Murray Valley Winegrowers' Inc

Australian Government
Grape and Wine Research and Development Corporation

Soil Health –
Developing an Understanding



FINAL REPORT to
GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION

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Organisations: **Murray Valley Winegrowers' Inc.**

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Executive Summary

Soil Health is defined as the capacity of a living soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health (Doran *et al*. 1996; 1998).

Sustainable production is a critical issue for winegrape growers in the Murray Valley. The concept of "soil health" has been recognised by growers for its potential to buffer extreme climate changes and has challenged current viticulture management practices

The aim of this project was to investigate and develop an understanding of the biological component of soil health. It was the expectation that this investigation would allow the development of techniques that could be used in the vineyard for improvements in vine health and fruit quality.

A literature review was commissioned to develop an understanding of soil health research relating to soil biology and viticulture. The review was finalised in January 2008 and covered the following headings:

1. What microbial populations are found in agricultural soils?
2. What conditions/ factors affect soil biota populations?
3. Effects of soil biota on soil health, vine health and fruit quality.
4. Measuring soil biota populations in the vineyard.
5. Soil biota testing facilities – Australian laboratories.
6. Interpretation of results.
7. Techniques to increase soil biota activity.
8. Recommendations for the Murray Valley.

In the 2007/08 season, a demonstration trial investigating four treatments (permanent sward, compost, microbial solution and compost plus the microbial solution) and a bare soil control began. The aim was to investigate management practices that may improve soil biology and thus positively impact vineyard productivity.

The trial suffered set backs in regards to water availability with only 43 % water allocation delivered to growers in the 2007/08 season. While the trial site was being irrigated by low level sprinklers irrigation, the permanent sward did not grow well. The trial results were varied, without showing clear treatment trends; however, the fruit quality results indicated that the compost treatment was improving vineyard water retention, resulting in larger berry size. This was confirmed through visual observation. The compost results were the only results consistent with the "expected" outcomes of this trial. The water and industry situations resulted in the demonstration trial block being placed on the market at the end of the season, causing a sudden end to the trial.

In 2008/09, a new demonstration trial was developed, looking at quantifying the type of biology in the soil, through principles of the soil food web and using new parameters to manipulate production outcomes. This trial investigated the multiplication and reintroduction of soil biology namely bacteria and fungi to create a favorable soil environment, with the expected results including an increase in soil moisture holding capacity, nutrient cycling capacity and suppression of disease.

This trial was delayed by the late arrival of equipment and still requires more work to develop plausible results, however the theory behind this trial shows merit and given longer-term application and observation this trial could produce positive results that may assist growers to reduce input costs and manage changes in climate.

- Doran JW, Sarrantonio M and Liebig MA, 1996. Soil health and sustainability, *Advances in Agronomy*, **56,** 2-54.
- Doran JW, Elliott ET, Paustian K 1998 Soil microbial activity, nitrogen cycling, and long-term changes in organic carbon pools as related to fallow tillage management, *Soil & Tillage Research*, **49(1),** 3-18

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- Dr. Nicole Dimos

Background

In 2006/07 winegrape growers in the Murray Valley gave an 80% approval rating to a project investigating soil health in vineyards funded by the Murray Valley Winegrapes Industry Development Committee. Co-funding was sort from and approved by GWRDC for a two year period.

Healthy soils function to sustain biological activity, breakdown organic matter, hold water and nutrients and suppress pathogens.

Soil Health was seen by growers as a critical component of sustainable production and growers were looking for new management techniques that would allow improvements in fruit quality and maintain future viability of winegrape production in the Murray Valley.

Due to unforseen circumstances the project was not started until the 2007/08 season.

The 2007/08 season experienced decrease water availability in Victoria with only a 43% water allocation received. This season also experienced elevated temperature impacts which detrimentally affected fruit quality.

In 2008/09 the project was located on the NSW side of the Murray River, with NSW growers receiving a 95% water allocation while Victorian growers received a 35% water allocation for the season. Two weeks of extreme temperatures were experienced in the vineyard just prior to harvest which severely affected fruit, resulting in reduced crop load, poorer fruit quality and in some cases fruit rejection.

Soil Health has become a hot topic amongst growers, with early expectations of this management technique including the ability to buffer and reduce the severity of extreme events, such as low water availability and the impacts of excessive temperatures.

Project Objectives

1. To develop a Literature review investigating scientific research conducted on soil health and the impact that soil health has on the productivity and environmental sustainability of the vineyard.
2. To develop a number of small trials demonstrating techniques to improve and maintain soil health; to measure impacts on the productivity and environmental sustainability of the vineyard.
3. To develop a number of field walks at different times during the season to observe the progress of the soil health treatments. Field walks will also provide the opportunity to present the results of the literature review and provide practical soil health information to growers.
4. To determine the level of adoption of soil health principles by growers' in their own vineyards.

Method

Literature Review

Dr. Nicole Dimos was contracted on a private basis to research and compile a soil health literature review incorporating the following points.

1. The types of microbial populations found in agricultural soils. Which microbial populations are deemed to be beneficial and which are deemed to be detrimental to soil health?
2. The implication of microbial population numbers i.e. what is the meaning of microbial population levels?
3. What conditions/factors affect microbial population fluctuation e.g. temperature, nitrogen, cultivation, compaction etc.
4. The effect microbial populations have on soil health and the implications of this for vine health and fruit quality parameters.
5. A "how to: guide measuring microbial populations in the vineyard. For example, where to take the sample for the best representative results, how much soil is required, what storage conditions are required to keep the sample viable etc.
6. What type of testing should be specified when sending samples to a laboratory? Where are suitable laboratories located? Cost? Would the sampling techniques vary from lab to lab and what are the implications of this?
7. Interpretation of sample results.
8. A comparison of soil health techniques that could potentially be used to improve soil health, beneficial soil microbial populations, vine health and fruit quality e.g. cover crops, mulching, microbial liquids such as BioAg soil & seed etc.
9. Recommendations for the use of soil health techniques in the Murray Valley divided into light, medium and heavy soil types.

