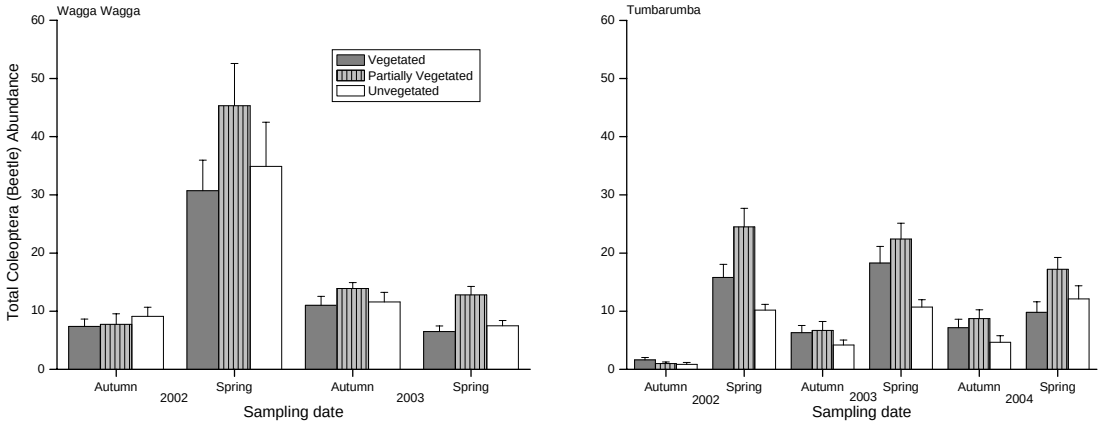


Figure 6.8. Mean ± s.e. abundance of beetles at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

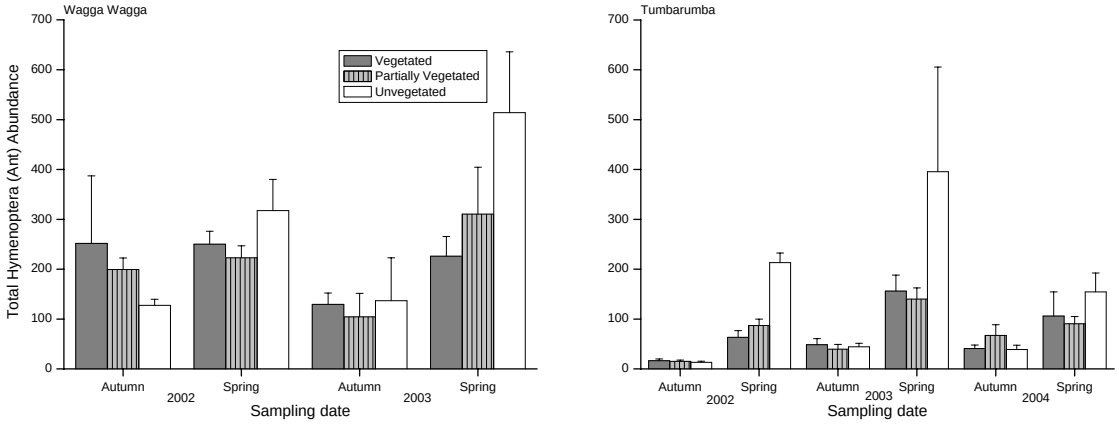


Figure 6.9. Mean ± s.e. abundance of ants at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

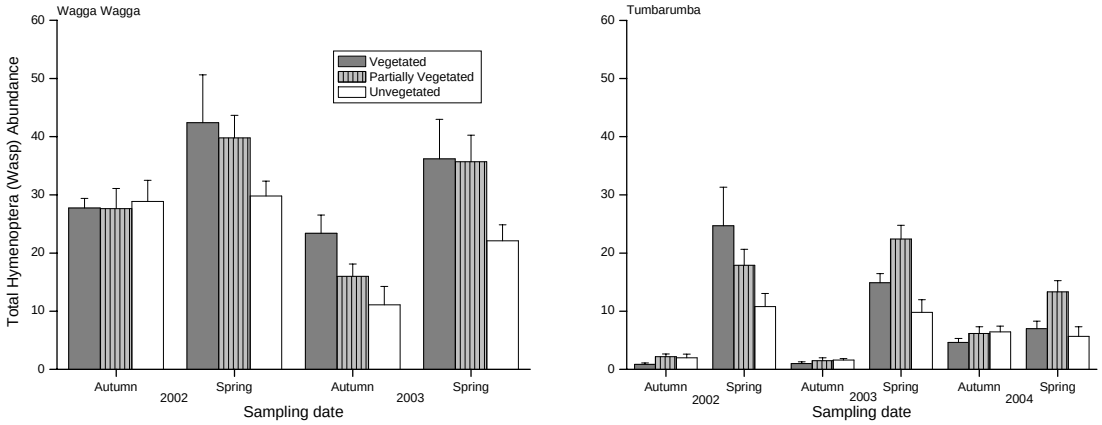


Figure 6.10. Mean ± s.e. abundance of wasps at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

The four most species rich insect groups from both vineyards were wasps, flies, beetles and sucking bugs. Species richness of each group varied greatly between and within different treatments and over time, but again there was no strong or consistent effect of floor management treatment (Figs 6.11-6.14). More species of bugs, flies, beetles and wasps were collected in pitfall traps in the vegetated and partially vegetated treatments than the unvegetated treatments at Tumbarumba on at least one of the sampling dates. At Wagga Wagga, species richness of all four orders was more even across the three treatments than at Tumbarumba.

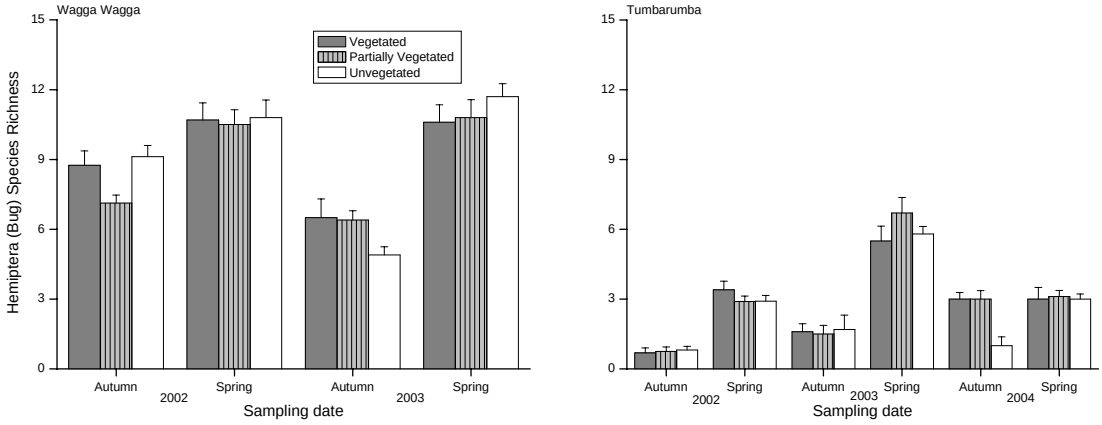


Figure 6.11. Mean ± s.e. species richness of sucking bugs at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

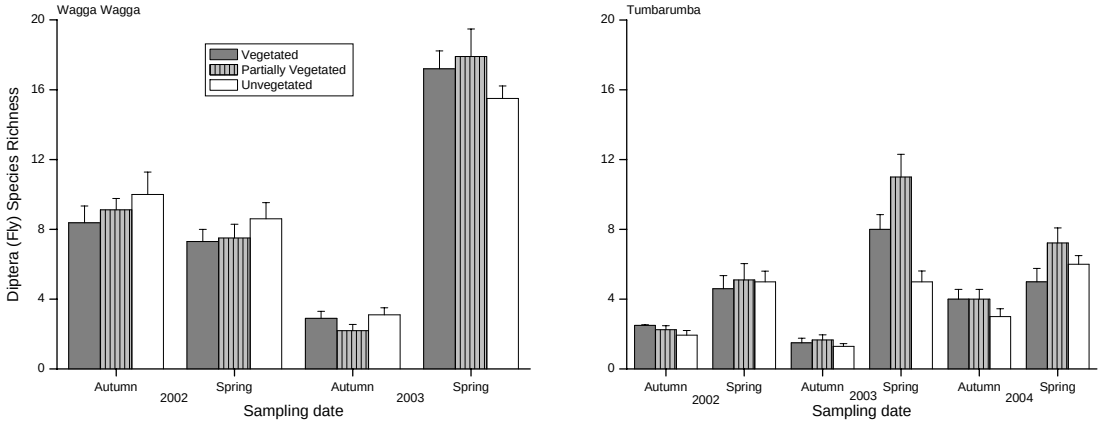


Figure 6.12. Mean ± s.e. species richness of flies at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

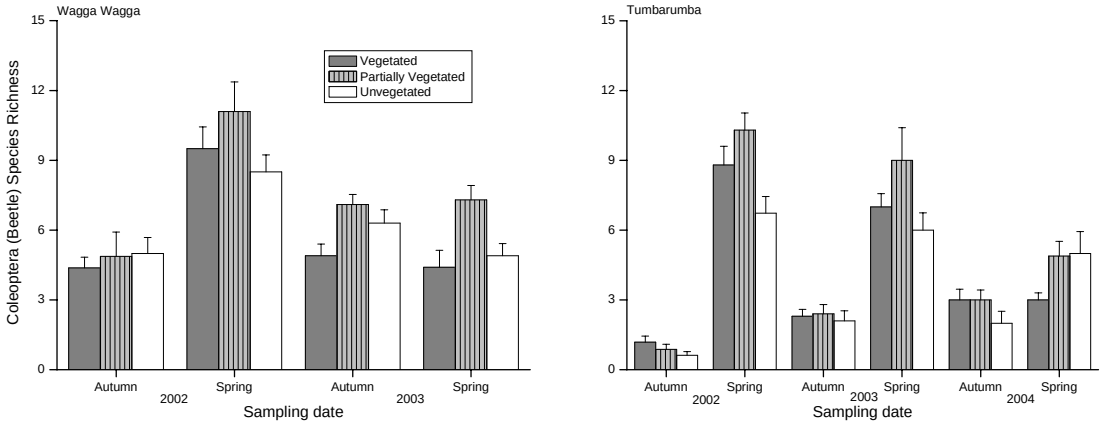


Figure 6.13. Mean ± s.e. species richness of beetles at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

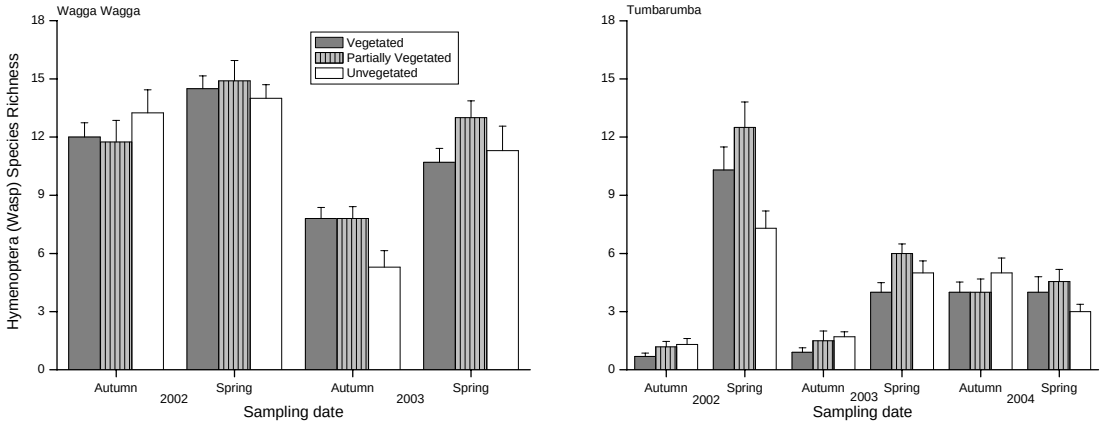


Figure 6.14. Mean ± s.e. species richness of wasps at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

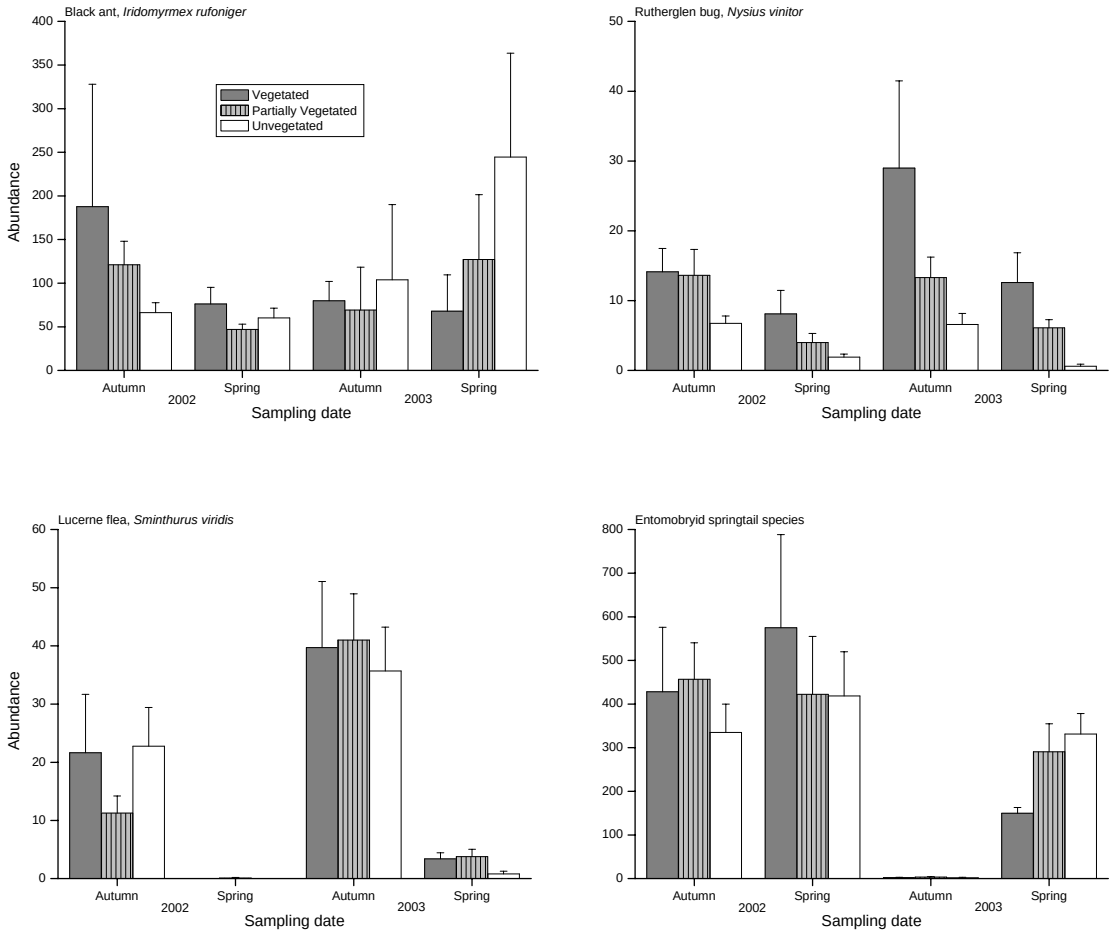


Figure 6.15. Mean ± s.e. abundance of four of the most abundant insect species collected at Wagga Wagga under three vineyard floor management regimes.

Insect pests of grapes were rarely collected in pitfall traps and few, if any, pest problems developed at both vineyards during the study. In addition, numbers of plant-feeding insects that could be pests on other plants were generally low with most sampled arthropods being beneficial natural enemies or non injurious scavengers. Trends in the abundance of four of the most abundant insect species at Wagga Wagga and Tumbarumba varied greatly across the three different treatments. Abundance of the black ant, *Iridomyrmex rufoniger*, was greatest in the vegetated treatment and lowest in the unvegetated treatment in Autumn 2002 but in Spring 2003 the trend was reversed at Wagga Wagga (Fig. 6.15). However, there was substantial variation in numbers of this ant species within treatments. Black ant abundance at Tumbarumba was even across the treatments except during Spring 2002 and Spring 2003 when numbers were higher in the unvegetated treatment (Fig. 6.16). Numbers of Rutherglen bug, *Nysius vinitor*, were consistently higher in the vegetated treatment than the unvegetated treatment at Wagga Wagga but was only rarely collected at Tumbarumba (Fig. 6.15). Lucerne

flea, *Sminthurus viridis*, was principally collected during Autumn at both sites and numbers were similar across the different treatments at both sites except at Tumbarumba in Autumn 2004 when numbers were greatest in the unvegetated treatment (Figs 6.15, 6.16). An entomobryid springtail species was highly abundant in all three treatments at Wagga Wagga except during Autumn 2003 when numbers decreased sharply in all treatments (Fig. 6.15). Similarly, the neanurid and entomobryid springtail species at Tumbarumba were highly abundant on some sampling dates and extremely rare on other dates (Fig. 6.16). Abundance of the entomobryid springtail species was highest in the unvegetated treatment in Spring 2003 and Spring 2004 (Fig. 6.16).

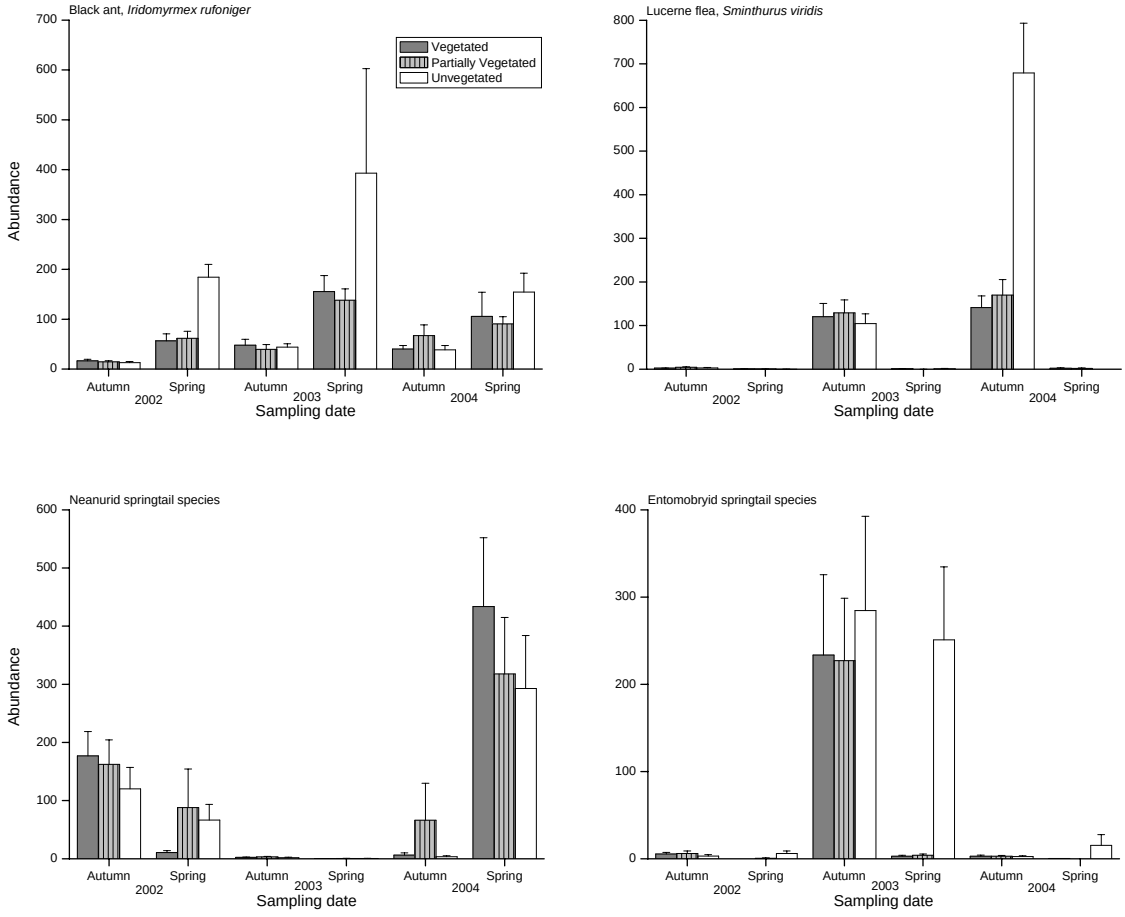


Figure 6.16. Mean ± s.e. abundance of four of the most abundant insect species collected at Tumbarumba under three vineyard floor management regimes.