The literature review is located in Appendix 1.

Soil Health Trial – Year 1

Aim: To improve soil health and thus fruit quality using a number of different treatments.

The soil health trial was set up in the 2007/08 season in a Shiraz block with low level sprinkler irrigation. The Shiraz was own rooted and was planted in 1997. There was some soil variation however the patch was managed the same throughout.

The trial was designed using a control (bare soil) and four treatments which included:

Treatment	Description	Application
Bare soil - control	Bare soil on the vine bank and the in the mid row.	Weeds were removed from vine bank and the mid row leaving the soil bare in June 2007.
Permanent sward	Mix of grasses and medic sp.	Sown in the mid row in June 2007.
Compost	Woody chunky material	Applied on the vine bank, approximately 30cm thick in October 2007
Microbial solution (Nutri-tech, Myco-Tea)	A microbial solution containing: *Trichoderma lignorum, Chaetomium globosum, Verticillium lecanii, Paecilomyces lilacinus, Penicillium chrysogenum, Azotobacter chroococcum, Bacillus polymyxa, Saccharomyces cerevisiae.*	The solution was applied as per the label directions using a hand wand. The solution was applied every month during a 7 month period starting in September 2007.
Compost and Microbial solution	A combination of the above.	The compost and microbial solution were applied as described above.

The control and treatments were replicated three times for the trial and were applied to random panels in the vineyard. The panels were 3.6 m long and contained three vines each. See the trial design in Appendix 2 and Appendix 9 for trial photos.

Soil samples were taken from the 15 replicate sites in September 2007 and were sent for chemical analysis, organic carbon and hot water extractable carbon. These samples were meant for comparison in the following season, however the sudden end to this trial made these results irrelevant and as such they have not been included in the report.

Soil samples were taken in September 2007 and November 2007 and were analysed for microbial biomass and respiration rate – see results in Appendix 3. Separate soil samples were analysed from the vine bank and from the mid row for comparison purposes. The soil samples were taken in the cooler temperature of the morning, with sampling concluding once the temperature reached 30^{o}C.

Fruit quality samples were taken in February 2008 and were analysed for Baume, pH, Titratable Acid (TA), Anthocyanins, Phenolics and Tannins – See results in Appendix 4.

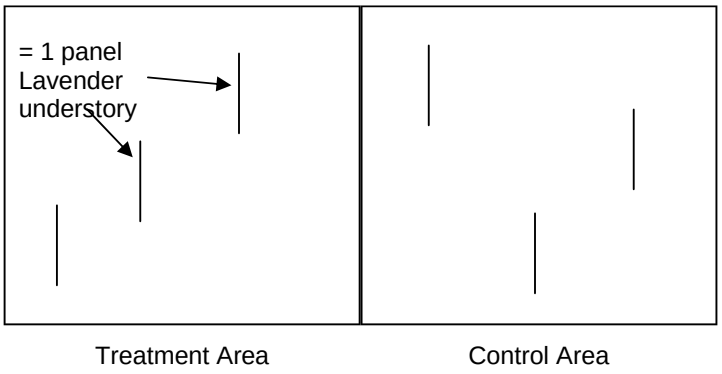
A field walk was organised for December 2007 with guest speakers, Dr. Melanie Weckert from NSW DPI and Dr. Nicole Dimos to present the progress of the literature review findings.

Soil Health Trial – Year 2

Aim: To investigate soil health through the multiplication and introduction of fungi rich microbial solutions to the vineyard.

The soil health trial 2 was set up in the 2008/09 season in a Cabernet Sauvignon block on drip irrigation. This patch had previously been managed with synthetic fertilisers and chemicals for nutrients and pest / disease / weeds control measures.

The Cabernet Sauvignon was planted in 1997/98; there was some soil variation in the patch, however it was treated all the same. The trial was set up with a control (2.4Ha) and a treated (3 Ha) area. There were three panels of lavender planted in both the control and the treated area to investigate companion planting. The diagram below demonstrates the trial set-up.



Soil tests were sampled in the control and treatment areas for biology purposes before commencing the trial. Samples were also taken after the microbial solutions had been applied to the vineyard several times for comparison to the initial sample. (See Appendix 5).

Compost was applied in October 2008 to the vine bank at a rate of 5 tonnes per hectare, with the expectations of creating a favourable environment for the added micro-organisms to colonise before moving deeper into the soil profile around the root zone. The compost applied was of a woody nature to encourage the colonisation and multiplication of beneficial fungi.

The microbial solution commonly referred to as “compost tea” was made in a “Dirt Simple” brewer. The brewer was installed in December 2008 and has a holding capacity of approximately 500L. The compost used in the brewer was obtained from a worm composting company based in Broken Hill and was tested for biology levels before purchase – See Appendix 5.

The operating procedure for multiplication of micro-organisms using the brewer is as follows:

1. Fill the brewer with non-chlorinated water (chlorine kills micro-organisms).
2. Measure the oxygen and temperature level
3. Add food ingredients for the micro-organisms (See Appendix 6 for an example of recipe used to multiply micro-organisms)
4. Add compost into the compost bag and add this to the brewer.
5. Connect and turn on air pump and ensure that air is pumping into the brewer through the liquid.
6. Close brewer lid.
7. Measure oxygen and temperature every 1-3 hours if possible to ensure the oxygen doesn’t fall below 6 mg/L.
8. If the oxygen level falls below 6mg/L, remove some of the liquid from the brewer and re-fill the remaining space with fresh water. Measure oxygen level again.
9. Sample solution at 24 hours and examine under the microscope for levels.
10. If levels are satisfactory, prepare applicator to apply solution to the vineyard.
11. If levels are not satisfactory, continue to oxygenate the solution for another 24hrs.
12. Sample solution again at 48 hours and examine under the microscope for levels.

13. Prepare applicator to apply solution to the vineyard.
14. Applying the solution to the vineyard requires transfer of solution to the applicator using a non-propeller pump. The solution should be pumped into water already present in the applicator to ensure minimal damage to micro-organisms.
15. Apply the microbial solution to vineyard using non-propeller pump and ensuring the solution is placed as close to the vine row as possible.

The following operating procedure outlines the use of the microscope to measure the quality of the microbial solution:

1. This procedure requires the use of a light microscope.
2. A sample of the microbial solution is prepared on a 81 grid microscope slide.
3. This sample is viewed under the 4x, 10x and 40x lens to examine the micro-organisms in the individual grids, recording the number of beneficial fungi present. Beneficial fungi are defined for this project as have a wide diameter with easily viewed septa and are brown in colour.
4. Using the definition of a good tea as detailed by the "Australian Soil Food Web Institute" (See Appendix 7), the microbial solution is categorised as: Bad, Poor, Acceptable, Good, Very Good and Excellent.

The lavender planted to investigate companion planting was chosen as an investigation indicated that lavender preferred a fungal dominated soil environment much like the grapevine. Two types of dwarf lavender (Munstead and Rosea) were hand planted on the vine bank in close proximity to the dripper line. The lavender was planted on the 19th and 20th March 2009.

A field walk was held in April 2009 with a NSW grape growers group. The trial site was also used as an example during the visit of microbiologist, Dr. Elaine Ingham in May 2009.

Discussion

Literature Review

The review was finalised in January 2008 and covered the following headings:

1. What microbial populations are found in agricultural soils?
2. What conditions/ factors affect soil biota populations?
3. Effects of soil biota on soil health, vine health and fruit quality.
4. Measuring soil biota populations in the vineyard.
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The literature review contains detailed information on soil health, however comments from the author indicated that soil health was not an area that had been investigated widely in viticulture. While the literature review is very detailed and might be off-putting to some growers, the information has been clearly grouped in the above headings, which allows growers to search relevant sections as required. The review is available on the MVW website at www.murrayvalleywinegrapes.com.au and is available in hardcopy on request.

Soil Health Trial – Year 1

The design of this trial was to illustrate different techniques, how they might improve soil health and thus be used to manipulate plant health and fruit quality outcomes.

The design of the trial incorporated a control and four different treatments, replicated three times within the block to ensure accurate results. The theory behind this demonstration trial was promising, however the seasonal conditions, the size of the trial and slowness of contractors contributed to the slow development of the project.

Treatments

Bare Soil - Control

The bare soil "control" treatment consisted of the removal of weeds in the mid-row and on the vine bank and maintenance to ensure true results. This procedure was carried out for all treatment plots to ensure the presence of any weeds did not impact on the microbiology processes being used as a measure of improved micro-organism presence and activity.

The soil results (See Appendix 3) showed an increase in microbial biomass from September to November 2007. Results also showed a decrease in microbial activity on the vine bank and an increase in the mid-row area between the two sampling periods. It was expected that if microbial activity was to increase it would increase on the vine bank where the bulk of the vine root zone would be. This assumption is not apparent from the samples taken.

The fruit quality results (See Appendix 4) will provide a basis for comparison of the trial treatments, though it is important to note that the control produced the lowest results for Titratable Acid and Anthocyanins indicating potentially a bland tasting wine with low colour would be produced from this treatment.

Permanent Sward

The trial included the use of a permanent sward containing a mix of grass and medic species in the mid-row. The presence of the low level sprinkler allowed the opportunity to maintain a cover in the mid-row, manipulating soil health around the vine root zone that would be present in this area. Many vineyards in the Murray Valley have converted to drip irrigation, limiting the rootzone area to the vine bank and leaving the mid-row bare of plant life and extremely dry. The harsh soil environment created by drip irrigation negatively impacts the ability to manipulate soil health in the entire vineyard.

A mix of plant species was chosen for the permanent sward to ensure growth throughout the season and acclimatisation to different conditions e.g. temperature.

The permanent sward was planted in June 2007 by direct drill, with a good germination rate seen during the early season.

While all the boxes were ticked to ensure the effectiveness of this treatment, the lack of water available in the 2007/08 season resulted in patchy ground cover and the eventual drying off of the permanent sward.

The results from the soil testing (See Appendix 3) indicated that there was an increase in the amount of micro-organisms present in this treatment as seen in both vine bank and mid-row samples, though the respiration rate results indicate the level of activity from micro-organisms increased slightly on the vine bank and decreased in the mid-row area. While it would be expected that there would be an increase in the mid-row sample and a

lesser increase on the vine bank the weak state of the permanent sward could have limited the levels of exudates present in this area and therefore limited the microbial activity.

The fruit results (See Appendix 4) showed an increase in Baume, Titratable Acid, Anthocyanins and Tannins in comparison to the control "bare soil", though the pH and the Phenolics levels were the same as the control. The Anthocyanin level was the highest level recorded and sits at the upper end of the average range for the Sunraysia region.

Compost

Compost was applied to the vine bank, with the expectation of providing water saving mulch and a barrier against extreme climatic conditions. The compost used was of a woody nature which ensured that water and gases would be able to infiltrate. The compost which was sourced from composting company "Jefferies Compost" was dark in colour and easy to handle.

The compost was applied to the vine bank approximately 30 cm thick by shovel, however this type of compost could be applied easily to the whole vineyard using a spreader.

The soil results (See Appendix 3) for this treatment indicated an increase in the volume of micro-organisms present on the vine bank and in the mid-row. While an increase in the volume of micro-organisms would be expected on the vine bank, it was less expected in the mid-row due to the confined location of this treatment. However if these results are showing an accurate picture, the use of compost on the vine bank could have beneficial results for the whole vineyard, as long as moisture was available.

The soil results also indicated that there was a decrease in the level of microbial activity from September to November. It was the expectation that the respiration rate would increase as the season progressed, however the dry conditions or increased temperatures could have reduced the level of microbes that were active. Alternatively, an increase in the level of moisture retained under the compost could have also been a cause for reduced activity if the moisture was reducing the amount of oxygen present.

The fruit results (See Appendix 4) for the compost treatment show a lower Baume, pH, Anthocyanins and tannin levels in comparison to the control. This treatment recorded the highest level of Titratable Acid, which could indicate the wine produced from this treatment would have "tart" qualities. The Phenolic readings for all treatments were equal.