The most abundant groups of beneficial arthropods sampled by pitfall trapping at the two vineyards were wasps, ladybird beetles, rove beetles, lacewings and spiders. Other beneficial arthropods collected in very low numbers included predatory beetles like ground and soldier beetles, flies such as robber and hover flies, predatory bugs like assassin and big eyed bugs, parasitic twisted-winged flies on leafhoppers, and predatory mites. Wasps, ladybird beetles, lacewings and spiders were all more abundant during Spring at both vineyards but particularly at Tumbarumba (Figs 6.10, 6.17, 6.19, 6.20). Ladybird numbers were three- to five-fold less in the unvegetated treatment at Tumbarumba during Spring 2002 but this trend reversed in Spring 2004, although ladybird numbers were less across all treatments (Fig. 6.17). Rove beetles were less abundant in the unvegetated treatment on several sampling dates at Tumbarumba, whereas numbers were much lower at Wagga Wagga (Fig. 6.18). Lacewings were also less abundant in the unvegetated treatment on several sampling dates at Tumbarumba, whereas at Wagga Wagga lacewing numbers were low and roughly similar across treatment and sampling date (Fig. 6.19). Spider numbers were lower during Autumn at both sites and varied greatly between and within treatments (Fig. 6.20).

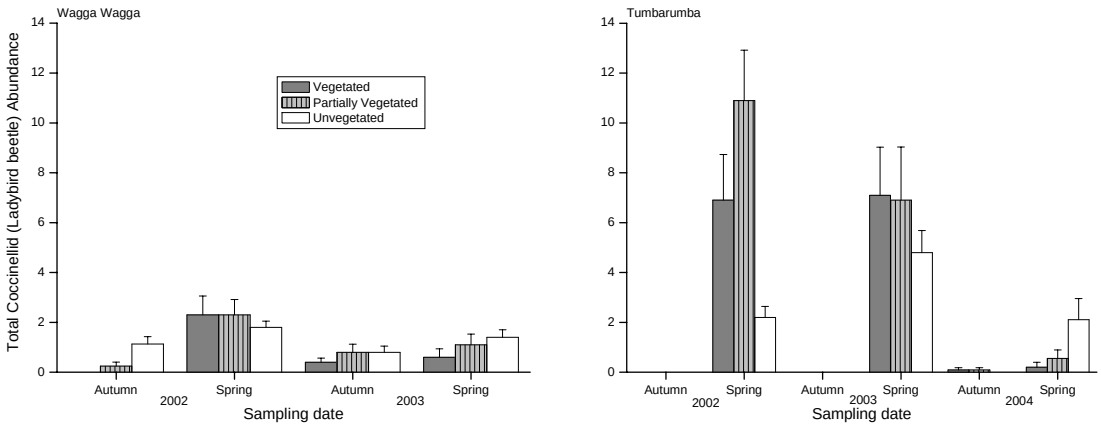


Figure 6.17. Mean ± s.e. abundance of ladybird beetles at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

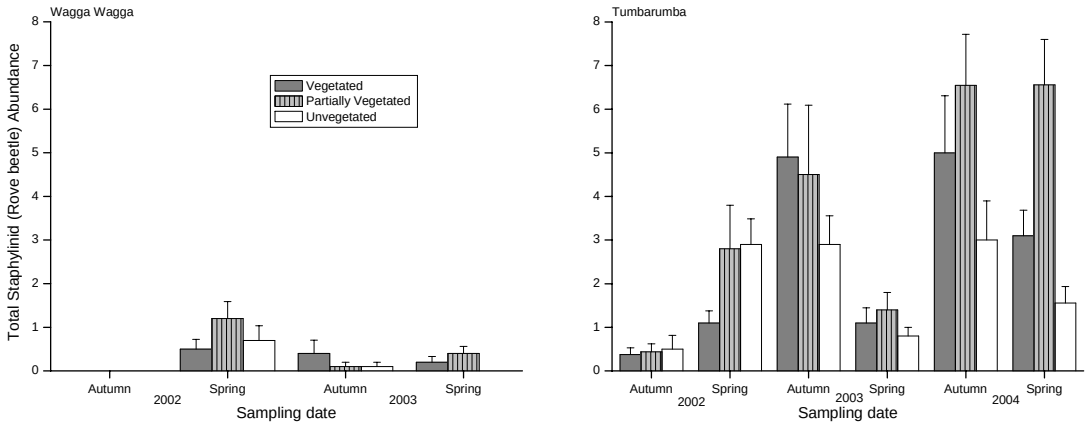


Figure 6.18. Mean ± s.e. abundance of rove beetles at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

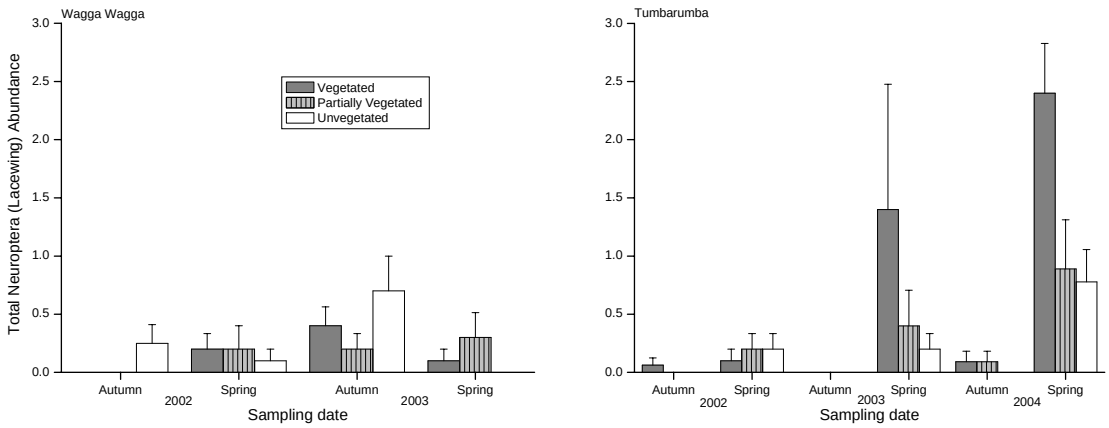


Figure 6.19. Mean ± s.e. abundance of lacewings at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

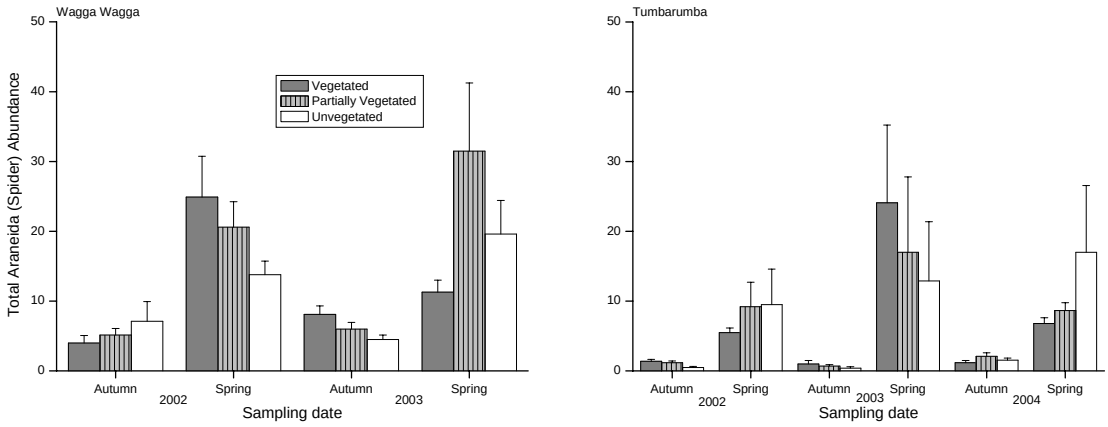


Figure 6.20. Mean ± s.e. abundance of spiders at Wagga Wagga and Tumbarumba under three vineyard floor management regimes.

6.5 Discussion

Overall arthropod species richness, abundance and biodiversity at Wagga Wagga and Tumbarumba, appeared not to be affected by floor management treatment because there was no strong or consistent trend in any of the above measures. Even when the most abundant insect orders were examined, variation in species richness and abundance between and within treatments were similar. However, there was some evidence of increased springtail and ant abundance in the unvegetated treatment, and natural enemies like ladybird and rove beetles, lacewings and wasps tended to be more abundant in vegetated and partially vegetated treatments. Of the more abundant insect species, only Rutherglen bug showed a consistent response to treatment and was more abundant in vegetated than unvegetated treatments at Wagga Wagga.

Although such contrasting floor management treatments would be expected to lead to significant changes in arthropod biodiversity, there may be several explanations for why this did not occur or was not detected. First, the size of replicate plots may not be large enough to affect the abundance of many arthropod species such as winged insects that would probably operate on a larger spatial scale. Treatment plot replication may also have been inadequate to detect changes in biodiversity because substantial variation within treatments was recorded on most sampling occasions for different species and arthropod groups. Changes in the abundance of rare species would also not be detected, with most collected species at both vineyards being recorded in very low numbers.

Results from this study suggest that future biodiversity studies in Australian vineyards should concentrate on selected abundant species from a range of arthropod groups rather than quantify changes in the biodiversity of all species or functional groups of arthropods. In this study there was some evidence of different springtail species showing contrasting responses to the three management practices. Similarly, Renaud et al. (2004) recorded springtail species responding differently to four soil management practices in a French vineyard (Renaud et al. 2004). Other arthropod groups also appear to show differences in species responses to floor management practices such as spiders in a Californian vineyard (Costello and Daane 1998). Studies investigating changes in abundance of arthropod functional groups are therefore likely to overlook key changes in the abundance of individual species unless all species in a functional group respond similarly to environmental changes. Species from abundant arthropod groups like wasps, ants, beetles, flies, sucking bugs, springtails and spiders would provide a variety of different functional groups (e.g. predators and parasitoids, herbivores and decomposers) and a range of potentially useful bioindicators. In terms of potential bioindicators from this study, plant feeding bugs like Rutherglen bug, springtails, ants and some of the beneficial natural enemies like wasps, predatory beetles and lacewings would appear to be the most responsive and abundant.

Both vineyards recorded high levels of arthropod species richness and biodiversity, and in particular, beneficial and non-injurious arthropods. On average, traps at Wagga Wagga recorded more species and higher levels of biodiversity, whereas at Tumbarumba, more species were recorded throughout the trial, although this would be at least partly explained by the extra year of data recorded from Tumbarumba. Biodiversity was higher in Spring at both sites, and generally higher at Wagga Wagga. This is at least partly a reflection of temperature with Tumbarumba having a much cooler climate, and Autumn samples being collected later at Tumbarumba.

Beneficial predatory and parasitic arthropods were particularly abundant at both vineyards and there was some evidence of increased abundance of wasps, ladybird and rove beetles, and lacewings in the vegetated treatment compared to the unvegetated treatment. This suggests that some predators and parasitoids are responding positively to the presence of vineyard floor vegetation. The presence of ground vegetation in Californian vineyards has been shown to increase the richness and abundance of spiders (Costello and Daane 1998; Hanna et al. 2003), but there was no strong consistent trend in spider numbers across the different floor

management treatments in this study. The next chapter explores, in more detail, the response of winged natural enemies like ladybird beetles and lacewings to vegetated and unvegetated floor treatments.

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7. Abundance and biodiversity of winged beneficial insects, and biological control of grapevine moth, Phalaenoides glycinae, under vegetated and unvegetated vineyard floor management regimes

Andrew Loch

7.1 Abstract

Vineyard floor management practices may affect the abundance of beneficial insects and thus levels of pest biological control. In this study I compared the composition and abundance of beneficial insects in vineyards with vegetated and unvegetated floor management treatments and quantified whether levels of biological control of grapevine moth could be affected by floor management treatment. Beneficial insects were abundant in both vineyards but there was only minimal or weak evidence of any effect of floor management treatment on overall beneficial insect abundance or on levels of biological control. Rove beetles showed the strongest and most consistent response to floor management treatment with higher numbers and richness recorded at both sites in the vegetated treatment. There was some evidence of increased abundance of brown lacewings in the vegetated treatment but this only occurred at Tumbarumba, with the reverse occurring at Wagga Wagga. Overall, wasps showed no strong response to treatment although one species was significantly more abundant in the vegetated treatment for the December 2003 sample at Tumbarumba. In general, floor traps captured more wasps, the ladybird beetles *D. notescens*, *C. transversalis* and *H. variegata*, and rove beetles whereas brown lacewings and the ladybird beetle *H. conformis* were more abundant in canopy traps. These results suggest that natural enemies have different flight behaviours and may have different patterns of resource use. Pilot biological control field trials showed that predation and parasitism rates of grapevine moth eggs were very low in both vegetated and unvegetated treatments. In contrast, high rates of predation of grapevine moth larvae by predatory shield bugs and green lacewing larvae were recorded but there was no significant difference between treatments. Vineyard managers may increase populations of some beneficial insects by maintaining a vegetated vineyard floor. However, this recommendation may have limitations as results are of a preliminary nature from only two vineyards in New South Wales and therefore further research is needed to test these observed trends in other Australian vineyards.

7.2 Introduction

Conservation biological control is a relatively new term that describes manipulation of the environment to enhance survival and reproduction of natural enemies and thus their effectiveness (Landis et al. 2000). Conservation biological control recognises that many agroecosystems are unfavourable for natural enemies and aims to ameliorate conditions by providing more food resources, alternative prey or hosts, and shelter. Typically conservation biological control has concentrated on enhancing the provision of food resources for natural enemies. All parasitoids and many predators need a diet of sugars and proteins to survive and reproduce, with nectar and/or pollen the principal components of such a diet for many species. Encouraging the growth of, and planting, flowering plants in an agroecosystem is the easiest way to increase the availability of nectar and pollen, which in turn should lead to higher numbers of natural enemies. This can be easily accomplished in a vineyard situation by planting specific flowering species on the vineyard floor or by allowing weeds and grasses to grow and flower on the vineyard floor as has been done in this study.

In the previous chapter there was some evidence of increased abundance of some natural enemies like wasps, ladybird and rove beetles, and lacewings in treatments with floor vegetation suggesting that some of these beneficial insects are responding positively to floor vegetation. In this study I compared the abundance of beneficial insects in vegetated and unvegetated vineyard floor management treatments at Wagga Wagga and Tumbarumba. Sticky clear window traps were used to intercept the flight activity of beneficial insects both above the vineyard floor and in the canopy to determine if there were any differences in the composition and abundance of beneficial insects between the two floor management treatments. The second part of this study involved testing whether floor management treatments affected biological control of the minor pest grapevine moth, *Phalaenoides glycinae*. Rates of predation and/or parasitism of eggs and larvae were measured under the two floor management treatments by attaching egg strips and pinning larvae to shoots.

7.3 Materials and Methods

7.3.1 Beneficial insect abundance and biodiversity

The abundance and biodiversity of winged natural enemies was quantified using A4 sized (ca 30 x 21 cm) sticky clear window traps made of stiff flexible plastic and coated on one side with a thin layer of Tangle-Trap Insect Trap Coating (Tanglefoot Company). Although yellow sticky traps have traditionally been used to trap flying insects and are more effective in

trapping insects such as wasps, flies, bugs and thrips (Thomson et al. 2004), clear window traps were used in this study because the aim was to intercept the activity of beneficial insects in the different treatments and not attract beneficial insects. Traps were placed in each of the 12 replicate plots of the vegetated and unvegetated treatments at both Wagga Wagga and Tumbarumba. No traps were placed in partially vegetated treatment plots. Two traps were erected in each replicate plot: one at ground level just above the vineyard floor in the centre of the vine inter-row and plot, and a second hung in the vine canopy in the centre of the plot (see Fig. 7.1). The floor trap was placed approximately 5cm above the ground in the centre of each plot using stiff wire to hold it vertical and just above the ground. The canopy trap was attached with twist-ties to the vine and vine wires so that the top of the trap was approximately level with the vine arms. Both floor and canopy traps were arranged so that the sticky surface faced along the vine inter-row in a westerly direction, which is the common prevailing wind direction.

Traps were placed between September and March during the growing seasons of 2003/04 and 2004/05, and only when the vineyard floor had live flowering vegetation. The effectiveness of sticky window traps was trialled during 2003/04 such that traps were only placed once each at Wagga Wagga and Tumbarumba (see Table 7.1). During the 2004/05 season traps were placed five times at Tumbarumba but only twice at Wagga Wagga because the vineyard floor vegetation at Wagga Wagga did not survive or flower much after October due to drought conditions.



Figure 7.1. Sticky clear window traps on vineyard floor (top) and in canopy.

Table 7.1. Sticky window trap placement dates at Wagga Wagga and Tumbarumba. Results are only presented for the shaded sampling dates.

Growing season	Wagga Wagga	Tumbarumba
2003/04	17 October 2003	4 December 2003
2004/05	23 September 2004	24 November 2004
	22 October 2004	21 January 2005
		5 February 2005
		25 February 2005
		23 March 2005

Traps were collected one week after placement, with each trap placed carefully in a large ziplock plastic bag. Bagged traps were stored in the freezer until they were viewed under a stereomicroscope for the collection of any trapped beneficial insects. All winged beneficial insects caught on each trap were carefully removed using a scalpel and placed in a vial containing mineral turpentine to dissolve the sticky Tangletrap coating. All winged beneficial insects caught in each trap were later examined under a stereomicroscope and sorted and counted into morphospecies. Some insects such as ladybird beetles were identified to species, whereas other insects were identified to at least Order.

Species richness, the total number of species, was calculated for each pitfall trap sample. Species diversity considers two important aspects: species richness and dominance (Magurran, 1988). Biodiversity indices were calculated for each pitfall trap sample as described in Chapter 6

7.3.2 Biological control of grapevine moth

Pilot experiments were conducted at Wagga Wagga and Tumbarumba to quantify levels of biological control of eggs and larvae of grapevine moth in vegetated and unvegetated treatments. For the grapevine moth egg trial, adult grapevine moths were collected from the Wagga Wagga vineyard between late September and early October 2004 and at Tumbarumba in early February 2005 when a peak in adult grapevine moth activity was observed. Moths are day-flying and at the Wagga Wagga vineyard, moths tended to aggregate around olive trees growing near the vineyard and at Tumbarumba moths aggregated to large heaps of dead removed vines (A.D. Loch, personal observation). This aggregation behaviour enabled the

easy capture of large numbers of moths with an insect net. Captured moths were placed in large ventilated plastic containers and supplied a liquid honey solution for food and strips of paper for laying eggs. Moth cultures were checked daily and food and paper strips replaced, dead moths removed, and newly collected moths added. Grapevine moth lays eggs singly and any eggs laid on paper strips were removed using scissors such that there was one egg on a paper strip ca 2x5cm. The egg on the paper strip was circled in pencil so that it could be easily found and these strips were then stored in a refrigerator at 4°C for up to 1 week.

Grapevine moth eggs were placed in the Wagga Wagga vineyard on 6 October 2004 and left for 1 week. Egg strips were placed in each of six vegetated and unvegetated treatment plots. At Tumbarumba, egg strips were placed in each of 10 vegetated and unvegetated treatment plots on 9 February 2005 and left for one week. Plots selected for egg strips were the innermost plots furthest from the vineyard edge. Nine egg strips were attached with adhesive tape to randomly selected shoot tips (ca 20cm from tip) on each of the central five vines in each selected plot making a total of 45 egg strips per plot at Wagga Wagga (see Fig. 7.2). At Tumbarumba eight egg strips were attached to randomly selected shoot tips on each of the central five vines in each plot giving a total of 40 eggs per plot. After 1 week the fate of egg strips in each plot was classed as either (1) eaten, (2) egg missing on strip, (3) egg strip missing, (4) hatched or (5) intact. All strips with intact eggs were returned to the laboratory to assess for parasitism.



Figure 7.2. Paper strip containing a grapevine moth egg.

Two pilot trials assessing predation rates of grapevine moth larvae were conducted in the Wagga Wagga vineyard during November 2004. The first trial ran from 8-12 November and the second ran between 15-29 November. Larvae used in both trials were reared from eggs laid in the laboratory or field-collected larvae. Larvae were reared in the laboratory under ambient conditions in large ventilated containers and supplied daily with shoots of grapevine foliage that were placed into vials of water to maintain freshness. Large (ca 5cm long) late instar larvae were used in the trials. To assess the predation rate of a mobile insect like a grapevine moth larva, a method of affixing live larvae to the grapevine was needed that prevented larvae escaping but also enabled them to live. I modified the method used by Frank and Shrewsbury (2004) to pin larvae of the caterpillar pest *Agrotis ipsilon* to turfgrass through their last abdominal segment with thin insect pins. Each grapevine moth larva was pinned through their last abdominal segment with a 000 sized (38mm x 2.5mm) stainless steel insect pin with nylon head (Austerlitz). Each pinned larva was attached to a tendril about 20cm from the growing tip of a shoot that was marked with flagging tape (see Fig. 7.3). This method enabled larvae to survive up to 2 weeks under field conditions.



Figure 7.3. Grapevine moth larva pinned to grapevine shoot.

For the first larval predation trial, 40 larvae were pinned in each of 9 vegetated and 8 unvegetated treatment plots. For the second larval predation trial, 40 larvae were pinned in

each of 8 vegetated and unvegetated treatment plots. In each plot, 8 larvae were pinned to each of the 5 central vines, with larvae placed evenly on both sides of the vine and on randomly selected shoots. Larvae were pinned to vines on either 8 November or 15 November 2004 between 8:30 and 18:30 hours. Selected plots were the innermost plots furthest from the vineyard edge. For the first larval predation trial, larvae were checked for predation on 12 November 2004. The second larval predation trial was run for longer (2 weeks) and larvae were checked for predation every 1-4 days.