The fruit quality results indicated that the compost treatment was improving vineyard water retention resulting in larger berry size. This was confirmed through visual observation. The compost results were the only results consistent with the "expected" outcomes of this trial.

While the composting treatment showed the potential to retain moisture in the vineyard which could be critical in dry years, the extra moisture can affect canopy size and fruit quality, indicated by the fruit quality results. The increase in moisture under the compost could provide a more favourable environment for microbial activity as long as the environment is not too wet and becomes oxygen deprived. If managed correctly, this treatment could be easily incorporated into the vineyard and could have beneficial impacts for soil health.

Microbial Solution

There are a number of ready packaged microbial solutions on the market. After investigating the different types that were available it was decided to use the Nutri-tech solutions "Myco-Tea" product which describes the following benefits:

- Fungal Domination - achieved with ease.
- Phosphate Solubilisation - contains species to 'unlock' phosphate reserves.
- Nitrogen Fixation - contains specialist species to tap into free atmosphere nitrogen.
- Cellulose Digestion - contains species to break down fibrous plant matter (i.e. stubble).
- Bio-balancing - helps to balance the ratio of desirable to undesirable organisms in your system.

This is a dry product that requires a water medium for activation and application. Non-chlorinated water was used as the medium for application. The solution was applied to the treatment areas using a hand wand once a month for a period of 7 months.

This product was applied in accordance with the "Un-brewed" label requirements. This product suggests adding ingredients that would activate the micro-organisms and feed them allowing them to multiply for the best outcome. Having used this approach in the second trial of the soil health project, it is possible that the initial approach used limited its effectiveness in the trial environment. It should also be considered, in hindsight, that applying this produce to bare soil with no additional food sources in the soil would have limited benefits for soil health and fruit quality manipulation.

The soil results (See Appendix 3) for this treatment indicate a large increase in the volume of micro-organisms present on the vine bank and in the mid-row area. The expectation for this treatment was to add micro-organisms to the vineyard; these results could confirm that this was occurring. The level of the September 2007 results is quite low in comparison with the other treatments which could be due to vineyard soil variability and where the treatment replicates were placed.

The fruit quality results (See Appendix 4) show that the Myco-Tea treatment produced the highest Baume reading though the other quality parameters show similar levels to other treatments with no obvious trends.

The use of ready made microbial liquids as a method to improve soil health has merit, however an important part of using this management method in the vineyard should be quality control, monitoring and measuring the micro-organisms being applied to the vineyard to ensure micro-organisms **are** being applied and the micro-organisms being applied are beneficial.

Compost and Microbial Solution

This treatment consisted of the application of the "Jefferies Compost" at a thickness of 30 cm, consistent with the compost treatment and the application of the Nutri-tech Solutions "Myco-Tea" consistent with the above treatment. This treatment was used to measure any magnified effects caused by the combination of two separate treatments.

The soil results (See Appendix 3) indicated an increase in microbial biomass between the sampling times, however the initial sample recorded higher levels of microbes than the rest of the treatments at the beginning of the trial. This could be due to the variation in soil and the placement of the treatment replicates.

The activity of the microbes present decreased slightly between the sampling periods, which may be due to climatic conditions at the time of sampling or could be part of the natural cycle for this time of the season.

The fruit quality results (See Appendix 4) show a decrease in the Baume level in a trend similar to the compost treatment, though the pH of this treatment is equal to the other treatments / control and does not follow the same trend as the compost treatment. The

Titatable Acid result for the combined treatment is more comparable with the Myco-Tea result than it is with the compost. The colour result was equal with the result for the Myco-Tea and the tannins result was similar to the result for the Myco-Tea.

This treatment did not show any magnified results due to the combination of two single treatments. Once again the suggested limitations of the "un-brewed" "Myco-tea" could have negatively impacted the outcomes of this treatment. Given time this treatment might exceed the expectations of the single treatments "compost" and "Myco-Tea" due to improvements in the soil environment and the addition of micro-organisms. This could potentially meet the aims of this project and improve soil health and fruit quality.

Soil Testing

Four soil tests were planned initially. Due to the dry and hard condition of the soil as well as the high number of samples required, only two sets of soil samples were conducted.

Field Day

A field day was organised for December 2007, providing the opportunity for growers to visit the soil health site amongst a number of other project sites Murray Valley Winegrowers was managing. Dr. Melanie Weckert from NSW DPI was invited to speak to growers about soil health and Dr. Nicole Dimos had organised to give growers an update on the progress of the literature review. Unfortunately, there was not enough interest from growers at this time and the field day was cancelled. It is believed the low interest from growers was due to the time of year, with growers too busy to spend time away from their vineyards in the lead up to Christmas.

Conclusion

The soil microbial biomass results showed clear trends of increasing microbial numbers in the soil from September to November in both the vine bank and mid-row areas. The similar increase for the control as well as the treatments indicates that this might be a natural occurrence. However, there has not been enough time to conclude that the treatments are causing the improvement in microbe numbers.

The activity of the microbes present shows no clear treads between the vine bank and the mid-row, however the results indicate that in most treatments there was a decrease in respiration rate indicating a decrease in microbial activity. This outcome might also be a natural occurrence with more time required to measure the impact of the treatments.

The fruit quality results indicated that the compost treatment was improving vineyard water retention, resulting in larger berry size. This was confirmed through visual observation. The compost results were the only results consistent with the "expected" outcomes of this trial.

Ultimately this soil health trial did and does show a lot of promise for investigating techniques for making potential gains in soil health and saleable produce. The size of the trial, combined with the seasonal conditions and the growers decision to sell were the reasons for the incompletion of this trial.

Soil Health Trial Year 2

The soil health trial was redesigned in year 2 rather than replicating the year 1 trial for two reasons:

1. The size of trial 1 was too large to dedicate sufficient time for satisfactory outcomes to be achieved and,
2. After completing a course with soil microbiologist, Dr. Elaine Ingham, it was decided to use the soil food web as the basis of the project, measuring the types of

biology present in the soil rather than the combined activity level of biology in the soil as the indicator of soil health.