On each predation assessment date, pinned larvae were counted as either (1) eaten by predatory shield bugs or green lacewing larva (presence of shrivelled larva or predators), (2) consumed by other predator (presence of predator or majority of body eaten), (3) larva missing but pin intact, (4) larva and pin missing, or (5) alive.

7.4 Results

7.4.1 Beneficial insect abundance and biodiversity

The most abundant beneficial insects collected in sticky traps were wasps (Hymenoptera), ladybird beetles (Coleoptera: Coccinellidae), rove beetles (Coleoptera: Staphylinidae), the pollen or red and blue beetle, *Dicranolaius* sp. (Coleoptera: Melyridae), and brown lacewings (Neuroptera: Hemerobiidae). Other beneficial insects collected included green lacewings (Neuroptera: Chrysopidae), hover flies (Diptera: Syrphidae), earwigs (Dermaptera) and dragonflies (Odonata).

No strong trend was recorded in species richness across treatments at both sites although canopy traps in the unvegetated treatment tended to record the lowest species richness (Fig. 7.4). Abundance also tended to be lowest in the unvegetated canopy traps (Fig. 7.5). Abundance was at least three-fold higher in the vegetated floor trap during December 2003 at Tumbarumba but this was principally because of the elevated abundance of one wasp species. As a result, both biodiversity indices were very low for the vegetated floor trap at Tumbarumba in December 2003 (Figs 7.6 and 7.7). For the other sampling periods both biodiversity indices were relatively even for the different traps and treatments. The only exceptions were at Tumbarumba in December 2004 where biodiversity was lowest in vegetated floor traps and at Wagga Wagga in September 2004 when biodiversity was highest in unvegetated canopy traps.

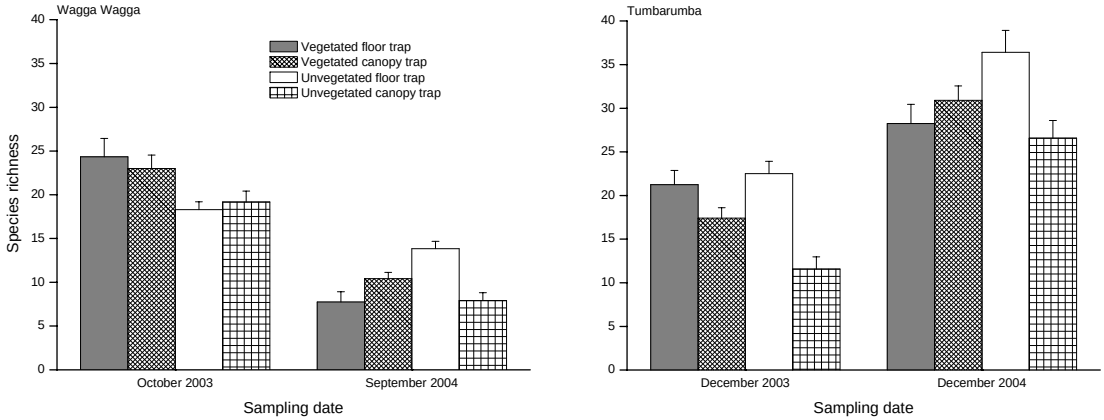


Figure 7.4. Mean ± s.e. species richness of beneficial insects in vineyard floor and canopy sticky traps in vegetated and unvegetated treatments at Wagga Wagga and Tumbarumba.

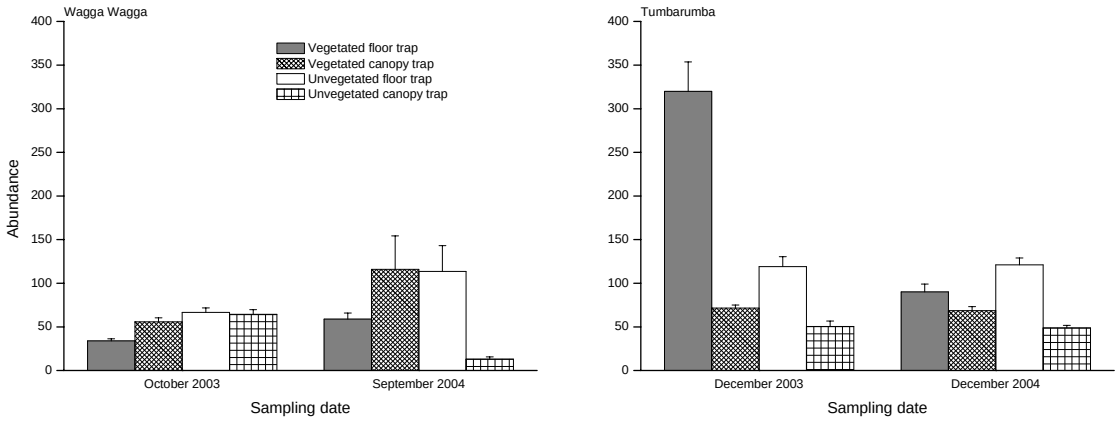


Figure 7.5. Mean ± s.e. abundance of beneficial insects in vineyard floor and canopy sticky traps in vegetated and unvegetated treatments at Wagga Wagga and Tumbarumba.

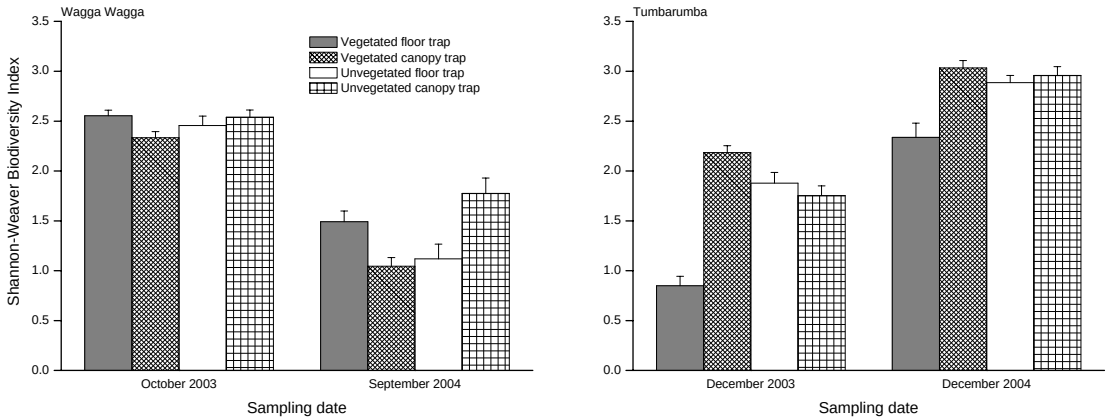


Figure 7.6. Mean ± s.e. Shannon-Weaver Biodiversity Index of beneficial insects in vineyard floor and canopy sticky traps in vegetated and unvegetated treatments at Wagga Wagga and Tumbarumba.

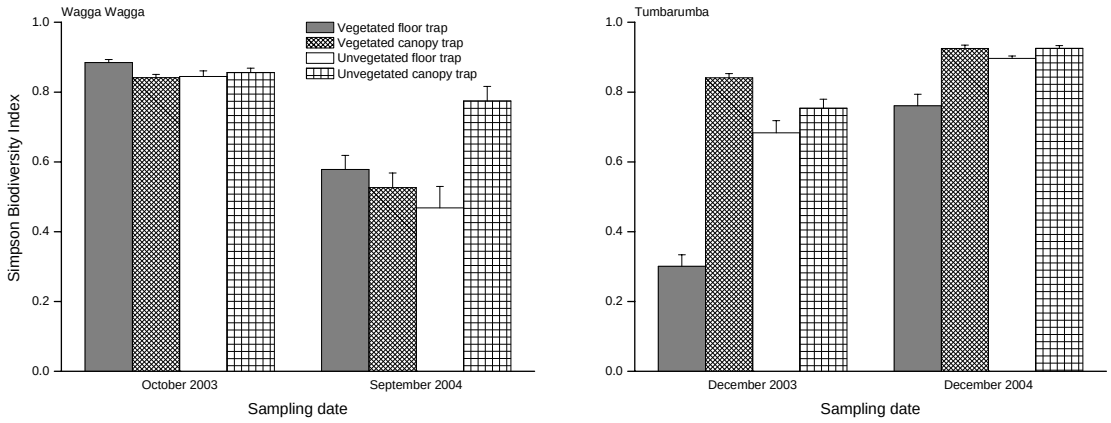


Figure 7.7. Mean ± s.e. Simpson Biodiversity Index of beneficial insects in vineyard floor and canopy sticky traps in vegetated and unvegetated treatments at Wagga Wagga and Tumbarumba.

Wasp species richness varied greatly between treatment and trap type at both sites. Wasp richness was greater in the unvegetated treatment at Wagga Wagga during October 2003 but in September 2004 wasp richness was much lower in all traps but richness was highest in the vegetated floor trap (Fig. 7.8). At Tumbarumba, wasp richness was highest in floor traps in December 2003 but had increased across all trap types a year later. Wasp abundance was lowest in the vegetated floor trap at Wagga Wagga in October 2003 whereas in September 2004 abundance was lowest in vegetated floor traps and unvegetated canopy traps (Fig. 7.9). The trend in wasp abundance was clearer at Tumbarumba with abundance higher in floor

traps than canopy traps, and especially in the vegetated floor trap in December 2003 when one wasp species dominated.

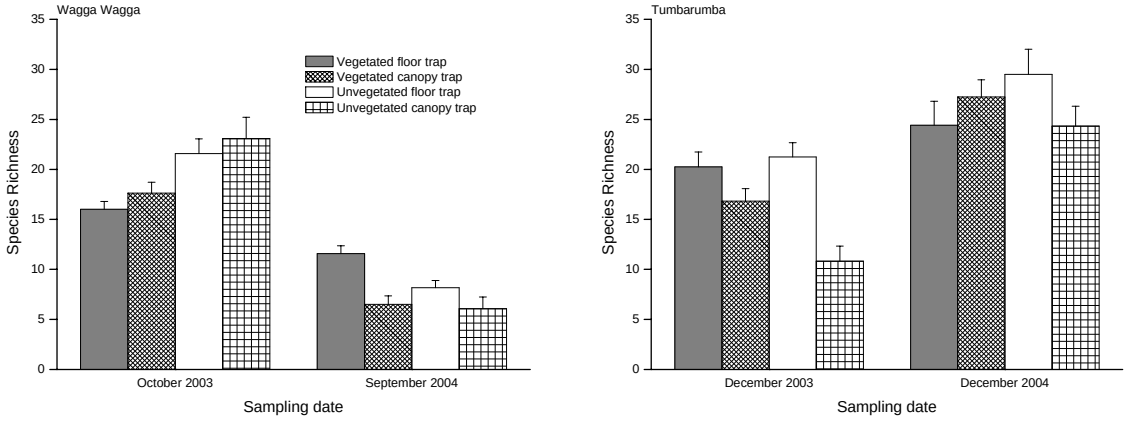


Figure 7.8. Mean ± s.e. species richness of wasps in vineyard floor and canopy sticky traps in vegetated and unvegetated treatments at Wagga Wagga and Tumbarumba.

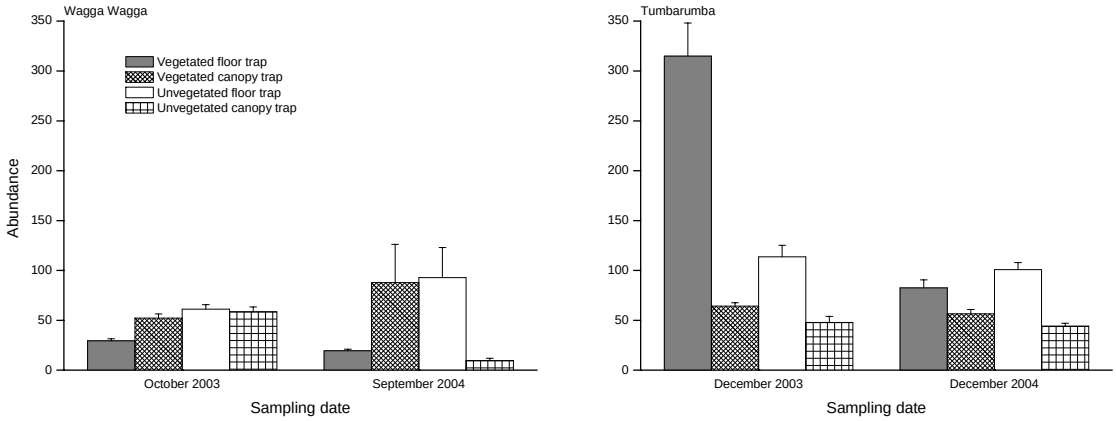


Figure 7.9. Mean ± s.e. abundance of wasps in vineyard floor and canopy sticky traps in vegetated and unvegetated treatments at Wagga Wagga and Tumbarumba.

Ladybird beetle richness was generally greater in floor traps than canopy traps (Fig. 7.10). Ladybird richness was highest in the unvegetated floor trap for the December 2004 sample at Tumbarumba. The abundance of ladybird beetles varied greatly across site, treatment and trap type depending on species. The minute two-spotted ladybird beetle, *Diomus notescens*, transverse ladybird beetle, *Coccinella transversalis*, the white-collared or spotted amber ladybird beetle, *Hippodamia variegata*, and mite-eating ladybird beetles, *Stethorus* spp., were

in general more abundant on the floor than in the canopy (Figs 7.11-7.14). In contrast, the common spotted ladybird beetle, *Harmonia conformis*, was more abundant in the canopy (Fig. 7.15). There was no consistent effect of either floor management treatment on the abundance on any of the ladybird species. Abundance of some ladybird species was much higher in the unvegetated treatment at Tumbarumba during December 2004 but this was not observed in December 2003, whereas at Wagga Wagga some species were more abundant in the vegetated treatment during October 2003 (Figs 7.11-7.13).

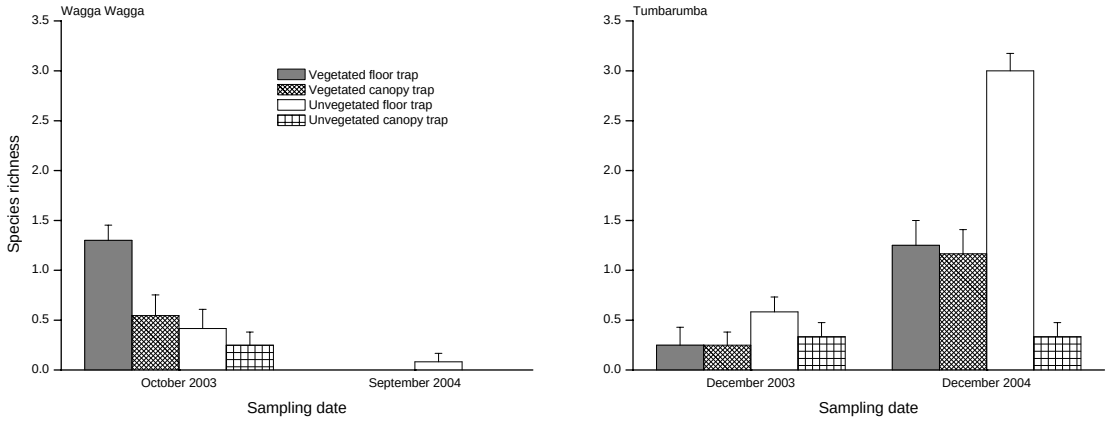


Figure 7.10. Mean ± s.e. species richness of ladybird beetles in vineyard floor and canopy sticky traps in vegetated and unvegetated treatments at Wagga Wagga and Tumbarumba.

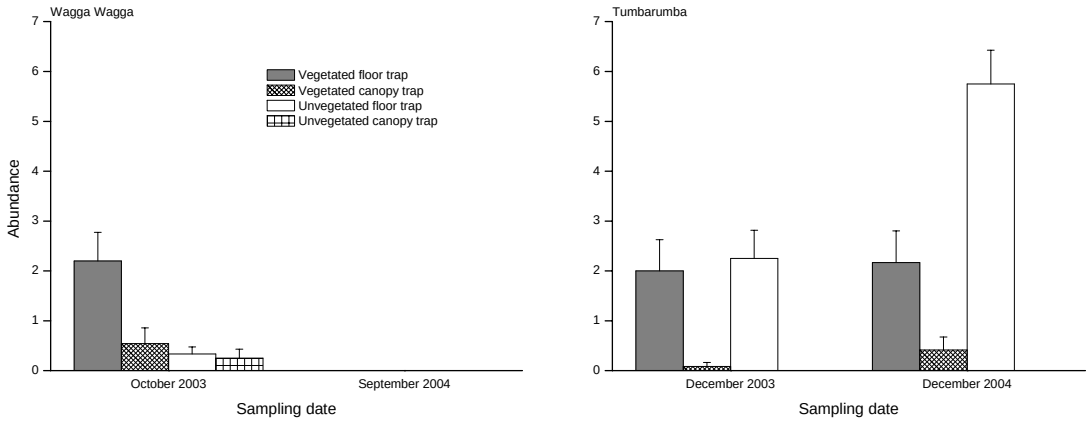


Figure 7.11. Mean ± s.e. abundance of the minute two-spotted ladybird beetle, *Diomus notescens*, in vineyard floor and canopy sticky traps in vegetated and unvegetated treatments at Wagga Wagga and Tumbarumba.

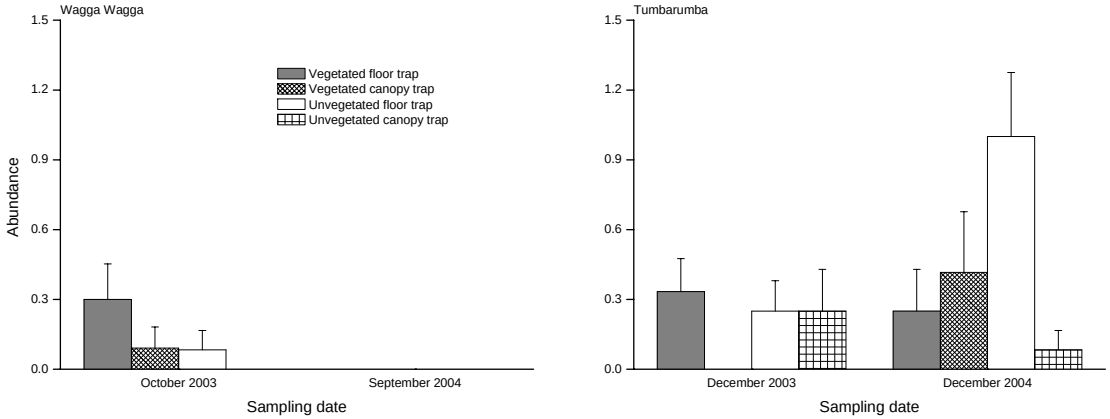


Figure 7.12. Mean ± s.e. abundance of the transverse ladybird beetle, *Coccinella transversalis*, in vineyard floor and canopy sticky traps in vegetated and unvegetated treatments at Wagga Wagga and Tumbarumba.

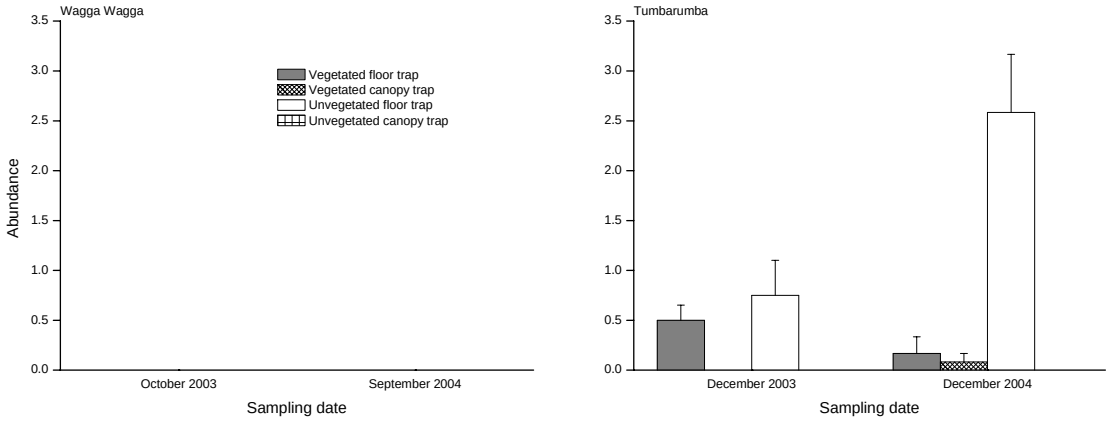


Figure 7.13. Mean ± s.e. abundance of the white-collared or spotted amber ladybird beetle, *Hippodamia variegata*, in vineyard floor and canopy sticky traps in vegetated and unvegetated treatments at Wagga Wagga and Tumbarumba.