The aim of the second soil health trial was to improve soil health by adding biology to the soil. This required the development of a plan, new trial design and operating procedures (See Methods). The trial began with soil tests taken in both the control and treatment areas, the results shown in Appendix 5 show that both plots have excellent levels of bacteria and both have low levels of fungi. Before conducting the test, low fungi numbers were the expected outcome due to the levels of fungicides, especially sulphur, that are used in most vineyards. Due to the low levels of both active and total fungi in comparison to bacteria the ratio of fungi to bacteria were recorded well below the required levels for a fungal dominated soil food web.

The use of fungicides in the vineyard to control fungal diseases such as powdery mildew is a barrier to success for this project, however the application of compost at the rate of 5t/Ha was expected to not only create a favourable environment for the additional micro-organisms, but also act as a physical barrier to protect the colonies of micro-organisms in the soil. While the rate of compost applied provided the opportunity to develop an initial physical barrier, this barrier will eventually be incorporated into the soil profile and thus will need to be re-applied. From the experience of this trial, it is recommended that a higher rate of compost be applied to create a bigger environment for colonisation and as a physical barrier that covers a larger area.

The progress of the project was slowed by the unforseen delay in delivery of the "Dirt Simple" brewer. The brewer arrived in late December and was installed in early January. In mid February, using the operating procedure described in the methods, brewing began. There have been mixed results with the multiplication process; however this was to be expected with adjustments required to the level of compost and ingredients added to the "Dirt Simple" brewer to adapt to the growth and multiplication of the micro-organisms under the environmental conditions present.

Key considerations when starting the brewing process include:

- The type and volume of micro-organisms that are in the compost to be added to the brew,
- The type of micro-organisms to be multiplied,
- The type of ingredients required to feed the desired micro-organisms,
- The quality of the ingredients to be added to the brewer,
- The amounts of ingredient to be added to the brewer,
- The temperature expected over the next 48 hours and
- The temperature expected in the shed where the brewer is located.

These considerations are important because:

- Without an understanding of the types and volumes of micro-organisms present in the compost to be added to the brewer, the multiplication process might be limited due to limited numbers or perhaps non-beneficial micro-organisms being present.
- Without an understanding of the type of micro-organisms to be multiplied, in this case fungi, key ingredients used to grow the micro-organisms might be absent limiting the ability to achieve the project goal.
- Without an understanding of how different ingredients and the quality of the ingredients added to the brewer assists or impede the growth of the desired micro-organisms, the ability to grow the desired micro-organisms to a maximum level will be limited. For example, it has been suggested that humic acid made from brown coal is detrimental to the growth of fungi.
- The amount of ingredients added will determine the growth level of micro-organisms in the brew which if accelerated can reduce the level of oxygen in the

brewer below the 6mg/L required for it to remain aerobic. This causes the destruction of the beneficial micro-organisms and the potential growth of anaerobic micro-organisms e.g. plant pathogens.

- There is a relationship between temperature and the level of oxygen in the brewer. As temperature increases the level of oxygen in the brewer solution decreases, therefore on a hot day it will be more important to check the oxygen levels in the brewer and this may need to be done more often than usual.

Oxygen is a key component to producing a beneficial solution of micro-organisms for addition to the soil. In order to keep the microbial solution aerobic, the oxygen level must remain above 6mg/L. Once the oxygen drops below this level the solution is considered anaerobic and provides the opportunity for the growth of anaerobic micro-organisms and the destruction of beneficial micro-organisms. Anaerobic micro-organisms fall in the category of plant pathogens and can cause detrimental impacts if added to the vineyard. As can be seen in the results from each brew in Appendix 8 the first microbial solution that was brewed as part of the trial became anaerobic, producing little growth of beneficial micro-organisms and the growth of some suspect organisms. The microbial solutions developed since then have remained aerobic and are developing a better rating using the "Australian Soil Food Web Institute" definition of a good tea.

While only fungi was chosen as an indicator for the quality of the microbial solutions developed in this trial, it is important to note that a healthy soil food web would not function without all biological components and thus fungi **should not** in the long-term be the only component considered under the microscope.

Perfecting an excellent microbial solution will be a learning process and will require some trial and error, however the results developed thus far are promising and moving in the right direction. To see photos of the beneficial micro-organisms grown as part of this project, see Appendix 9.

The microbial solution was applied to the vineyard using a home-made applicator (See Appendix 9) that consisted of a stainless steel tank with minimal sharp edges or right angle fittings that could destroy the micro-organisms in the solution. The applicator delivers approximately 12.6L / 100m. The amount of microbial solution applied is largely dependent on the quality of the solution i.e. if the solution has low volumes of bacteria and fungi then a larger volume is required to be applied to achieve the end result. This is an area that requires more work to ensure that a sufficient level of micro-organisms are being applied to the vineyard. Further work is also required to ensure the application process is not damaging the micro-organisms in the solution and to examine the possibilities of apply the microbial solution through the irrigation system.

To date five microbial solutions have been applied to the vineyard in the treatment area. The control and treatment areas were soil tested again in April (See Appendix 5), however while the results show a slight increases in fungi numbers from the initial results, it could be argued that this is a natural increase in the biology for this time of the season.

Companion planting is not a new concept and has been used in many home vegetable gardens. This concept can be easily used in the home garden due to the small scale of production and is rarely seen in large scale agricultural practices due to its time consuming nature. The concept of companion planting is different to that of cover cropping which is primarily used for ground cover, adding organic matter back into the soil and in the Murray Valley was until recently generally conducted only once a year with a mid-row annual species. The concept of companion planting is planting two or more species that enjoy the same growing conditions e.g. soil conditions and growing them together with the expectation that they assist one another, in this case to maintain and improve the soil food

web for the benefit of both plant species. Lavender was chosen as the companion planting species as it prefers the same fungal dominated soil conditions in which grapevines grow well and is relatively easy to access.