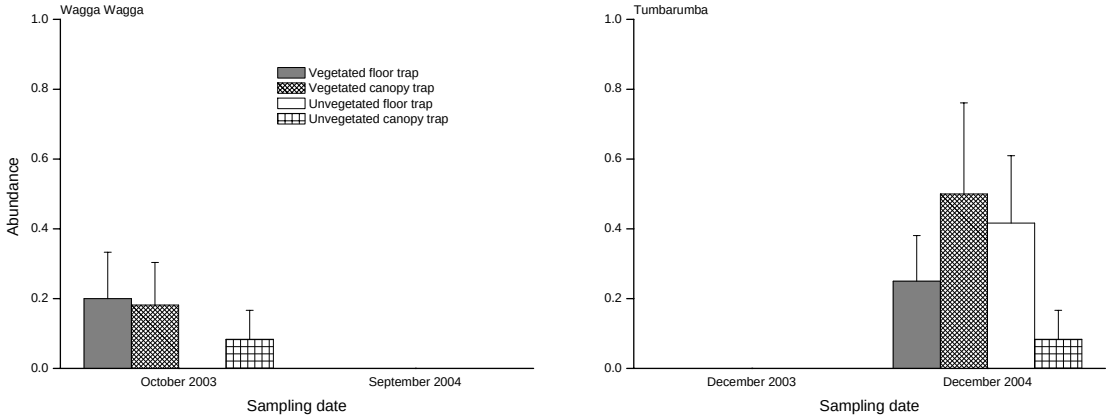


Figure 7.14. Mean ± s.e. abundance of mite-eating ladybird beetles, *Stethorus* spp., in vineyard floor and canopy sticky traps in vegetated and unvegetated treatments at Wagga Wagga and Tumbarumba.

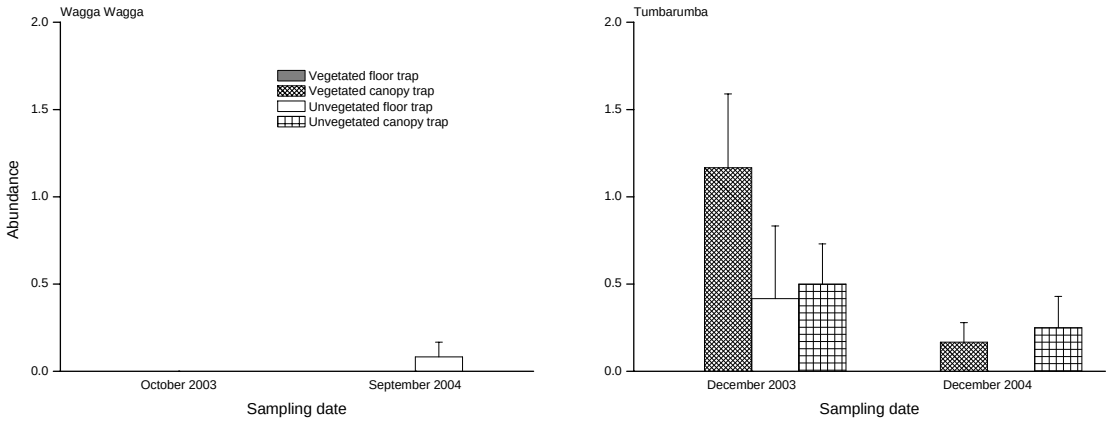


Figure 7.15. Mean ± s.e. abundance of the common spotted ladybird beetle, *Harmonia conformis*, in vineyard floor and canopy sticky traps in vegetated and unvegetated treatments at Wagga Wagga and Tumbarumba.

Abundance and richness of rove beetles was generally highest in the vegetated floor traps and lowest in the unvegetated canopy traps (Figs 7.16, 7.17). Pollen or red and blue beetles, *Dicranolaius* spp., were not recorded on the two sampling occasions at Wagga Wagga and were mainly recorded from vegetated floor traps at Tumbarumba (Fig. 7.18). Brown lacewings were mostly collected in the canopy with higher numbers collected in the unvegetated treatment at Wagga Wagga and vegetated treatment at Tumbarumba (Fig. 7.19).

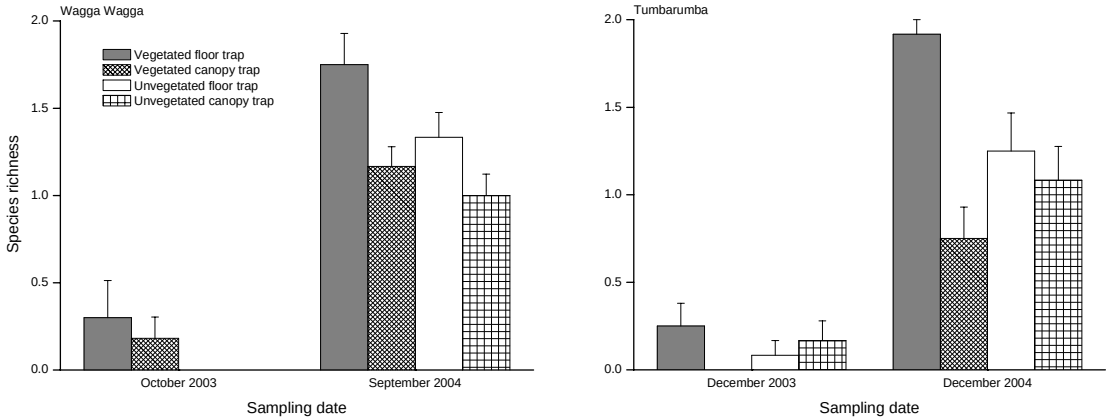


Figure 7.16. Mean ± s.e. species richness of rove beetles in vineyard floor and canopy sticky traps in vegetated and unvegetated treatments at Wagga Wagga and Tumbarumba.

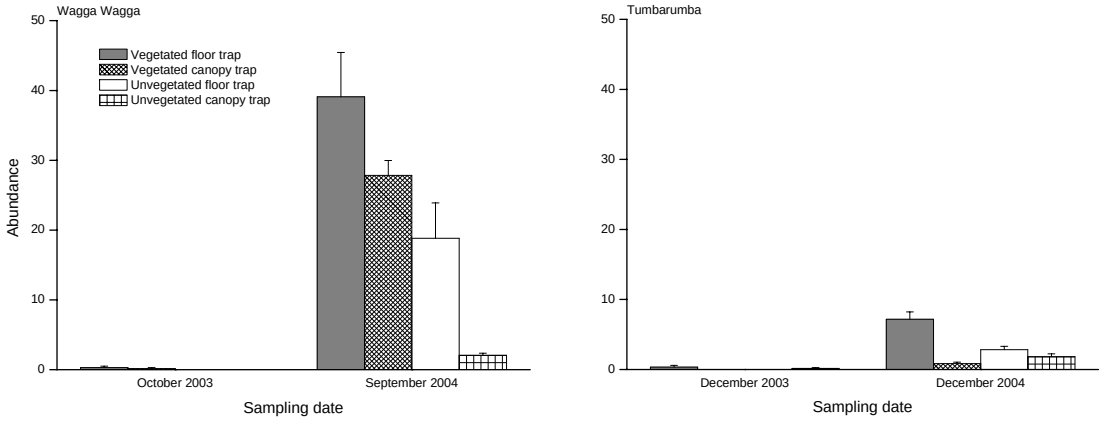


Figure 7.17. Mean ± s.e. abundance of rove beetles in vineyard floor and canopy sticky traps in vegetated and unvegetated treatments at Wagga Wagga and Tumbarumba.

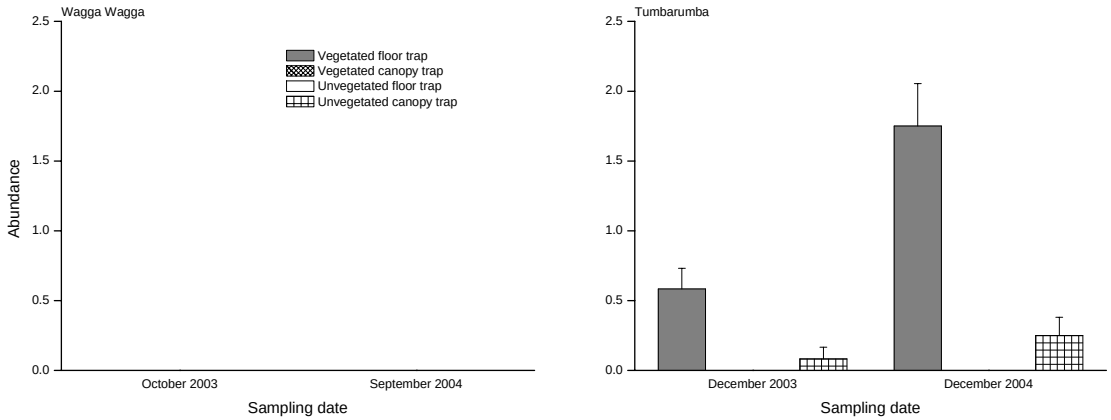


Figure 7.18. Mean ± s.e. abundance of pollen or red and blue beetles, *Dicranolaius* spp., in vineyard floor and canopy sticky traps in vegetated and unvegetated treatments at Wagga Wagga and Tumbarumba.

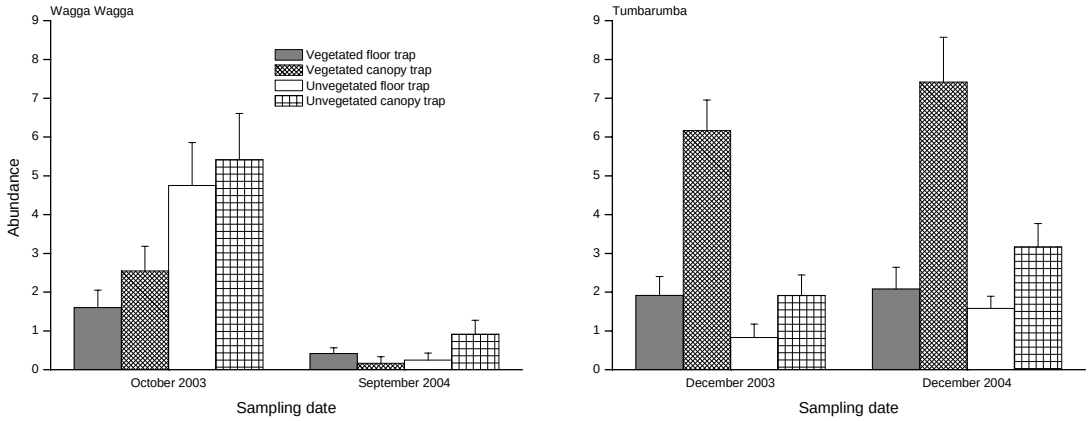


Figure 7.19. Mean ± s.e. abundance of brown lacewings in vineyard floor and canopy sticky traps in vegetated and unvegetated treatments at Wagga Wagga and Tumbarumba.

7.4.2 Biological control of grapevine moth

Rates of predation and parasitism of grapevine moth eggs were very low during the two trials at Wagga Wagga and Tumbarumba. At Wagga Wagga the mean ± s.e. number of eggs eaten per plot of 45 eggs was only 2 ± 0.6 and 1.3 ± 0.5 eggs for vegetated and unvegetated treatments respectively. Parasitism rates were even lower with 0.8 ± 0.3 and 1.5 ± 0.8 eggs parasitised per treatment plot for vegetated and unvegetated treatments respectively. At Tumbarumba, the mean ± s.e. number of eggs eaten per treatment was 1 ± 0.3 and 2.2 ± 0.5 and the number of parasitised eggs per treatment was 1.8 ± 0.7 and 1.5 ± 0.4 eggs for vegetated and unvegetated treatments respectively. The only predators observed eating eggs

during the trial were spiders and green lacewing larvae. Parasitic wasps were reared from both vineyards. Most eggs that were not eaten or parasitised hatched larvae or died during the experiment from desiccation.



Figure 7.20. Predatory shield bugs, *Oechalia schellenbergii* (top) and *Cermatulus nasalis* (bottom) feeding on a pinned grapevine moth larva.



Figure 7.21. Green lacewing larva feeding on a pinned grapevine moth larva.



Figure 7.22. Predatory caterpillar feeding on a pinned grapevine moth larva.

The major predators of grapevine moth larvae during both trials at Wagga Wagga were two species of predatory shield bugs, *Oechalia schellenbergii* and *Cermatulus nasalis*, with the latter being the less abundant species (Fig. 7.20). Other predators included green lacewing larvae (Fig. 7.21), spiders, an unidentified nabid bug and an unidentified caterpillar (Fig. 7.22). Rates of larval predation were very high during both trials. During the first trial over half of the larvae were eaten within four days and only a low percentage of larvae had an unknown fate (Table 7.2). ANOVA revealed that the there was not a significant difference at the 5% level between the two floor management treatments for bug and lacewing predation. For the second trial, the rate and cumulative number of larvae consumed was higher in the vegetated than the unvegetated treatment (Fig. 7.23). A series of ANOVA on the cumulative number of larvae consumed by predatory bugs and lacewings over time found that there was no significant difference between treatments at the 5% level, although there was a significant difference at the 10% level two and three days after larval placement.

Table 7.2. Mean ± s.e. number of grapevine moth larvae that survived, died from predation or had an unknown fate during the first grapevine moth larval predation trial conducted at Wagga Wagga from 8-12 November 2004.

Fate of larvae	Floor management treatment	
	Vegetated	Unvegetated
Alive	11.9 ± 2.1	14.3 ± 2.2
Bug and lacewing predation	24.2 ± 2.7	19.0 ± 2.8
Other predation	2.6 ± 0.8	3.8 ± 1.6
Larva missing	0.7 ± 0.3	2.4 ± 0.6
Larva and pin missing	0.7 ± 0.3	0.6 ± 0.3

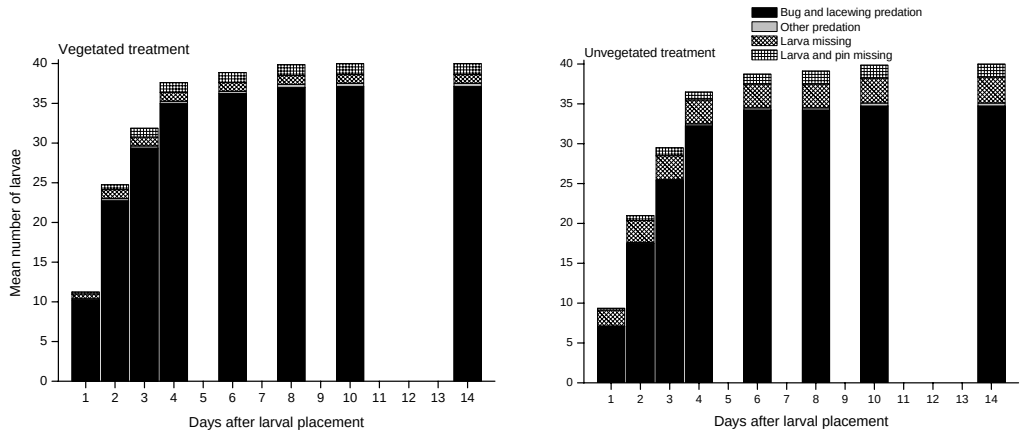


Figure 7.23. Mean number of grapevine moth larvae that died from predation or went missing in the vegetated and unvegetated treatments during the second grapevine moth larval predation trial at Wagga Wagga from 15-29 November 2004.

7.5 Discussion

Beneficial insects were abundant in both vineyards during the study but there was only minimal or weak evidence of any effect of floor management treatment on their abundance or on levels of biological control. Similar to the findings on arthropod abundance using pitfall traps (previous chapter), recorded effects of floor management treatments on overall beneficial insect abundance, richness and biodiversity were neither strong nor consistent but highly variable between and within treatments. Rove beetles showed the strongest and most consistent response to floor management treatment with higher numbers and richness recorded at both sites in the vegetated treatment. There was some evidence of increased abundance of brown lacewings in the vegetated treatment at Tumbarumba, but the reverse

occurred at Wagga Wagga. Overall, wasps showed no strong response to treatment although one species was significantly more abundant in the vegetated treatment for the December 2003 sample at Tumbarumba. These sticky trap results are supported by pitfall trapping results, which also showed increased abundance of rove beetles, wasps and lacewings in vegetated and partially vegetated treatments. Results from both pitfall and sticky traps also showed increases in numbers of ladybird beetles in vegetated treatments, but results were not consistent across site or over time.

Like the pitfall trap study, plot size and replication may have been inadequate to detect changes in the abundance of beneficial insects between floor management treatments. Another difficulty was the low number of beneficial insects caught in traps. Mean numbers of beneficial insect species and groups were typically less than 10 per trap and in many instances were less than 1 per trap, making meaningful and robust statistical comparisons difficult. Future studies may thus have to consider larger plot sizes, increased replication, traps of larger size and longer trapping durations to overcome some of these potential problems.

The placement of sticky traps in the canopy or on the vineyard floor influenced the capture of wasps, ladybird and rove beetles and brown lacewings. In general floor traps captured more wasps, the ladybird beetles *D. notescens*, *C. transversalis* and *H. variegata*, and rove beetles whereas brown lacewings and the ladybird beetle *H. conformis* were more abundant in canopy than floor traps. These results suggest that natural enemies have different flight behaviours and may have different patterns of resource use. Results also suggest that some ladybird beetles and rove beetles are not common in the vine canopy and therefore may not be significant natural enemies of grapevine pests. However, another possible explanation for their low abundance in canopy traps is that these species may conduct most of their movement in the canopy on the vine surface rather than in the air. In contrast, the ladybird beetle *H. conformis* was more abundant in canopy traps indicating that different species within the same group of beneficial insects can have vastly different ecology and behaviour. This result reinforces the recommendation made in the previous chapter that future studies should concentrate on selected species rather than groups of species. Results also demonstrate that trap placement can strongly influence the number and composition of insects captured. Future studies should thus consider trap placement as well as trap type, which are also known to influence trap catches (Thomson et al. 2004).

Pilot biological control field trials revealed that predation and parasitism rates of grapevine moth eggs were very low in both vegetated and unvegetated treatments. In contrast, high rates of predation of grapevine moth larvae by predatory shield bugs and to a lesser extent green lacewing larvae were recorded in both treatments. Although, larval predation rates were slightly higher in the vegetated treatment in both pilot experiments at Wagga Wagga, they were not significantly different from the unvegetated treatment. Larval predation rates could be expected to be higher in the vegetated treatment where there was significantly less vine vigour than in the unvegetated treatment (see Chapter 3) and thus predators may have found larvae easier to find. Larval predation rates would be elevated in these experiments because larvae were pinned to vines and thus had reduced or limited predator evasion and defence capabilities. However, larval predation commonly occurs in vineyards under natural conditions (A.D. Loch, personal observation), and the brightly coloured larvae would be easily located by predators. Despite this limitation, the method of pinning larvae to vines was highly successful and should be adaptable to other species such as the more important grapevine pest, lightbrown apple moth.

Results from both pitfall and sticky traps showed some evidence of increases in the abundance of beneficial insects such as rove beetles, lacewings, wasps and perhaps also ladybird beetles in the vegetated treatment. Vineyard managers may therefore be able to increase populations of some beneficial insects by maintaining a vegetated vineyard floor. However, this recommendation may have limitations as results are of a preliminary nature from only two vineyards in New South Wales and therefore further research is needed to test these observed trends in other Australian vineyards. Further research is also needed to assess the influence of floor management practices and vegetation on levels of biological control in the vineyard. Many studies have demonstrated the positive influence of flowering vegetation on beneficial insect abundance in many cropping systems, yet few studies have taken the next step to determine if there is a positive influence on levels of pest control.

7.6 References

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8. Weed control effects on plant species diversity

Deirdre Lemerle, Rhonda Smith, Emily Rouse and Simon Clarke

8.1 Abstract

Vineyard managers routinely spray weeds occurring under drip-irrigated vines with herbicides. The aim of this aspect of the vineyard floor management research is to determine the effects of three different weed management practices on the species diversity of groundcover plants. These practices are: maintaining inter-row and undervine vegetation by mowing and no herbicide (vegetated); spraying herbicide under-vines and maintaining inter-row vegetation (partially vegetated); and applying herbicide to undervine and mid-row areas (unvegetated). Although obscured by inter-annual and between-treatment variation in species composition, botanical analyses indicate that, in general, the spraying of herbicide is effective at reducing the species diversity and abundance of groundcover plants in vineyards, whereas the effects of mowing on these attributes are more subtle. Analysis of viable ungerminated seeds in vineyard soils sampled before and after the application of the treatments provides support for conclusions drawn from the botanical analyses, and reveals that some species poorly represented amongst the emergent plants have large seed banks. Several species frequently identified in the botanical and seed bank surveys are known to have glyphosate tolerance.

8.2 Introduction

Vineyard managers routinely spray weeds occurring under drip-irrigated vines with herbicides. The rationale of this practice is to minimise competition between grapevine and weeds for water and nutrients. Herbicide application rates are moderated by the need to minimise the use of herbicides to reduce costs, the importance of limiting the amount of chemicals put into the environment, and the risk of promoting herbicide resistance in weeds.

Although weeds may compete for water and nutrients, they also provide a potentially valuable source of species diversity. The vineyard is a high output monoculture maintained with high inputs, of which high species diversity is not an inherent characteristic. Benefits accruing from the high species diversity provided by weeds include: providing habitat for predators that target organisms whose activities may be deleterious to grape vines; attracting insect

pollinators to vineyards; and providing a source of organic matter necessary for maintaining soil health.

8.3 Research objectives

The aim of the research is to determine the effects of three different weed management practices on the species diversity of plants comprising the groundcover of cool and warm climate vineyards. The objective is to provide viticulturalists with a better understanding of the effects of their weed management practices in order to promote sustainable vineyard floor management systems. Research is focused on the assemblage and composition of (1) emergent plant species and (2) ungerminated but viable plant seeds in the soil. An account of preliminary results can be found in Smith *et al*. (2003).

8.4 Methods

8.4.1 Treatments

In 2002 two field trials were established to represent cool and warm climate viticulture. The cool climate site is located in the Tumbarumba Wine Estates vineyard, Tumbarumba, and the warm climate site is in the Charles Sturt University vineyard, Wagga Wagga. The trials were conducted in drip-irrigated blocks of *Vitis vinifera* L. cv. Chardonnay.

Each year, using a randomised split-plot design, twelve replicates of each of the following treatments were imposed.

(1) *Unvegetated* - Herbicide (principally glyphosate) applied to undervine and mid-row areas.

(2) *Partially vegetated* - Herbicide applied under vines and mid-row mowed as required (standard vineyard practice).

(3) *Vegetated* - No herbicide applied and mowed as required.

8.4.2 Botanical analysis

In spring and autumn the botanical composition of areas under vines and in the mid-rows were assessed at both vineyards using the point quadrant method. Briefly, this method involves the use of a 50 x 50 cm cross. The cross is laid flat in the sampling area and the species that occur at each of the four points are recorded. These analyses provide numbers on species present and the average frequency of species within treatment areas (occurrences as a percentage of recordings).

Botanical analyses were conducted in October 2002, March and November 2003, and March and October 2005 for the Tumbarumba vineyard. Similarly, botanical analyses were conducted in February and October 2002, March and November 2003, September 2004, and January 2005 for the Wagga Wagga vineyard.

Due to difficulties associated with identification to the species level and to artefacts of the recording process it was necessary to group some species under their corresponding family or genus headings. For example, all clovers are grouped under *Trifolium* spp. Furthermore, a small number of infrequently occurring unidentifiable species were encountered during the analyses. Therefore the 'true' species diversity of both vineyards is likely to be underestimated by the species counts presented here by a small number (probably by five species or less).

8.4.3 Soil seed bank composition

The species composition of the soil seed bank was assessed by taking 5 cm soil cores at the beginning (Wagga Wagga: February 2002; Tumbarumba: June 2002) and end (May 2005) of the trial. The soil cores were placed in glasshouse trays and watered to promote seed germination. Plants that germinated were counted to provide numbers on species present and abundance (frequency expressed as a percentage of all observations made within each treatment), and each was removed prior to producing seed.

Seed bank data for the beginning of the study are based on cumulative counts made after watering in 2002, 2003 and 2004 for the both vineyards. Seed bank data for the end of the study are based on counts made after watering in 2005.

8.5 Results

8.5.1 Botanical analyses

8.5.1.1 Composition

The botanical analysis of the Tumbarumba vineyard identified 47 groundcover plant species amongst the top 20 most abundant species within each treatment. Similarly, botanical analysis of the Wagga Wagga vineyard identified 48 species. Species common to both vineyards and often present in abundance included *Polygonum aviculare*, *Trifolium* spp., *Cynodon* spp., and *Stellaria media*. *Rumex acetosella* was often present in abundance at the Tumbarumba vineyard but not at the Wagga Wagga vineyard. Conversely, species often abundant at the

Wagga Wagga vineyard only include *Lolium* spp. and *Vulpia* spp. Overall, approximately half of the 61 species identified in the botanical analyses were common to both vineyards.

8.5.1.2 Species diversity

The number of species identified within treatments was often far less than the total number of species identified in the respective vineyard. The lowest number of species identified in any treatment was at Tumbarumba: in Spring 2002 the partially vegetated and unvegetated treatments were effective at removing all plant species from the under-vine understorey within these areas. At this vineyard the highest number of species identified was amongst the under-vine under-storey of the vegetated treatment (30 species) in Spring 2003. The lowest number of species identified amongst the treatments at the Wagga Wagga vineyard was five (under-vine area of the partially vegetated treatment, Summer 2005), and the highest was 25 (mid-row of unvegetated treatment, Summer 2002). At the Tumbarumba vineyard, the areas with the highest species diversity tended to be those of the vegetated treatment, especially under-vines. The species diversity of the vegetated treatment at Wagga Wagga was also high relative to both herbicide treatments, but the trend was not as well defined as at the Tumbarumba vineyard. At Tumbarumba, those areas treated with herbicide (unvegetated, under-vine areas of partially vegetated treatment) tended to exhibit the lowest species diversity. At Wagga Wagga, the under-vine area of unvegetated treatments tended to exhibit the lowest species diversity.

8.5.1.3 Changes in composition and species diversity

One of the most pronounced contrasts between Tumbarumba and Wagga Wagga vineyards was the change in species diversity over time. At Tumbarumba there was initially (Spring 2002) a wide range in species counts amongst treatments (0 to 18 species). At Wagga Wagga in the same season this range was smaller and the treatments tend to be slightly more species-rich (13 to 20 species). The species diversity across the Wagga Wagga treatments then dropped over the following seasons, reaching (in Spring 2004) species counts (9 to 14) similar to those observed at Tumbarumba in the same season (5 to 14). The declining species diversity trend in the Wagga Wagga vineyard was most pronounced for the inter-row areas of the unvegetated treatment. Overall, the range in species counts across the treatments at the Wagga Wagga vineyard for any given season was less variable (10 species difference between the most and least species-rich treatments) than that observed at the Tumbarumba vineyard (the range varies from close to 10 to more than 15).

The decrease in the species diversity of the Wagga Wagga vineyard understorey was driven primarily by a loss of species and not an assemblage turnover. That is, the species dominant at the end of the observation period (e.g., summer/autumn observations: *Polygonum aviculare*, *Cynodon* sp., *Epilobium billardierianum*, spring observations: *Lolium* spp., *Arctotheca calendula*, *Vulpia* spp., *Epilobium billardierianum*, *Polygonum aviculare*) were present initially, but their initial cohorts appear to have been selected against over the intervening seasons (see Figure 8.1, for an example). The few species absent in the first recording seasons but present in the latter observation periods tended to occur at low frequencies (e.g. summer: *Paspalum dilatum*, *Portuluca oleraceae*, spring: *Oxalis* spp., *Sida* spp., *Hypochoeris radicata*). However, there appear to be some important exceptions to these general trends. For example, from the first to last spring observations the frequency of *Polygonum aviculare* occurrences under vines increases from values close to zero to values in excess of 14 % in the unvegetated and partially vegetated treatments. Similarly, in the last spring observation period the occurrence of *Arctotheca calendula* under vines in the vegetated treatment is high relative to earlier spring observations.

Spring observations at Tumbarumba show a contrast between those areas sprayed with herbicide and those which were vegetated and not sprayed in terms of change to the most frequently occurring species. In inter-rows and undervine areas that were sprayed there was a shift from *Polygonum aviculare* being dominant to *Stellaria media* and *Poa annua* being the most dominant. In contrast, where the vegetated treatment was applied *Trifolium* spp. continued to be one of the most frequently occurring species throughout the spring observations. Across all treatments, changes in species composition for the spring observations were common, with species such as *Salvia verbenaca*, *Hordeum leporium*, *Vulpia* spp. and *Hypochoeris radicata* replacing species such as *Cynodon* sp. and *Malvaceae*.

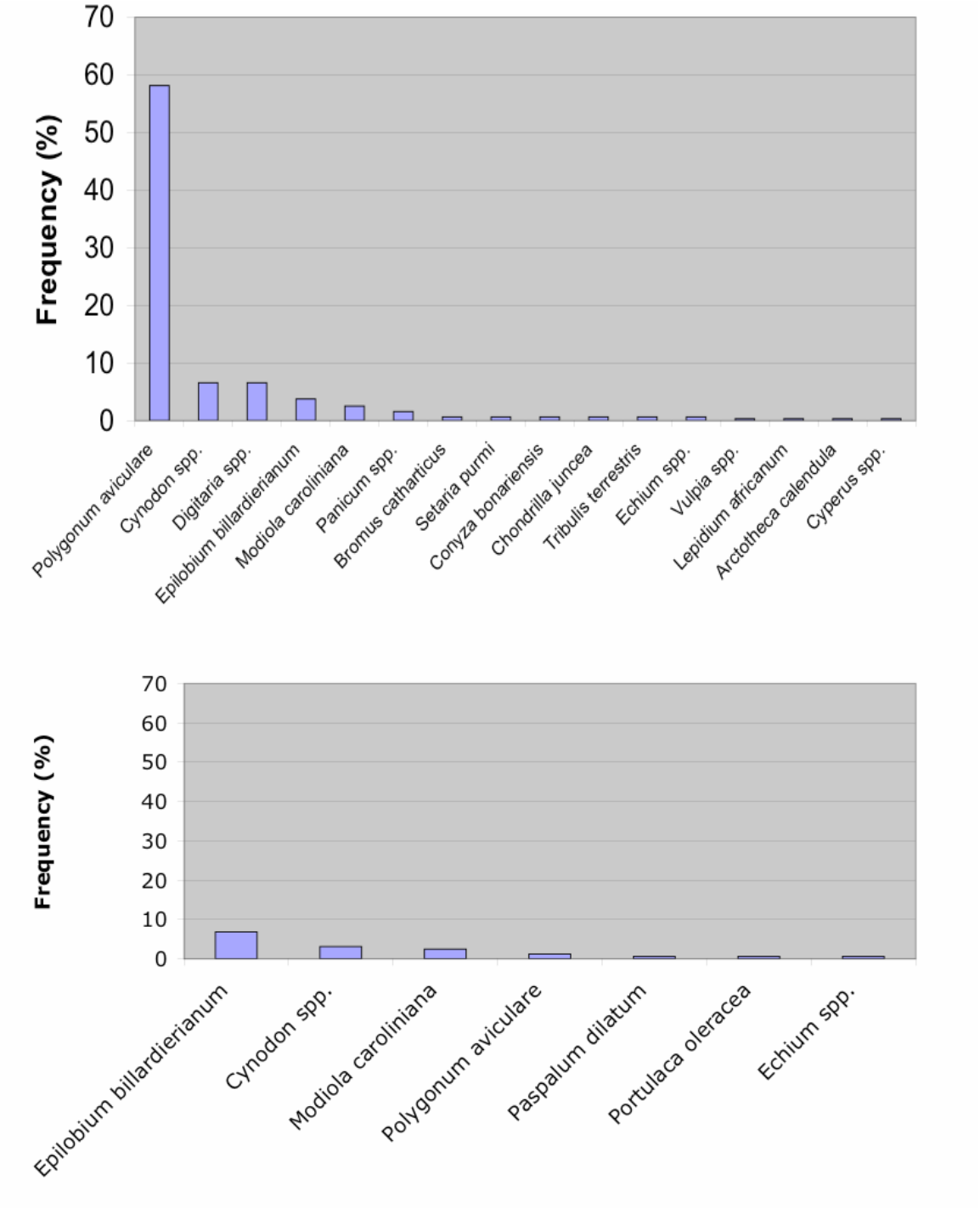


Figure 8.1. Contrasts in the species diversity and abundance of groundcover species in summer 2002 (top) and 2005 (bottom) at the Wagga Wagga vineyard.

Between the 2003 and 2004 autumn observations at the Tumbarumba vineyard there were few changes to the species that dominated each treatment in these seasons (i.e. *Polygonum aviculare*, *Cynodon* spp.). However, each treatment appears effective at reducing the frequency of *Polygonum aviculare* frequency under-vines, but less effective on this species in mid-row areas.

Overall, the species diversity of the unvegetated treatments in 2004 is higher than that in 2003 due to the presence of several additional species occurring at low frequencies.

8.5.1.4 Differences in the effects of treatments

The spraying of herbicide at the Tumbarumba vineyard seems to be highly effective at keeping the species diversity and frequency of weed occurrence low, particularly under vines. Conversely, the vegetated treatment was equally effective under vines and in mid-row areas at maintaining high species diversity and frequencies. Similarly, at the Wagga Wagga vineyard herbicide applications were effective at gradually reducing the species diversity of the groundcover. Mowing employed in the vegetated treatment also appeared to have the effect of reducing species diversity, but to a lesser degree than the herbicide treatments.

8.5.2 Soil seed bank

8.5.2.1 Composition and species diversity

There were 31 species identified in the Tumbarumba vineyard soil seed bank analyses, nine of which (*Lolium spp., Amaranthus retroflexus, Heliotrope europaeum, Cirsium vulgare, Juncus bufonius, Oxalis spp., Stachys arvnensis, Polycarpon tetraphyllum*, *Solanum nigram*) were not recorded in the botanical analyses. A total of 43 species were identified in the Wagga Wagga vineyard soil seed bank analyses, many of which were not identified in the botanical analyses (*Chenopodium pumilio*, *Anagallis arvensis*, *Poa annua*, *Juncus bufonius*, *Chenopodium album*, *Crassula* spp., *Medicago* spp., *Bromus diandrus*, *Lythrum hyssopifolia*, *Polycarpon tetraphyllum*, *Stachys arvensis*, *Avena* spp., *Carduus* spp., *Microleana* spp.). These identifications bring the combined species count for the two vineyards to 78.

8.5.2.2 Changes in composition and species diversity

In sharp contrast to the Tumbarumba botanical analyses and final seed bank observations, the most frequently occurring species in the initial seed bank analyses for this vineyard was *Juncus bufonius* (see Figure 8.2 for an example). *J. bufonius* always comprised more than 60% of the observations. Where herbicide was applied, increases in the frequency of *Stellaria media* were noted, along with less pronounced increases in the occurrence of *Poa annua* and a decline in *Trifolium* spp. counts. Where there was no herbicide spraying the best-defined trend was an increase in *Stellaria media* counts, along with those of *Poa annua*, at least in the vegetated treatment. One of the major differences between the initial and final seed bank analyses was a reduction in species diversity: *Poa annua*, *Polygonum aviculare*, *Stellaria*

media and *Trifolium* spp. were important contributors to both assemblages. Absent from the final observations were species such as *Chenopodium pumilio* and the *Malvaceae*. However, as the initial seed bank analyses were more rigorous (more wetting, drying and observation phases) than the final analyses the significance of this apparent decline in species diversity is not clear.

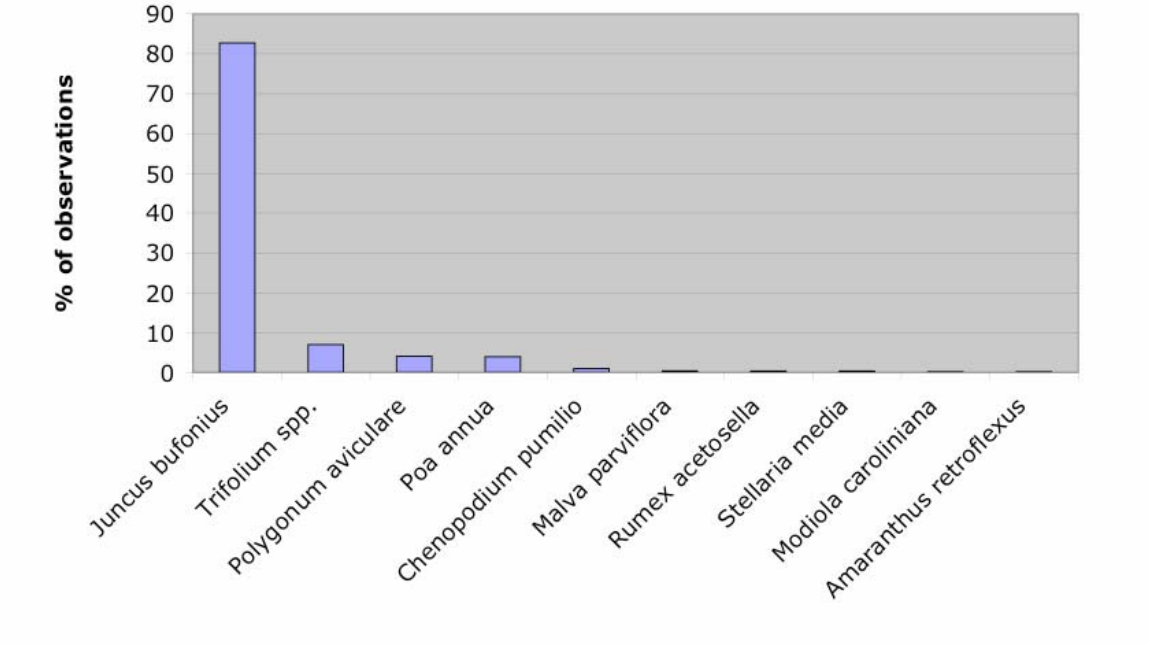


Figure 8.2. An example of the high abundance of *Juncus bufonius* counts in the Tumbarumba vineyard seed bank analyses.

At the Wagga Wagga vineyard the application of herbicide to inter-row and undervine areas did not appear to influence the frequent occurrence of *Stellaria media* in the seed bank assemblage. However, notable reductions in the frequency of *Stellaria media* were recorded in the vegetated treatment. Where undervine areas were sprayed the contribution of *Polygonum aviculare* and *Trifolium* spp. were both reduced. However, the universal trend across treatments was a pronounced increase in the frequency of *Vulpia* spp. The diversity of species recorded in the initial soil seed bank survey was far greater than that of the latter survey, but as mentioned with respect to the Tumbarumba vineyard dataset, this is likely to be an artefact of the number of counting events.

8.6 Discussion

One of the major differences in species composition between the two vineyards was the absence of *Poa annua* from Wagga Wagga, and the contrasting abundance of this species at Tumbarumba. However, there was much overlap in terms of species occurring at the two localities. From the general decline in species diversity and abundance under herbicide treatments at both sites it is likely that the application of herbicide under vines is a highly effective means of minimising competition between vines and weeds for water and nutrients. Conversely, the results of this study support the idea that mowing of mid-row areas is a simple and cost-effective means of providing the agricultural ecosystem of the vineyard with species diversity.

Like the botanical analyses, the soil seed bank observations revealed complex interactions between treatments and species diversity and abundance. However, some coherent trends are apparent. For example, from the seed bank analyses it appears that herbicide application had opposing effects on *Stellaria media* at Tumbarumba (increase) and Wagga (decrease), whereas spraying appears to reduce *Trifolium* spp. numbers at both vineyards. At Tumbarumba the soil seed bank analyses support the botanical analyses of the emergent species: an increase in *Stellaria media* and *Poa annua* numbers where herbicide is applied. At Wagga Wagga there was less coherence between the seed bank and botanical analyses. For example, the increase in *Vulpia* spp. observed in the seed bank was not replicated in the botanical analyses. However, the results agree insofar as species such as *Stellaria media* and *Polygonum aviculare* are frequently occurring weeds at this warm climate vineyard.

When interpreting the soil seed bank analyses in the context of vineyard floor management it is important to remember that the seed bank analyses were performed by imposing environmental conditions on samples of vineyard soils, and that these artificial conditions may not accurately represent those of the vineyard. For example, the germination of *Juncus bufonius* seeds is favoured in wet soils. Thus, the contrast between the high *J. bufonius* counts in the soil seed bank observations (Figure 8.2) and the absence of this species from both surveys of emergent plants is explicable in terms of the glasshouse watering regime and the prevalence of drought conditions during the study, respectively. While observations such as these highlight the artificial conditions of glasshouse studies, they also serve to emphasise the importance of the artificial setting for more fully assessing vineyard groundcover species diversity (i.e. viable seeds).

Many of the species encountered in this study are known to exhibit tolerance to glyphosate. Such species include *Lolium* spp., *Polygonum aviculare*, *Lepidium africanum*, *Malva parviflora*, *Erodium* sp., *Echium* sp., *Chondrilla juncea* and *Capsella bursa-pastoris*. Of these *Lolium*, *Polygonum* and *Echium* were recorded in the botanical analyses of at least one of the mid-row or under-vine areas sprayed with glyphosate in the last spring and summer observation periods at Wagga Wagga, while *Lolium*, *Polygonum*, *Malva*, *Chondrilla* and *Capsella* were present in at least one of the sprayed areas at Tumbarumba over the last two seasons of observation. While the presence of these species in herbicide-treated areas is insufficient to confirm herbicide-tolerance, the observations serve to highlight the possibility of a reduction in the effectiveness of glyphosate as a vineyard weed management tool.

8.7 References

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9. Effects of mid-row vegetation on grape berry quality and wine characteristics.

Michel Meunier, Emily Rouse and Rhonda Smith.