Two types of dwarf lavender were chosen with the expectation of creating plant community rather than a monoculture and to ensure that the lavender did not grow too tall on the vine bank.

While this project still requires time to develop satisfactory results, it has sparked an interest with growers investigating new techniques to buffer the effects of drought, climate change and changing industry conditions. Growers are starting to consider alternative management techniques to improve production and cut cost. The concept of this project has started some discussion and questions are being asked. In April 2009 a field walk was held with a NSW grape growers group which provided the opportunity for growers to view the different processes of the project including the brewer, the lavender, the applicator and the quality management using the microscope. Approximately 20 people attended this field walk and many participants have since made contact with enquires.

The trial site was also used as an example during the May 2009 visit of world renowned soil microbiologist Dr. Elaine Ingham. A number of growers who attend this workshop were Murray Valley Winegrowers' members and have since indicated that they will be trialling the techniques used in this soil health trial in a small patch of their own vineyards and are very keen to see some more results from this trial.

Conclusion

This is a promising soil health trial that requires more time to develop satisfactory conclusions. It is the expectation of Murray Valley Winegrowers, with agreement from GWRDC, to continue this project under the banner of the GWRDC Regional Grassroots Solutions program to ensure the investment already committed by both GWRDC and the Murray Valley Winegrapes Industry Development Committee is not lost and to ensure informative outcomes regarding soil health and this demonstration trial are delivered to growers.

Project Conclusion

This project has had a varied development with unforseen circumstances disrupting the development and requiring significant changes to be made to the project structure. Despite the delays this project has developed into a promising trial, which given the opportunity to continue is expected to deliver practical and relevant information to growers on soil health.

APPENDIX 1 – Literature Review

Soil Health

"Developing an understanding"

Prepared for: Murray Valley Winegrowers' Inc.

By Dr. Nicole F Dimos *B.Agr Sci (Hons.) PhD*

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Prepared by: Dr Nicole Dimos (PhD, B Agr. Sci.(Hons.))

Acknowledgements are made to Murray Valley Winegrowers' Inc and Grape and Wine Research and Development Corporation (GWRDC) for the opportunity to compile this report on soil health in viticulture. It is hoped that the information contained within will be useful to winegrape growers' in the Murray Valley.





1. Introduction

Sustainable production for future profitability is always forefront in the minds of Murray Valley Winegrowers. Soil health is gaining more interest amongst winegrape growers, with a good understanding of its impact on production and profitability seen to be a potential key to making improvements in the vineyard.

Soil health can be broadly defined as the capacity of a living soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health (Doran *et al*. 1996; 1998). Soil quality and health change over time due to natural events or human impacts. They are enhanced by management and land-use decisions that weigh the multiple functions of soil and are impaired by decisions that focus only on single functions, such as crop productivity. Thus, balance between soil function for productivity, environmental quality, and plant and animal health is required for optimal soil health.

Healthy soils are described as those able to sustain biological life (the soil biota), breakdown organic matter, hold water and nutrients and suppress pathogens. These characteristics arise from an interaction between the following soil components (Slavich 2001):

- The physio-chemical components which consists of soil aggregates, organic and inorganic substances,
- The mineral component which consists of the sand, silt and clay make up of the soil and,
- The biological component, which consists of macro and micro – organisms, roots etc.

The biological component of soils develops from the physio-chemical and mineral components of the soil, which will differ from soil type to soil type. Therefore, it can be suggested that the soil biota population levels, diversity, and ability to function is a significant indicator of soil health (Slavich 2001).

Following is a summary of information related to soil health from a biological component viewpoint. Although much of the data included in this report does not include information specific to viticulture, this report is compiled with the expectations of providing practical information for winegrape growers to use in their vineyards.

2. What microbial populations are found in agricultural soils?

Throughout the Murray Valley, there exists a diverse variety of soil types; this is the same for the soil biota or soil life within the soil. While there are many different types of soil biota, they are generally divided into four categories. The following table describes the classes, function and examples of soil biota.

Soil biota class	Size	Function	Examples
Microflora	Not visible to human eye (m size).	Principle agents for cycling of nutrients e.g. nitrogen, phosphorus and sulphur. Help in formation of stable soil aggregates.	Bacteria, fungi and actinomycetes
Microfauna	Not visible to human eye (m size).	Regulate populations of bacteria and fungi. Play major role in mineralisation of nutrients.	Protozoa and nematodes
Mesofauna	0.1 – 1mm length	Assist in breaking down organic residues. They feed on litter and are predators of fungi and microfauna. Regulate microbial populations and nutrient turnover.	Mites and collembolla
Macrofauna	> 1mm, easy to see	Help to form soil aggregates and pores. Important for breaking down organic residues.	Earthworms, termites, dungbeetles, snails, slugs, centipedes, crickets.

Table 1: Classes, function and examples of soil biota. Source: Hollier,2006.

Soil food webs

The different classes of soil biota interact with one another in the soil in what is described as a soil food web. The structure of a food web is the composition and relative numbers of organisms in each group within the soil system. Each type of ecosystem has a characteristic food web structure. Organisms reflect their food source. For example, protozoa are abundant where bacteria are plentiful. Where bacteria dominate over fungi, nematodes that eat bacteria are more numerous than nematodes that eat fungi. For example, the ratio of fungi to bacteria is characteristic to the type of system.

In general, agricultural soils usually have a bacterial dominated food web, i.e., the majority of soil biota is bacteria. However, for grapevines and commonly for row crops, there is a

need an increase organism diversity and the fugal to bacterial biomass ratios change to 2-5:1, i.e. for every 2-5 fungi counts there is 1 bacteria count present.

Food webs describe the transfer of energy between species in an ecosystem (e.g. the vineyard). While a food chain examines one linear energy pathway through an ecosystem **(Figure 1.)**, a food web is more complex and illustrates all the potential pathways (**Figure 2)**. The different classes of soil biota interact with one another on different levels as illustrated in **Figure 2**. These different levels are referred to as trophic levels. Trophic describes where an organism sits in the food chain, that is, what it consumes, and what consumes it.