9.1 Research Objectives

This study examined the effect of three vineyard floor management treatments on grape berry and wine attributes. Chemical analyses of fruit at harvest and the finished wine were performed to determine if floor management treatments have an effect on the ripening parameters including pH, Titratable acidity and Total soluble solids. Sensory analysis examined the impact of the treatments on wine characteristics.

9.2 Materials and Methods

9.2.1 Grape harvest

Harvests were performed for each vintage from 2002 to 2005. Grapes were hand harvested in the early morning to preserve berry quality. After harvest, the fruit received an addition of 30mg/L of sulfur dioxide and were immediately placed in a cool room at 4°C for 12 hours.

9.2.2 Grape processing

Grapes were crushed and de-stemmed using an *Enoitalia* stainless steel grape destemmer with feeder auger and spring mounted rubber roller, and then immediately pressed with a *Velo* PCM 7 membrane press. Juice was collected in a 25 litre glass demijohn and kept at 4°C for cold settling for a period of 12 hours.

9.2.3 Vinification

Juice was racked off lees and warmed up to 15°C for inoculation. Lallemand EC1118 *Saccharomyces cerevisiae* variety *bayanus* yeast (Lallemand 2002) was added as inoculum at a rate of 0.2g/L. Yeast was re-hydrated in a blend of 50% juice and 50% water and kept at 40°C for a period of 20 minutes before being inoculated to the juice. Measures of Total soluble solids (TSS) were monitored twice a day during fermentation while the temperature was maintained at 15°C. Residual sugar was measured with an Antonn Parr portable density specific gravity/concentration meter to determine the completion of alcoholic fermentation. At

the end of alcoholic fermentation, sulfur dioxide was added to achieve a concentration of 30mg/L of free sulfur dioxide. No malolactic fermentation was performed.

9.2.4 Analytical methods

A sample of the must was collected at crushing to determine pH, Titratable acidity (TA) and TSS. These analyses were performed according to Iland (2000). The pH was adjusted to 3.2 with the addition of Tartaric acid. TSS was measured twice a day. Residual sugar was measured using the Rebelein method and sulfur dioxide was determined according to the Aspiration method (Iland 2000). Alcohol content was analysed with an alcolyzer (Antonn Parr). Volatile acidity was measured according the Markham Still method using the VA (Glasschem VA/SO_2) from Filtech. Total Kjeldahl nitrogen was measured using the APHA 4500-Norg B method. Protein stability tests were performed according to the method describe by Iland (2000).

9.2.5 Sensory analysis

Discrimination tests using duo trio method were performed through a group of 10 panellists. Data were analysed with Compusense *five*® computer program.

9.3 Results and Discussion

9.3.1 Fruit quality

9.3.1.1 Total soluble solids

Vintage 2002-2003 did not show any difference in TSS for both Wagga Wagga and Tumbarumba. In 2003-2004, TSS was greater for fruit from the vegetated treatment (Fig. 9.1). Differences in TSS between treatments were greater during the 2004-2005 vintage at Wagga Wagga. TSS (Brix) levels increased with increasing levels of ground vegetation (Fig. 9.2). In contrast, no difference in TSS was observed between treatments at the Tumbarumba vineyard for either 2003-2004 or 2004-2005 vintages.

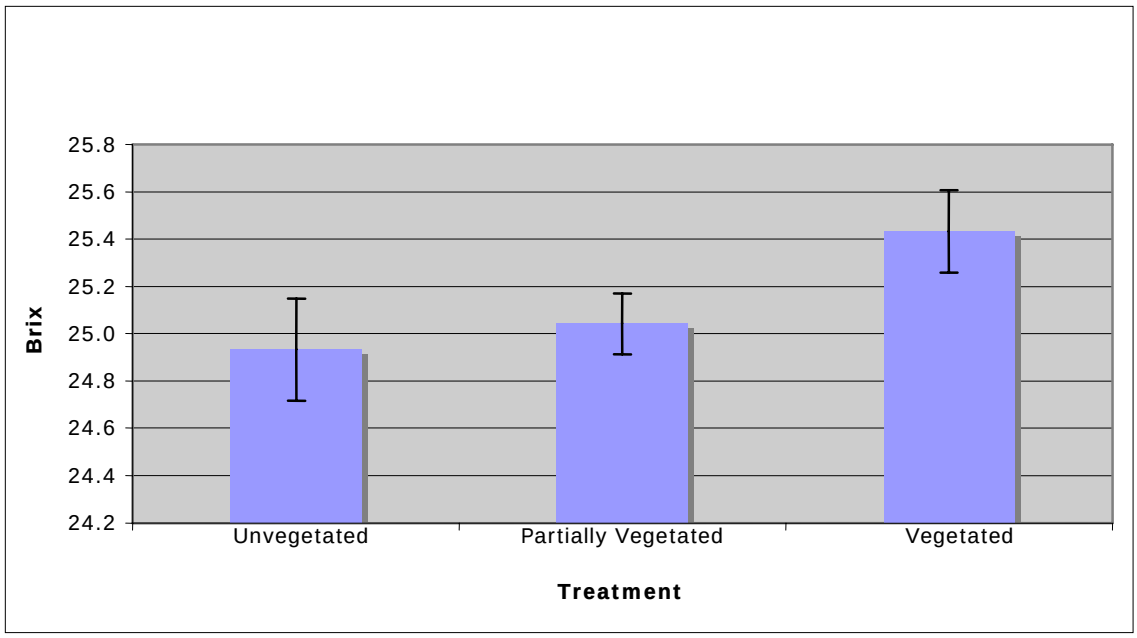


Figure 9.1. Mean ± s.e. Brix levels of Chardonnay from the three treatments at Wagga Wagga during the 2004 harvest.

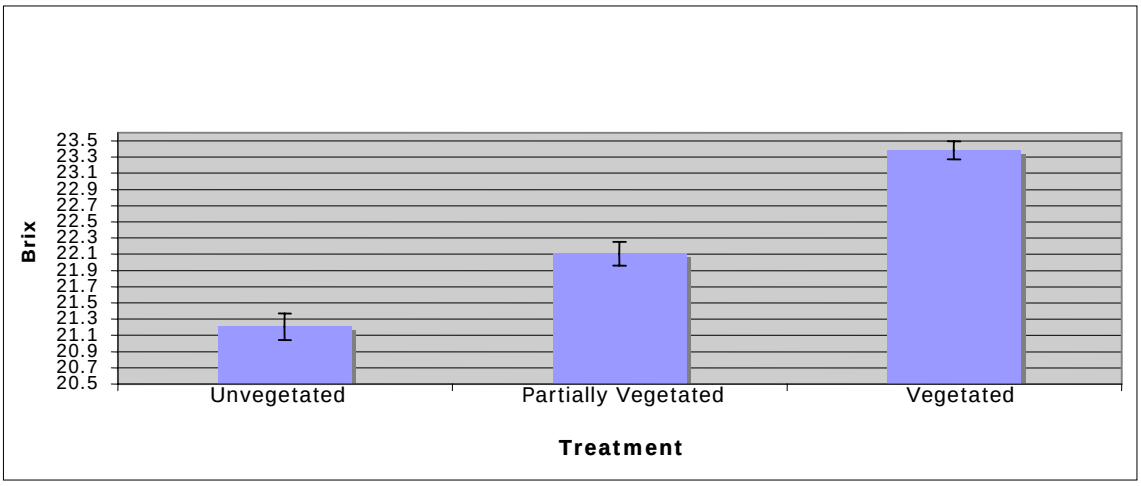


Figure 9.2. Mean ± s.e. Brix levels of Chardonnay from the three treatments at Wagga Wagga during the 2005 harvest.

9.3.1.2 pH

During all vintages, there were some differences in pH at harvest for each of the treatments at the Wagga Wagga site. The unvegetated treatment recorded the highest pH and the partially vegetated treatment the lowest pH during 2003 (Fig. 9.3). In 2004 increasing levels of ground vegetation led to decreases in pH (Fig. 9.4), which agrees with a study conducted in Switzerland (Maigre 2002). In 2005, pH was highest in the partially vegetated treatment (Fig. 9.5). There were no differences in pH at the Tumbarumba vineyard.

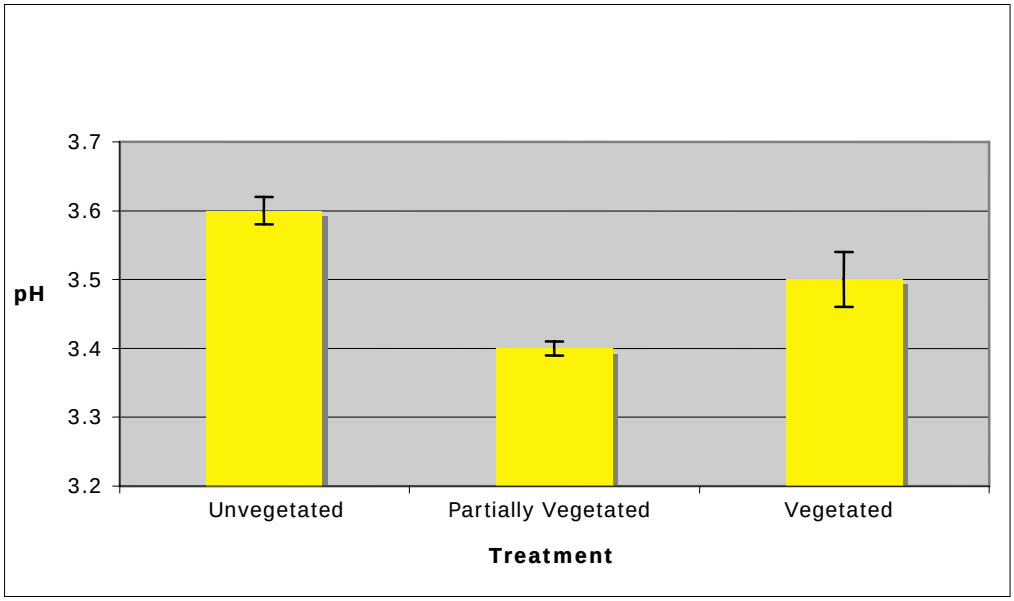


Figure 9.3. Effect of floor management treatment on pH of grapes at harvest in 2003 at Wagga Wagga.

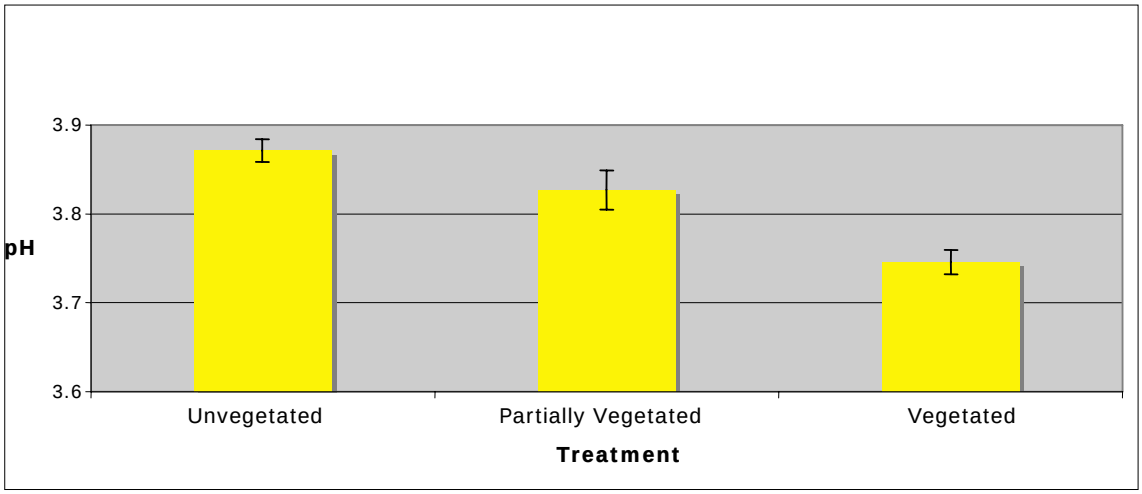


Figure 9.4. Effect of floor management treatment on pH of grapes at harvest in 2004 at Tumbarumba.

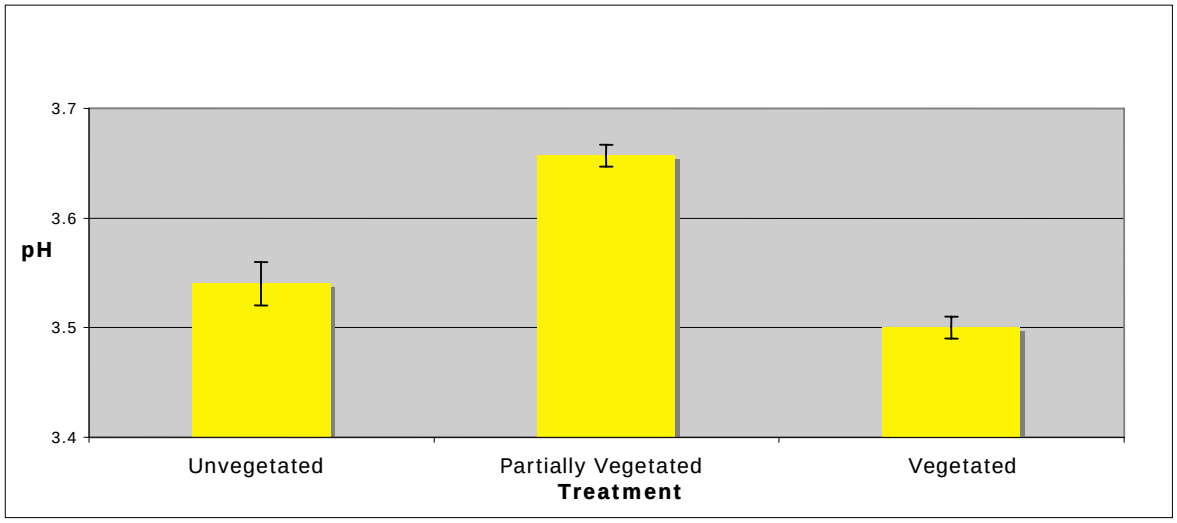


Figure 9.5. Effect of floor management treatment on pH of grapes at harvest in 2005 at Wagga Wagga.

9.3.1.3 Titratable Aciditry (TA)

No difference was recorded in TA of the juice from Tumbarumba during any vintage. At Wagga Wagga, the highest TA was generally found in grapes from the unvegetated treatment while the lowest TA was obtained from the partially vegetated treatment.

9.3.2 Fermentation

Fermentation of the fruit harvested in 2003 in Wagga Wagga took more than 150 days to ferment while wine made from Tumbarumba fruit finished in 60 days. In 2004, complete fermentation took 33 days for fruit from Wagga Wagga while wine made from Tumbarumba fruit was completed in 12 days. The main difference in fermentation time was between site. Nevertheless, in 2003 one of the three replicates of the Wagga Wagga vegetated treatment did not complete the fermentation to dryness wile two replicates did not completely ferment in 2004.

9.3.3 Nitrogen

Total nitrogen decreased with increasing levels of ground vegetation at both Wagga Wagga (Fig. 9.6) and Tumbarumba (Fig. 9.7) in 2004.

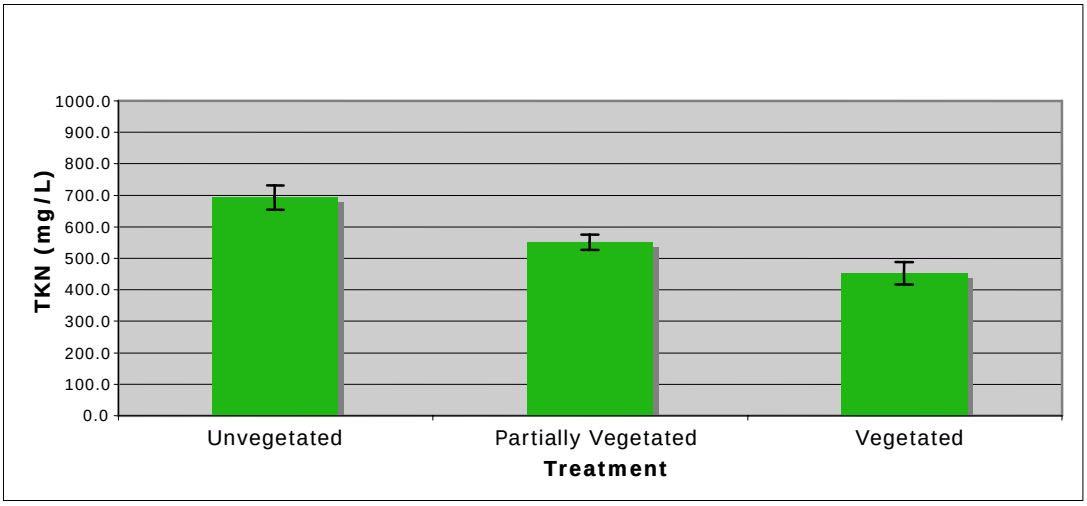


Figure 9.6. Impact of floor management treatments on total grape nitrogen content (TKN) at Wagga Wagga in 2004.

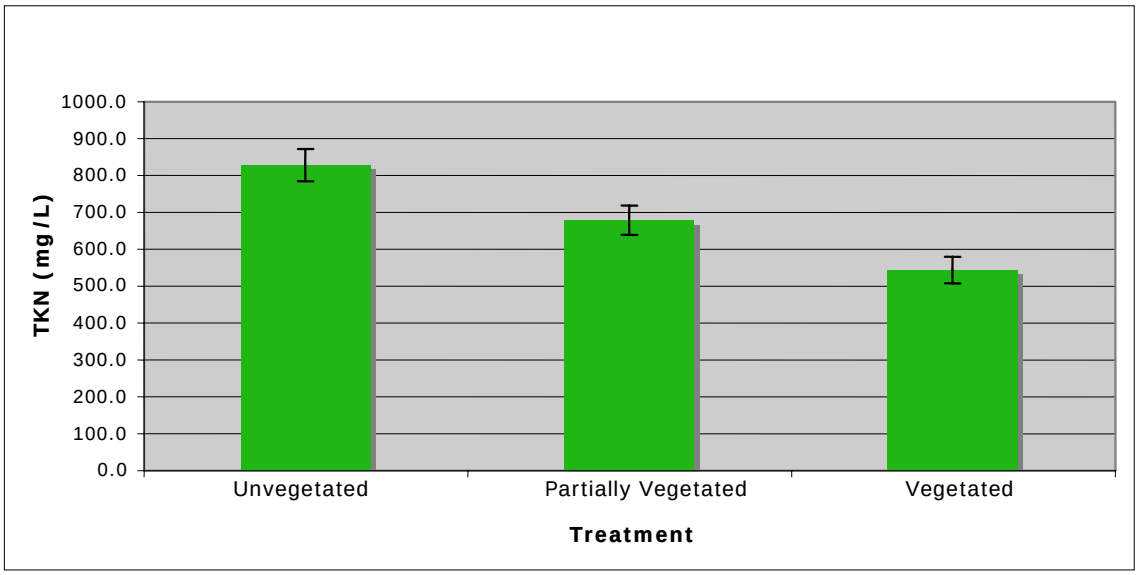


Figure 9.7. Impact of floor management treatments on total grape nitrogen content (TKN) at Tumbarumba in 2004.

9.3.4 Protein stability

Chardonnay wine obtained from Tumbarumba fruit in 2004 had more turbidity after heat treatment at 80°C for 6 hours than wine made from Wagga Wagga fruit (Fig. 9.8). High vigour of the Tumbarumba vines produced higher total nitrogen content in the juice and therefore more protein instability due to higher protein content. Turbidity was higher at Wagga Wagga in 2005 than 2004 (Fig. 9.9). In 2005 wine was made only from Wagga Wagga fruit since Tumbarumba fruit was affected by *Botrytis cinerea*.

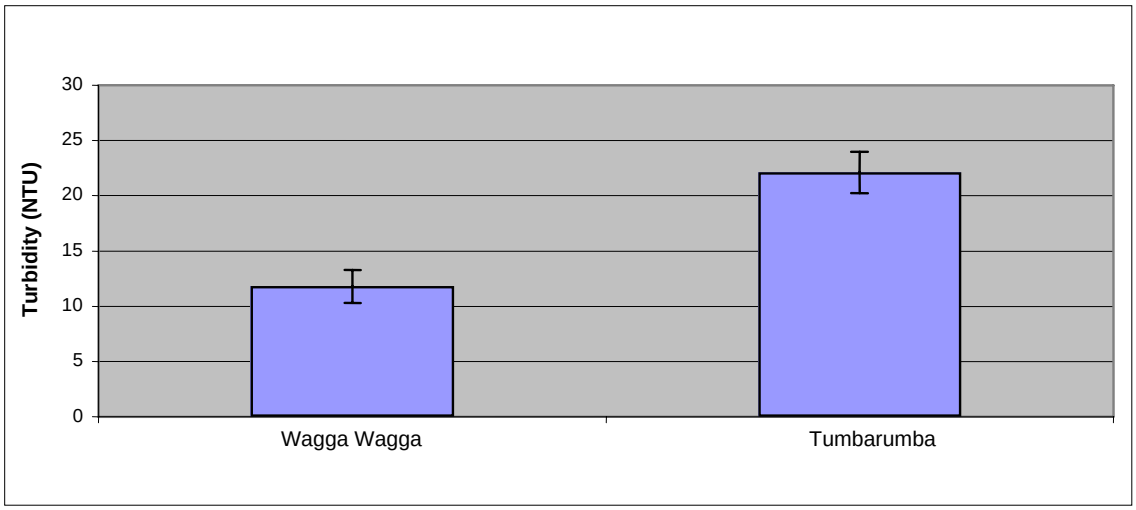


Figure 9.8. Effect of vineyard floor management treatments on mean ± s.e. wine turbidity from Wagga Wagga and Tumbarumba in 2004.

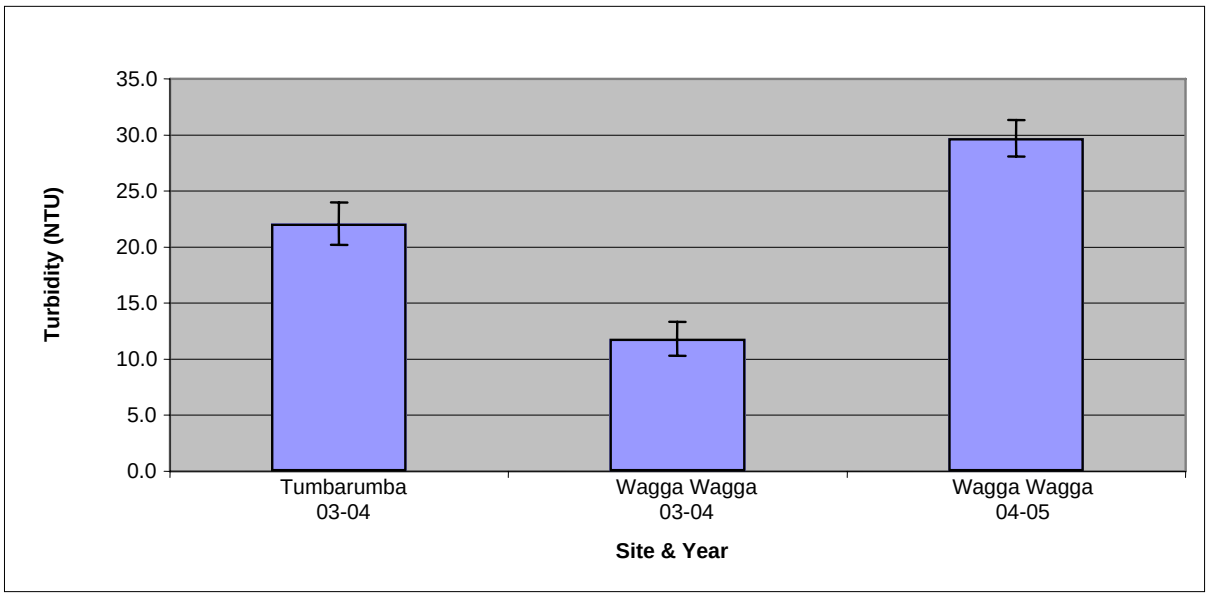


Figure 9.9. Effect of vineyard floor management treatments on mean ± s.e. wine turbidity from Wagga Wagga and Tumbarumba in 2003-2004 and 2004-2005 vintages.

Although initial turbidity before wine treatment shows negligible effects between treatments, higher nitrogen content tended to lead to higher turbidity caused by unstable proteins (Figs 9.10 and 9.11). The only exception occurs in the vegetated treatment at Wagga Wagga in 2003-2004 where we find the lowest amount of nitrogen causing the highest turbidity (Fig. 9.10). Proteins are identified as grape pathogenesis or stress related (Waters 1996). Because of the drought condition in Wagga Wagga in 2003-2004 growing season, there was more competition between floor vegetation and the vines, causing more stress. Tumbarumba has a

cooler climate having a higher rainfall therefore the vines were less stressed and produced less unstable proteins.

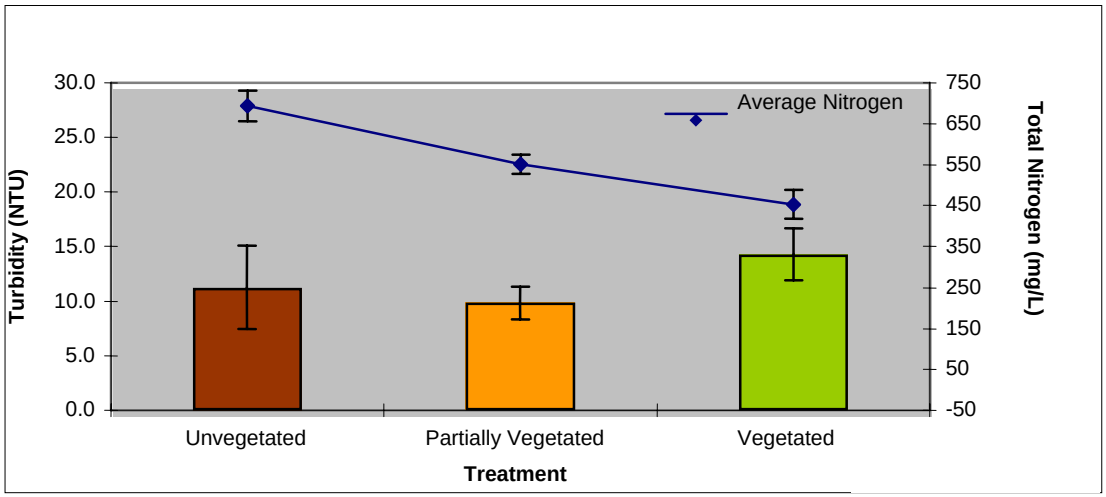


Figure 9.10. Effect of vineyard floor management treatment on mean ± s.e. wine turbidity and total nitrogen content of Chardonnay grape juice from Wagga Wagga in 2003-2004 vintage.

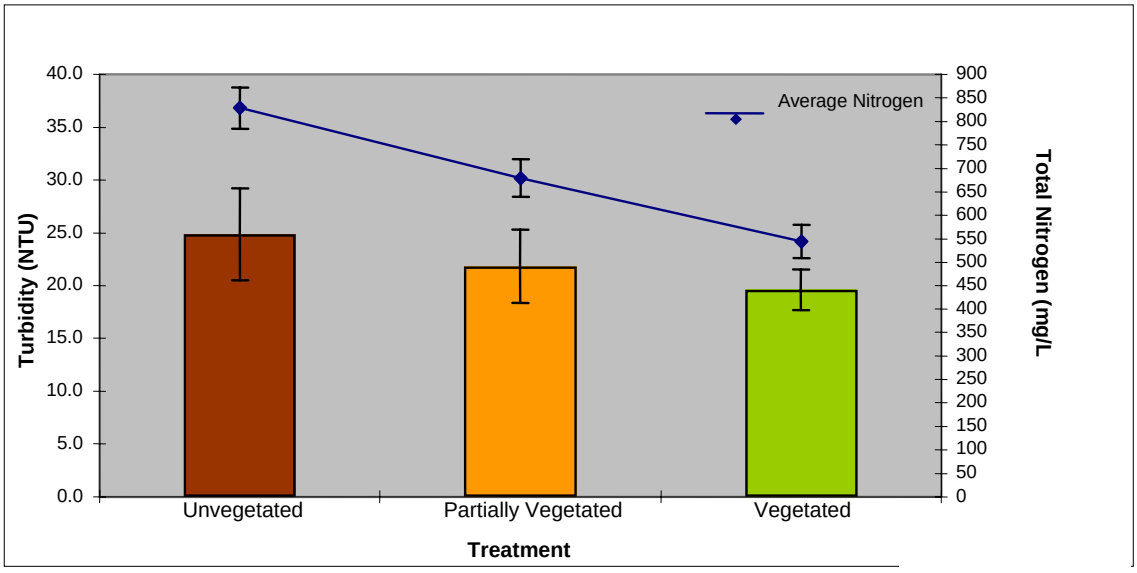


Figure 9.11. Effect of vineyard floor management treatments on mean ± s.e. wine turbidity and total nitrogen content of Chardonnay grape juice from Tumbarumba in 2003-2004 vintage.

9.3.5 Sensory analysis

Duo trio test on the 2002-2003 wines made from Wagga Wagga fruits showed a difference between the vegetated and unvegetated treatments at the 10% level. There was no difference between the other treatments. For the Tumbarumba site, a difference was also found between wines from partially vegetated and vegetated treatments at the 10% level.

No difference was found between the 2003-2004 wines made from the Wagga Wagga site. However, for the same vintage, the wines made from the partially vegetated treatment were found to be different from the other two treatments for the Tumbarumba site at the 10% level.

The Wagga Wagga Wines from 2004-2005 showed a difference between partially vegetated and unvegetated treatments at the 10% level and the wines from unvegetated and partially vegetated treatments were also found to be different at the 10% level.

9.4 Conclusion

After a period of 4 years, growing and mowing floor vegetation in the vineyard increased TSS while preserving a low pH. There were lower levels of total nitrogen in the berries obtained from the vegetated treatment while the unvegetated treatment had higher levels of total nitrogen content in juice. Although the variation in total nitrogen content did not significantly affect the fermentation, there was a trend toward an increased likelihood of incomplete alcoholic fermentation. The vineyard floor management treatments had more effects on berry composition at Wagga Wagga compared to Tumbarumba. For each year, except the Wagga Wagga site in 2003-2004, sensory analysis of the wines made from the vegetated treatment showed a difference from the other two treatments.

9.5 References

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10. Conclusion

Describe how your project performed against planned outputs and performance targets.

This project examined the effect of three different ground cover treatments on the plant, insect and soil microbial diversity in two climatically different Chardonnay vineyards, and how these impact on grape and wine quality.

The main outcomes from this investigation were:

- Increasing the level of mid-row vegetated ground cover decreased soil moisture and petiole nutrient status, and strongly reduced vine growth.
- After three years, grape yield became limited, and after four years, the grape composition was also altered. Wine evaluation and analysis is in progress. These effects were much stronger under hot than mild climatic conditions.
- Reduced herbicide use increased the soil organic matter and microbial diversity in the 0-10 cm soil layer.
- There was a slight increase of beneficial and decrease of parasitic nematodes with reduced herbicide use.
- There was also some evidence of increased abundance of natural enemies like ladybird and rove beetles, lacewings and wasps with reduced herbicide use.
- Some weed species, known to have the potential to develop herbicide resistance, became more abundant with increased herbicide application.
- Ecological studies that involve altered agronomic practices require a longer time frame than the traditional 3-year funding cycle to detect significant changes in biodiversity.

Provide an assessment of the practical implications of the research results for the Australian grape and wine industry.

Grape production systems in Australia are, by world standards, of low chemical input. However, European and Japanese markets are becoming increasingly sensitive to chemical usage in food and beverage production, requiring vignerons to pursue best practice management based on low pesticide input.

Australian vineyards have traditionally controlled weeds by using repeated cultivation in combination with herbicides. However weed control in vineyards, when poorly managed, has the potential to be very expensive, environmentally damaging and detrimental to vine productivity and grape quality.

Appropriate floor management practices that are linked to integrated pest and disease management and closed nutrient cycles are a means of overcoming dependence on herbicides for weed control. Reducing chemical inputs in this manner is an essential first step for successful implementation of sustainable production systems that maintain such complex viticultural ecosystems.

Creating an environmentally sustainable viticultural production system raises the issue of sward-vine interaction, which is an indirect result of reducing herbicide use and soil cultivation. Maintenance of mid-row grass swards in vineyards to produce high levels of biodiversity, sustained soil fertility and minimal unintended environmental side effects were investigated as a means to meet environmental requirements that would consolidate the 'clean and green' image of the Australian wine grape industry.

This study examined sward-vine interactions on irrigated Chardonnay grapevines by investigating three vineyard floor management treatments commonly used in Australia: (1) vegetated where floor vegetation was managed through mowing and no herbicide applications (2) partially vegetated comprising an under vine herbicide strip spray and mowing of inter-row vegetation, and (3) unvegetated involving removal of all floor vegetation by herbicide spray. These were monitored in a hot dry environment at Wagga Wagga and a cool climate vineyard at Tumbarumba.

We examined how vineyard floor vegetation management impacts on vineyard sustainability and whether inputs, like chemical inputs can be reduced while maintaining optimal grape production. To achieve this we monitored (a) shifts in vine water use, vigour, fruit quality and yield due to competition from competing plant species within the vineyard production system, (b) changes in weed species composition due to the use of herbicides and (c) impacts of treatments on soil-borne biota and arthropod biodiversity. This information will underpin the development and promotion of a sustainable low input integrated vineyard management system for vineyard managers.

Viticultural impact of vineyard floor management treatments

We have investigated how these treatments compare between hot dry and mild semi-humid climatic conditions and have shown that a permanent vineyard sward causes a striking decrease in Chardonnay vigour and yield in the hot and dry climate in comparison with a mild and semi-humid climate.

Increasing ground cover vegetation decreased early-season soil moisture and petiole nutrient status, and strongly reduced vine vegetative growth, particularly in the hot climate site at Wagga Wagga. After three years, grape yield also became limited. Large treatment differences in vegetative growth, canopy structure and yield contributed to differences in berry weight and composition observed between the two distinct climatic zones. Vine response to ground covers was less pronounced under the mild climatic conditions at Tumbarumba where no reduction in berry yield or composition was recorded because water was not limiting.

From a grape grower's perspective, most effects of vineyard sward described in this report, particularly in the warm dry Wagga Wagga vineyard, would seem negative. The decreased cost of not using herbicides would probably not offset the decrease in grape yield observed in hot arid environments. It would, however, be too simplistic to recommend maintaining bare soil with herbicides as a sustainable option in such conditions, as there could be other unintended negative effects associated with the use of herbicides, as seen in this study on soil micro-organisms.

After 4 years, comparison of different floor management treatments showed that growing site adapted cover crops in vine inter-rows increased Brix and maintained a low pH of the grape juice produced in warm climate vineyards, but this effect was not evident in grapes produced from the same treatment in the cool climate vineyard.

Generally, total berry juice nitrogen levels obtained from grapes produced in the cover crop treatments were lower than those recorded in the bare soil treatment. The decreased total nitrogen and pH and increased Brix levels in berry juice expressed from fruit grown in the full ground cover treatment extended the time for ferments to reach dryness and the resultant wines were assessed to be organoleptically different by a trained sensory panel. Although not significant, greater turbidity was observed in wines produced from the vegetated slashed-

sward treatment. This was attributed to the lower levels of protein stability evident in these wines.

Despite the potential drawbacks observed with use of total or partial ground covers using site adapted grasses in the vineyard floor inter-row, this technique was shown to be a powerful tool for controlling vegetative growth of grapevines. However, under hot and dry conditions, competition for water and nutrients, particularly if it occurs at sensitive growth stages (eg. flowering and berry set), can lead to a substantial decrease in vine yield. Therefore, this strategy of achieving vine balance would need to be modified according to the environment in which it is practised.

Alternative ground covers, pasture grasses and/or use of mulches need to be examined in the future for weed management, since floor covers can provide a viable option for accomplishing long-term environmental sustainability while reducing chemical inputs and achieving economic yields and favourable fruit composition. When using cover crops, mowing to decrease water use will be important and it was also evident that irrigation amounts in vineyards with floor covers will have to be adjusted due to the demand of increased biomass production, particularly if competition for water and nutrients occurs at sensitive growth stages of the developing wine grape crop (eg. flowering and berry set), when it can lead to a substantial decrease in vine capacity. These outcomes reflect aspects of environmental stewardship the Australian wine industry is endeavoring to pursue to produce high quality wines in an environmentally sensitive manner.

To further overcome negative effects of the excessive sward-vine competition, foliar nitrogenous fertilisers could be used to reduce sward-vine competition for nutrients. However, adding N fertilisers in any form is a management option that needs consideration, especially in the early establishment phase of mid-row vegetated swards. Armed with these tools, total or partial floor cover could be a powerful tool for controlling vegetative growth of grapevines.

Observations over a number of consecutive seasons will be essential to ascertain the consistency of applied treatments, since a cumulative effect of multiple seasons of applied treatments was evident. This observation warrants further investigation because current results indicate a very strong effect of seasonality on all components of the vineyard ecosystem in addition to its effect on vine growth and cropping.

Impact of vineyard floor management treatments on soil microbiology

Soils contain significant populations of microorganisms with the ability to attack or suppress plant pathogenic fungi, and disease suppression in some crops has been observed in soils with high organic matter content. However, disease suppressive soils capable of exerting natural biocontrol of plant pathogens have not been investigated in viticulture. The ability of soil microbes to directly compete with pathogens in the rhizosphere was investigated with the aim of improving 'soil health'. The populations of soil microbes under different vineyard cultural practices were monitored, with an emphasis on microbial biodiversity, suppression of soil borne disease and the possible increase in nutrient uptake by vines.

This investigation revealed that reduced use of herbicide and increased soil organic matter contributions from cover cropping with site adapted grasses increased the microbial biodiversity of the soil. Permanent swards increased the labile organic carbon levels (hot water extractable carbon - HWC), both in the inter-row and the under-vine soils at both Tumbarumba and Wagga Wagga. At the same time, the populations of soil bacteria were markedly higher in the sward than the bare soil and the total fungal population was increased in the sward inter-row soil. The population of biological agents such as *Verticillium chlamydosporium* (a fungus that parasitise eggs of root knot nematodes), *Mononchus* spp. and *Aporcelaimellus* spp. (predatory nematodes that prey on other nematodes) were predominant in vineyard soils with higher levels of organic matter due to the presence of inter-row cover crops and/or grasses. Most of the bulk soil and rhizosphere microbial populations were positively correlated with soil organic carbon (HWC). These biological control agents can enhance healthy vine growth by minimising root injury caused by pest nematodes, thus reducing root infections from fungal pathogens. Therefore, abundance of biological agents that suppress parasitic nematode activity in the vineyard soil can enhance healthy vine growth.

Beneficial nematodes, namely bacteria feeders; omnivores; fungi feeders and predators were also more abundant in the top 0-10 cm soil in inter-row positions than the under-vine positions. A consistent decrease of plant parasitic nematodes in the top 0 -10 cm soil layer suggested that natural enemies or antagonists of plant parasitic nematodes may have been enhanced with the addition of organic matter in this study. An overall increase of predatory nematodes both in the 0 -10 and 11 -20 cm soil layers may also be the reason for the decrease in population of plant parasitic nematodes observed in this study. There were slight increases

of beneficial nematodes in plots without herbicide application compared to the plots with herbicide application. In contrast, higher population densities of plant parasitic nematodes were recorded from the under-vine positions and their presence was greater in the 11-20 cm soil layer than the top 0-10 cm soil layer.

After only three seasons the increase of beneficial nematodes, particularly bacteria feeders and predatory nematodes in the top 0-10 cm soil layer, decreased the density of plant parasitic nematodes in the vine-line. However, more observations over another 3-5 years would be needed to demonstrate the potential use of beneficial nematodes as an indicator for good soil and vine health.

It has been suggested that microbes with competitive, predaceous and antagonistic nature may increase after addition of organic matters or amendments in soil with consequent decrease of plant diseases including pest nematodes, but this remains to be evaluated. Results from this preliminary investigation have revealed that the number of beneficial nematodes can be increased with a consequent decrease in the proportion of plant parasitic nematodes present in the soil after adding organic matters from mid-row ground covers in vineyards.

This study also demonstrated that there was a seasonal effect on the population abundance of beneficial nematodes in soil. The population densities were always higher in spring/summer than the autumn/winter seasons. This implies that temperatures are more favourable for nematode development in spring/summer in conjunction with the increase in organic matter that occurs during this period. It should be noted that food sources will also be more available for beneficial nematodes at this time following the decomposition of organic matters that were added from mowing mid-row ground covers in early spring. However, it will require more observations over a longer period of time to demonstrate whether beneficial nematodes can be used as an indicator of soil health in vineyards. Choice of ground cover is also important as some grasses and cover crops are hosts of plant parasitic nematodes.

Impact of vineyard floor management treatments on insect biodiversity

In this study we used pitfall and sticky traps to quantify changes in arthropod biodiversity between treatments to identify arthropod species and groups that could be useful bioindicators. Approximately 60% of all species collected at both vineyards come from three insect orders, Hymenoptera (wasps, bees and ants), Diptera (flies) and Coleoptera (beetles).

Spider biodiversity was also high at both sites accounting for about 15% of total species trapped. However, very few insect and mite pests of grapevines were collected in pitfall traps, with most species being beneficial or not harmful.

There was no strong or consistent impact of any of the vineyard floor management treatments on overall arthropod species richness, abundance or biodiversity. High levels of variation between and within treatments were recorded for individual orders or species. There was some evidence of increased springtail and ant abundance in complete cover herbicide spray treatments, and increased abundance of natural enemies like ladybird and rove beetles, lacewings and wasps in slash and partial spray treatments. However, Rutherglen bug was consistently more abundant in slash than complete spray treatments at Wagga Wagga. This suggests that some predators and parasitoids responded positively to the presence of vineyard floor vegetation. Nevertheless, it was evident that these investigations needed to run over a longer time frame to detect population changes that were significantly different.