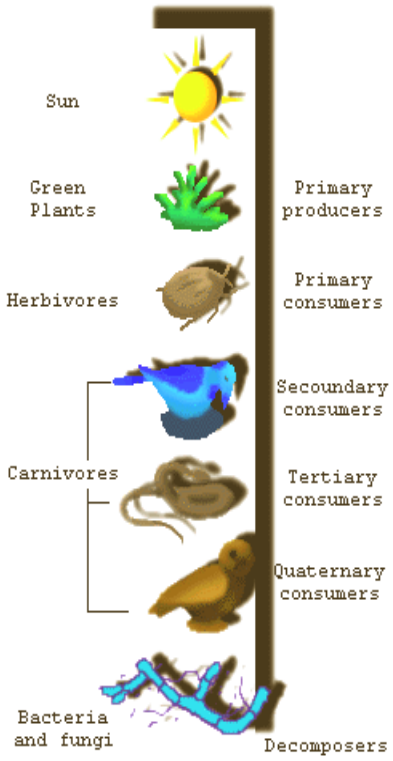


Figure 1 portrays a simple food chain, in which energy from the sun, captured by plant photosynthesis, flows from *trophic level* to trophic level via the *food chain*. A trophic level is composed of organisms that make a living in the same way, i.e. they are all *primary producers* (plants), *primary consumers* (herbivores) or *secondary consumers* (carnivores). Source:www.globalchange.umich.edu/globalchange1/current/lectures/kling/ecosystem/foodchain2.gif&imgrefurl

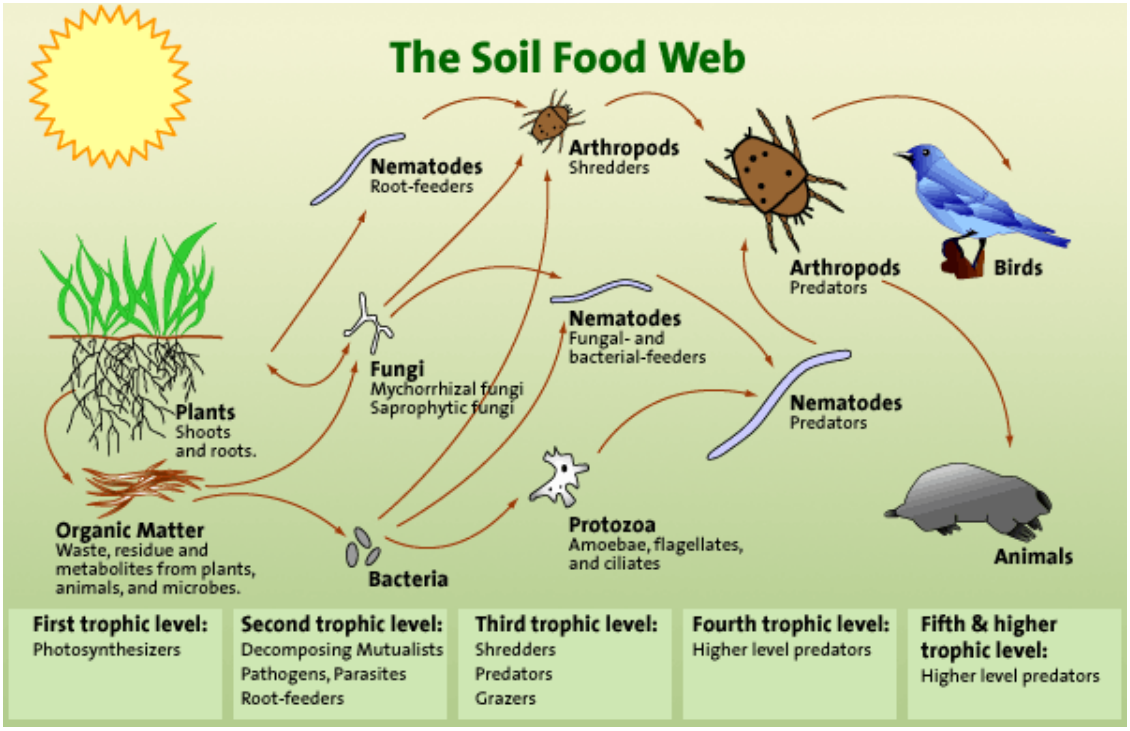


Figure 2: The Soil Food Web. Source: www.soils.usda.com

The first tropic level is comprised of energy that comes from the sun. Plants use the sun's energy to convert inorganic compounds into energy-rich organic compounds, turning carbon dioxide and minerals into plant material by photosynthesis. This energy is transferred to the soil food web through the incorporation of organic matter into the soil and the transfer of sugar / mineral based substances from the plant roots.

The second trophic consists of soil biota classes that can breakdown organic matter and help bind soil aggregates (soil and mineral particles bound together by the wastes of worms and composting bacteria and give soils its crumbly appearance); enhance plant growth through the fixing of nitrogen in the soil and converting nutrients to plant available forms. The primary consumers in soil are often microbes such as bacteria and fungi that consume plant material and dead or decaying organic matter. There are at least 10,000 species and more than 1 billion individual bacteria in 1 gram of soil (Torsvik *et al.*, 1990). These fast growing microbes act as a food base for many other soil organisms such as mites and nematodes. The second trophic level also contains pathogens (e.g. bacteria / fungi) and parasites (e.g. nematodes) that can promote and cause disease as well as root-feeders (e.g. nematodes) that can potentially reduce plant vigour and cause crop losses. An example of the second trophic in the vineyard is root-knot nematode attacking own-rooted grapevines causing a decrease in vigour and yield.

The third tropic consists of shredders (e.g. earthworms), predators (e.g. mites) and grazers (e.g. nematodes, micro arthropods) all of which are involved in breaking down plant residues, enhancing soil structure and converting nutrients to plant available forms. The trophic levels above this contain higher-level predators (e.g. nematode feeding nematodes) that improve soil structure and control the lower trophic level predators ensuring a balanced community.