The placement of sticky traps in the canopy or on the vineyard floor influenced the capture of wasps, ladybird and rove beetles and brown lacewings. In general, floor traps captured more wasps, the ladybird beetles *D. notescens*, *C. transversalis* and *H. variegata*, and rove beetles whereas brown lacewings and the ladybird beetle *H. conformis* were more abundant in canopy traps. These results suggest that natural enemies have different flight behaviours and may have different patterns of resource use. They also suggest that some ladybird beetles and rove beetles are not common in the vine canopy and therefore may not be significant natural enemies of grapevine pests. However, another possible explanation for their low abundance in canopy traps is that these species may conduct most of their movement in the canopy on the vine surface rather than in the air. In contrast, the ladybird beetle *H. conformis* was more abundant in canopy traps indicating that different species within the same group of beneficial insects can have vastly different ecology and behaviour.

Vineyard floor management practices may also affect the abundance of beneficial insects that live above ground and thus affect levels of pest biological control. To assess whether use of site adapted ground cover species increased presence of beneficial insects for the control of grapevine moth in vineyards, the composition and abundance of beneficial insects in vineyards with slash and complete spray floor management treatments was compared and quantified. Beneficial insects were abundant in both vineyards but there was only minimal or

weak evidence of any effect of floor management treatment on overall beneficial insect abundance or on levels of biological control within the three year time frame of this study.

Collections from both pitfall and sticky traps showed some evidence of increases in the abundance of beneficial insects such as rove beetles, lacewings, wasps and perhaps also ladybird beetles in the slash treatment. Results suggest that future insect biodiversity studies in Australian vineyards should concentrate on selected abundant species from a range of arthropod groups rather than quantify changes in the biodiversity of all species or functional groups of arthropods. Future studies must also consider plot size and replication because both may have been inadequate in the current study to detect changes in many arthropod species. They should also take into consideration the timing of such investigations since overall biodiversity was found to be significantly higher during spring than at any other time during the year.

Plant feeding bugs like Rutherglen bug, springtails, ants and some of the beneficial natural enemies like wasps, predatory beetles and lacewings appear to be the most responsive and abundant bioindicators. Vineyard managers may therefore be able to increase populations of some beneficial insects by maintaining a vegetated vineyard floor. However, this recommendation may have limitations as results are of a preliminary nature from only two vineyards in New South Wales and therefore further research is needed to test these observed trends in other Australian vineyards. Further research is also needed to assess the influence of floor management practices and vegetation on levels of biological control in the vineyard. Many studies have demonstrated the positive influence of flowering vegetation on beneficial insect abundance in many cropping systems, yet few studies have taken the next step to determine if there is a positive influence on levels of pest control.

Impact of vineyard floor management treatments on botanical diversity

Traditionally, weeds under drip-irrigated vines are routinely sprayed with herbicides because they compete for water and nutrients and may reduce vine vigour, yield and quality. This study showed that repeated spraying of glyphosate to the complete vineyard floor or to the vine line increased the abundance of some weed species relative to the use of slashing for weed control. Although obscured by inter-annual and between-treatment variation in species composition, botanical analyses indicated that, in general, removal of all floor vegetation by herbicide reduced the species diversity and abundance of groundcover plants in vineyards.

This was also true to a lesser extent in partially vegetated plots comprising an under vine herbicide strip spray coupled with mown inter-row vegetation. Conversely, the effects of maintaining a fully vegetated vineyard floor, managed through mowing with no herbicide applications, had a more subtle impact on these attributes.

One of the major differences in species composition between the two experimental vineyards was the absence of *Poa annua* from the hot and dry Wagga Wagga vineyard, and the contrasting abundance of this species in the cooler, mild climate of the Tumbarumba vineyard. Overall, however, there was much overlap in terms of species occurring at the two localities. From the general decline in species diversity and abundance under spray treatments at both sites, it is likely that the application of herbicide under vines is a highly effective means of minimising competition between vines and weeds for water and nutrients. Conversely, the results of this study support the idea that mowing of mid-row areas is a simple and cost-effective means of providing the agricultural ecosystem of the vineyard with species diversity.

Present results suggest that certain weed species are becoming more abundant under vines that are frequently sprayed to maintain weed-free conditions. Wire weed *(Polygonum aviculare*) has colonised the under-vine area in the complete spray out treatment, representing over 50% of the species found there. It is evident that the increased presence of these weeds in vineyards under herbicide management is a significant biological indicator of the negative impact that herbicides have on plant biodiversity in vineyards.

Some of the commonly found species resistant or tolerant to glyphosate include annual ryegrass, mallows, stocksbill, wireweed, goosefoot, peppercress, shepherd's purse and skeleton weed. These species increased in dominance over time and have the potential to develop herbicide resistance. Although the increased presence of these weeds it is already evident in vineyards under herbicide management, more time is needed to monitor the long-term impact of this change in weed species mix. They could however, serve as a significant biological indicator of the negative impact of herbicides on vineyard biodiversity.

11. Outcomes and Recommendations

Outcomes - general

The role of the mid-row area in vineyard needs further definition. This will vary according to geographical location, soil type, climate, irrigation system, vineyard age, variety, rootstock, establishment techniques and management preferences.

The growth of competitive cover crop species using good agronomic practice can effectively suppress the growth of most winter weed species. Native perennials might provide a viable alternative to the use of conventional cover crops as weed suppressants.

This project has extended previous work into a systems based approach to floor management, where the impact of practices designed to reduce weed growth has been quantified in terms of effects on grapevine yield and must quality.

Grower verification through on-farm trials to test the validity of these research outcomes over a range of environments is now required and should lead to the adoption of many practices, which ultimately will reduce herbicide usage in Australian viticulture.

This project has produced a number of specific outcomes, which are listed below.

1. Increasing ground cover vegetation decreased early-season soil moisture and petiole nutrient status, and strongly reduced vine vegetative growth and subsequent yield, particularly in the hot climate vineyard site.

2. Vine response to ground covers was less pronounced under the milder climatic conditions where no reduction in berry yield or composition was recorded because water was not limiting.

3. Use of total or partial ground covers of site adapted grasses in the vineyard floor inter-row was a powerful tool for controlling vegetative growth of grapevines. However, under hot and dry conditions, competition for water and nutrients, particularly if it occurs at sensitive growth stages can lead to a substantial decrease in vine yield. Therefore, this strategy of achieving vine balance would need to be modified according to the environment in which it is practised.

4. In warm climate vineyards, vegetated vine inter-rows increased Brix and maintained low grape juice pH, but this effect was not evident in grapes produced from the same treatment in the cool climate vineyard.

5. The decreased cost of not using herbicides would probably not offset the decrease in grape yield observed in hot arid environments.

6. Soil microbial biodiversity was enhanced due to increased soil organic matter contributions from cover cropping with site adapted grasses following reduced use of herbicides.

7. The density of beneficial nematodes (particularly bacteria feeders and predatory nematodes) increased after adding organic matter contributed from mid-row ground covers in vineyards.

8. There was no strong or consistent impact of any of the vineyard floor management treatments on overall arthropod species richness, abundance or biodiversity.

9. Presence of vineyard floor vegetation increased the abundance of some natural enemies (predators and parasitoids) like Rutherglen bug, ladybird and rove beetles, lacewings and wasps.

10. Plant feeding bugs like Rutherglen bug, springtails, ants and some of the beneficial natural enemies like wasps, predatory beetles and lacewings appear to be the most responsive and abundant bioindicators.

11. Botanical analyses indicated that removal of vineyard floor vegetation by herbicide reduced the species diversity and abundance of groundcover plants in vineyards.

12. Repeated spraying of glyphosate to vine mid-rows or to the vine line increased the abundance of some weed species, but also reduced overall species diversity that minimized competition between vines and weeds for water and nutrients.

Recommendations

1. The role of the mid–row in vineyards of the many regions of Australian viticulture needs to be defined. If it is found to provide significant benefit to the vines, then it should be managed accordingly, with cover crops selected, grown and managed to serve the requirements of the vine.

2. Native perennial ground covers and grasses may have considerable potential as mid-row cover crops. They seem well adapted to a wide range of environments, and their water use and weed competitiveness suggests they could be well suited to vineyards.

3. Alternative ground covers, or pasture grasses and mulches need to be examined in the future for weed management, since vegetated vineyard floors can provide a viable option for accomplishing long-term environmental sustainability while reducing chemical inputs and achieving economic yields and favourable fruit composition.

4. Increased vegetative cover of vineyard mid-rows reduced the level of available water for vine growth (increased the soil moisture tension). This effect varied with time of season, vineyard site, measurement position within and between vine rows and root zone depth.

5. When using cover crops, mowing to decrease water use will be important and increased irrigation volumes in vineyards with floor covers will be required to support the increased overall biomass production, particularly if competition for water and nutrients occurs at sensitive growth stages of the developing wine grape crop when it can lead to a substantial decrease in and vine capacity.

6. Nutrient status of vines growing in competition with floor cover crops should be closely monitored since the sward-vine competition for available water leads to a decrease in soil moisture content, and consequently nutrient uptake is decreased.

7. The effect of mid-row vegetation on vine vigour can be estimated from correlations of petiole N content at flowering and mean November soil moisture tension with final shoot length. We conclude from these observations that sward-vine competition for nutrients is more important in soils with ample water availability, while under drier conditions the soil moisture effect became predominant.

8. The cost savings arising from the elimination of herbicide use associated with maintenance of vegetated vineyard mid-rows would not offset the decrease in grape yield observed in hot/dry climates.

9. A number of approaches exist to overcome a reduction in grape yield resulting from the transition from a clean vineyard floor to using partial or total floor cover. Mowing, for example, generally decreases water use by cover crops and species that are not characterised by intensive spring growth might be preferred as cover crops in addition to use of winter active/summer dormant species.

10. Use of drought tolerant grapevine rootstocks to minimise the effects of sward-vine competition for soil moisture should be considered. Changes in irrigation management could also mitigate some of the perceived negative aspects of the use of floor covers while preserving the positive effects.

11. There is a need to study long-term effects of vineyard soil management systems since the ability to increase soil organic matter content is vital for a successful implementation of herbicide-free viticulture. Sufficient time must be allowed for modified cultural practices to achieve ecological balance.

12. Results suggest that future insect biodiversity studies in Australian vineyards should concentrate on selected abundant species from a range of arthropod groups rather than quantify changes in the biodiversity of all species or functional groups of arthropods.

13. Future insect biodiversity studies should also consider plot size and degree of replication because both may have been inadequate in the current study to detect changes in many arthropod species. Timing of such investigations should also be considered, since overall vineyard biodiversity was found to be significantly higher during spring.

14. The outcomes of this work need to be transferred to the grower community. This requires an active extension process to disseminate the information.

12. Appendices

12.1 Communication

12.1.1 Communication within the project

Team meetings were regularly held to coordinate project activities and to generally manage the project to meet its objectives. Tasks were allocated to all team members and regular internal communication between participants ensured the timely and efficient execution of all activities necessary to produce the specified outputs scheduled in the workplans submitted in annual reports to GWRDC.

12.1.2 Communication with project stakeholders (GWRDC, R&D agencies and industry reference groups)

Reports on the project were prepared regularly for project stakeholders. These included progress and annual reports for GWRDC and the project's lead agency (NSW DPI).

Presentations and notes on the progress and outcomes of work in the project were presented in industry workshops and symposia. Most of the R&D activities in the project also involved regular interaction between project staff and staff of key industry organisations at each location.

12.1.3 Communication with industry and scientific audiences

Information about the progress and outcomes of R&D on vineyard floor management and its optimal use in management programs for control of spring vegetative vigour in vineyards was communicated to scientific and industry audiences through numerous industry publications and presentations (see 12.1.4.2).

12.1.4 Publications

12.1.4.1 Scientific publications (refereed)

12.1.4.1.1 Journal publications

Whitelaw-Weckert, M., Hutton, R., Rouse, E. and R. Lamont. (2004): The effect of herbicides and permanent swards on microbial populations in the vineyard. In: *Supersoil 2004*: Program and Abstracts for the 3rd Australian New Zealand Soils Conference, University of Sydney, Australia, 5-9 December 2004. (Ed Singh, B). www.regional.org.au/au/asssi/supersoil2004_pp).

Whitelaw-Weckert, M.A. and N. Coombes. (2005). Lower soil microbial biomass from long-term herbicide use in a warm climate vineyard. *Soil Biology and Biochemistry*. (under revision for Soil Biology & Biochemistry, October 2005).

Tesic, D., Keller, M. and R. Hutton. 2006. Vineyard floor management practices affect grapevine vegetative growth, yield and fruit composition. *American Journal of Enology and Viticulture.* Accepted 26/6/06.

Whitelaw-Weckert, M.A., Rahman, L., Hutton, R. and N. Coombes. (2006). Permanent swards increase soil microbial counts in Australian vineyards. *Applied Soil Ecology*. Submitted 4/7/06.

12.1.4.1.2 Industry journal publications

Weckert, M. A. (2002). Vineyard microbial soil health, *The Australian & New Zealand Grapegrower & Winemaker,* 464 September 2002 pp. 21-24.

Rahman, L., Smith, R., Lamont, R. and Hutton, R. (2003). Floor management systems to reduce vineyard inpiuts and improve grape quality: Abundance of beneficial nematodes. *The Australian & New Zealand Grapegrower & Winemaker,* 478: 21-24. November, 2003.

Smith, R., Lemerle, D. and Hutton, R. (2003). Improved management of weeds under drip-irrigated vines. *The Australian & New Zealand Grapegrower & Winemaker,* 475 August 2003 pp. 17-20.

Weckert, M., Smith, R., Rahman, L., Loch, A., Holloway, J., Lemerle, D., Tesic, D., Meunier, M and Hutton, R. (2003). Floor management systems to reduce vineyard inputs and improve grape quality. *The Australian & New Zealand Grapegrower & Winemaker,* 473 June 2003 pp. 39-40.

Hutton, R. (2006). Vineyard floor groundcover affects vine growth and beneficial soil micro-organisms. *The Australian & New Zealand Grapegrower & Winemaker,* 511 August 2006 (in press).

12.1.4.2.1 Technical publications (including conference papers and abstracts, industry journal articles, andnotes for industry field days and discussion groups) (non-refereed)

Hutton, R. and G. Small. (2002). Floor management for sustainable viticulture, *Farmer's Newsletter.* IREC No 186 winter 2002 pp. 24.

Weckert, M.A. (2002). Soil Health and Microbial diversity in the vineyard, *Farmer's Newsletter.* IREC No 186 winter 2002 pp. 32-33.

Weckert, M., Smith R., Rahman L., Loch A., Holloway J., Lemerle D., Tesic D., Meunier M. and R. Hutton. (2003). Floor management systems to reduce vineyard inputs and improve grape quality. In: *Grapevine Management Guide 2003-2004,* NSW Agriculture, pp. 51-53.

Loch, A.D. (2004). Vineyard floor vegetation influences the abundance of winged natural enemies. Poster presentation *at Australian Wine Industry Technical Conference,* Melbourne. 25-28 July 2004.

Loch, A.D. (2004). Vineyard floor vegetation influences the abundance of winged natural enemies. Poster presentation. *XXII International Congress of Entomology,* Brisbane. 15-21 August 2004.

Rahman, L. (2004). Nematode diversity under different cover crop management practices in vineyards. *Proceedings 12th Australian Wine Industry Technical Conference,* Melbourne, Victoria, 280p.

Weckert M.A. (2004). In vitro inhibition of grapevine root pathogens by vineyard soil bacteria and actinomycetes, *3rd Australasian Soilborne Disease Symposium.*

Tesic D. (2005). Vineyard floor management - balancing inputs. *2005 National Sustainable Viticulture Seminar – Protecting Profitability.* Mudgee, NSW. 23 June 2005.

12.1.4.2.2 Other Technical Publications (non-refereed)

Hutton, R., Small, G. and D. Lemerle. (2002). Defining the sustainable vineyard, *Wagga Wagga Agricultural Institute Update.* 2002 ISBN 07347 1419 pp76-77.

Rahman, L. (2002). Abundance of beneficial nematodes under different floor management practices in vineyard, *Wagga Wagga Agricultural Institute Update.* 2002 ISBN 07347 1419 pp. 80.

Weckert, M. (2002). Vineyard microbial soil health, *Wagga Wagga Agricultural Institute Update.* 2002 ISBN 07347 1419 pp78-79.

Smith, R. (2003). Making wine the clean green way. *Agriculture Today.* NSW Agriculture's advisory, management and research newspaper. A supplement of The Land Newspaper. October, 2003.

Rahman, L. and Hutton, R. (2004). Nematode community structure under different floor management practices in vineyards. In: *Wagga Wagga Agricultural Institute Update*. pp. 65-66.

Rahman, L. (2006). Population abundance of pest- and predatory-nematodes under different floor management practices in vineyards. In: *Wagga Wagga Agricultural Institue Update.* (in press).

12.1.5 Presentations

Hutton, R.J. (2002). Floor Management Systems for Sustainable Viticulture. Poster Presentation. *NWGIC Industry Symposium.* Wagga Wagga. 21 June 2002

Rahman, L., Lamont, R., Smith, R. and Hutton, R. (2002). Effects of herbicide on the beneficial nematodes in vineyards. Poster presentation. *NWGIC Industry Symposium,* Wagga Wagga, NSW. 21 June 2002.

Weckert, M.A. (2002). Soil Health and Microbial diversity in the vineyard. Workshop. *NWGIC Industry Symposium,* Wagga Wagga. 21 June 2002.

Weckert, M.A. and L. Rahman. (2002). Bugs in Soil. Workshop. *NWGIC Industry Symposium,* Wagga Wagga. 21 June 2002

Loch, A.D. (2003). Enhancing pest management through biodiversity. Oral presentation. *NWGIC Industry Symposium,* Wagga Wagga. 19 June 2003.

Loch, A.D. (2003). Biodiversity of insects and other arthropods in the vineyard. Poster presentation. *NWGIC Industry Symposium,* Wagga Wagga. 19 June 2003.

Loch, A.D. (2003). Enhancing pest management through biodiversity. Oral presentation. *NWGIC Industry Symposium,* Wagga Wagga. 19 June 2003.

Meunier, M. and R. Smith. (2003). Effect of floor treatments on wine quality. Workshop. *NWGIC Industry Symposium,* Wagga Wagga. 19 June 2003.

Rahman, L., Lamont, R., Smith, R. and R. Hutton. (2003). Effects of herbicide on the beneficial nematodes in vineyards. Workshop. *NWGIC Industry Symposium,* Wagga Wagga. 19 June 2003.

Small, G. and R. Hutton. (2003). Defining the sustainable vineyard. Oral presentation. *NWGIC Industry Symposium,* Wagga Wagga. 19 June 2003.

Smith, R, Lemerle, D and A. Smith. (2003). Are weed flora influenced by vineyard floor treatment? Poster presentation. *NWGIC Industry Symposium,* Wagga Wagga. 19 June 2003.

Weckert, M. (2003). Vineyard soil health: Improving the 'suppressiveness' of soils. Oral presentation. *NWGIC Industry Symposium,* Wagga Wagga. 19 June 2003.

Loch, A.D. (2004). Vineyard floor vegetation influences the abundance of winged natural enemies. Poster presentation. *NWGIC Industry Symposium,* Wagga Wagga. 24 June 2004.

Tesic D. (2004). Vineyard floor management and vine performance workshop. *NWGIC Industry Symposium,* Wagga Wagga. 24 June 2004.

Tesic D. (2006). Floor management - vine response and implications for industry adoption. *NWGIC Industry Symposium,* Wagga Wagga, 22 June 2006.

Smith, R,. Lemerle, D. and R. Hutton. (2005). Improved management of weeds under drip-irrigated grape vines. Oral presentation, International Weeds Conference. September, 2005.Wagga Wagga. NSW.

Rahman, L. (2006). Permanent sward increases beneficial and decreases harmful nematodes in vineyards. Poster presentation. NWGIC Industry Symposium, Wagga Wagga, NSW.

12.2 Intellectual property

No ‘commercial in confidence’ intellectual property was produced from R&D in this project. However, information in this report is confidential to project stakeholders until it is published.

12.3 References

References cited in this report are listed at the end of each chapter.

12.4 Project staff

Names, affiliations and the location of staff contracted to conduct R&D on the project are listed below. Authors of this report (listed at the front of the report) include these staff and other contributors. Contracted staff engaged on this project from 2001-2005 were a Technical Officer (1 FTE) and a part-time casual Assistant. The Technical Officer position was held by Mr David Forster from 2001 to March 2002, Ms Rhonda Smith from April 2002 to January 2004 and Ms Emily Rouse from February 2004 to March 2005. Temporary assistance was provided by Mr Andrew Smith for the duration of the project. He was engaged for approximately 15 weeks each year.