Aboveground trophic webs are well understood, for example, the energy required or produced moves from producers (plants) to primary consumers (herbivores) and then to secondary consumers (predators) with decomposition although on-going is the tail end of the food web, but belowground communities require further study since they are the basic biological system supporting many ecological functions and services, and the decomposers are the beginners in these food webs. Recent studies suggest that above and belowground biological communities are strongly related so that changes aboveground have important consequences belowground and vice versa.

Overall, the theory of a soil web is that in a positive environment the different trophic levels will work together to enhance soil aggregation and porosity, thus increasing infiltration and reducing runoff. Good soil structure will allow positive plant root growth and development. The soil food web can breakdown organic matter and make available nutrients in the correct form for plant use. They are able to break down pesticides preventing them from entering water and becoming pollutants and can suppress disease promoting organism.

Soil Organic Matter

The link between soil biota and soil organic matter has been recognised and intensively studied (Martin *et al*., 1955; Harris *et al*., 1966; Lynch and Bragg, 1985; Degens, 1997). Soil organic matter is many different kinds of compounds – some more useful to organisms than others. In general, soil organic matter is made of roughly equal parts humus and active organic matter. Active organic matter is the portion available to soil organisms. Bacteria tend to use simple organic compounds such as root exudates or fresh plant residues; whereas fungi tend to use more complex compounds such as fibrous plant residues, wood and soil humus. Intensive tillage triggers spurts of activity among bacteria and other organisms that consume organic matter (convert it to CO_2), depleting the active fraction. Practices that build soil organic matter (reduced tillage and regular additions of organic material) will raise the proportion of active organic matter long before increases in total

organic matter can be measured. As soil organic matter increases, soil organisms play a role in its conversion to humus; a relatively stable form of carbon sequestered in soils. Due to the diversity of soil organic matter components, its roles and properties in soil can be biological, chemical, physical and environmental, it is therefore important to manage organic matter. Ways to build organic matter into your soil and improve productiveity in your vineyard are discussed throughout this information booklet.

3. What conditions / factors affect soil biota population?

The interactions between soil biota can produce some very positive outcomes which affect the performance level of the vineyard; however, the types and level of soil biota that is present in the vineyard soil web change constantly with vineyard cultural practices and environmental conditions. The most influential factor on microbial community composition have been detected (Bossio and Scow, 1998; Bossio *et al*., 1998; Feng *et al*., 2003), likely due to environmental differences such as soil temperature and water availability and agronomy practices. Below is a summary of the understanding of the effects of agricultural inputs and environmental impacts on soil organisms.

Mineral fertilisers

Most mineral fertilisers in Australia are applied to systems with regular and significant nutrient exports to harvested products. Generally, data indicates that although plants and fertilisers do impact on microbial community structure, the relationship between diversity, community structure and function remains complex and difficult to interpret. Many field experiments have shown a lack of response of the microbial biomass and earthworms to mineral fertilisers, even in cases where production increased, for example pastures (Perrot *et al*., 1992; Sarathchandra *et al.*, 1993). Where a decrease in microbial C was observed, it was usually accompanied by a decrease in soil pH after application of N or S fertilisers (Gupta *et al*., 1988; Ladd *et al*., 1994; Sarathchandra *et al*., 2001). Other methods such as microbial enumeration by plant counts (Sarathchandra *et al*., 1993), enzyme activities (Graham and Haynes, 2005), and nematode counts (Parfitt *et al*., 2005), which are possibly more sensitive than measurements of microbial biomass show variable changes due to fertilisation. For example, although the total number of nematodes was not affected by N fertilisation, there was an overall decrease in soil pH, and variation in nematode species, with some nematode species increased, while other species decreased, regardless of their beneficial status (Sarathchandra *et al.*, 2001).

Schnürer *et al*. (1986) investigated during 3 years the effects of four cropping systems on soil micro organisms. The cropping systems were barley without N fertiliser; barley with 120 kg N ha^{-1} yr^{-1}; grass ley receiving 200 kg N ha^{-1} $year^{-1}$; and lucerne without N fertiliser. At samplings in September during three consecutive years no differences were found between treatments. Twenty samplings over 3 years in barley with fertiliser and in the grass ley treatment indicated higher numbers of bacteria and protozoa during the growing season, except for periods when moisture stress was recorded. No clear seasonal trends were found for the fungi. Seventy-nine per cent of the bacterial biomass and 73% of the total fungal lengths were found in the top soil.

The absence of changes in microbial C in response to N fertilisation and a related decrease in pH in two long term field experiments studied by Moore *et al.*, (2000) proved interesting because in this particular study, microbial C was found to be correlated to levels of organic C as induced by different crop rotations. Several long-term field experiments in which mineral and organic fertiliser inputs were compared have also shown good correlations between microbial biomass and soil organic C (Witter *et al.*, 1993; Houot and Chaussod 1995; Leita *et al*., 1999). Although, soil organic C levels are often increased compared to non-fertilised control, even greater increases in soil organic C are usually achieved in treatments receiving organic amendments.

Grahman *et al.*, (2002) investigated the amount of microbial C and N under sugarcane after 59 years of different crop residue management and NPK fertilisation and showed that the microbial biomass was directly influenced by residue management and indirectly by NPK fertilisation through increased residue inputs. A follow up study in the same trial revealed the interaction of soil acidification with negative effects and organic matter accumulation with positive effects on soil organisms and enzyme activities (Graham and Haynes, 2005).

The following examples show that by varying management practices, in this case nitrogen, we inevitably vary the ratios of fungi: bacteria. Bardgett and McAlister (1999) investigated the usefulness of measures of fungal: bacterial biomass ratios as indicators of effective conversion from an intensive grassland system, reliant mainly on fertilisers for crop nutrition, to a low-input system reliant mainly on self-regulation through soil biological pathways of nutrient turnover. The results showed that fungal: bacterial biomass ratios were consistently and significantly higher in the unfertilised than the fertilised grasslands.

In a two-year old field experiment, the effects of a grass crop (grass and clover-grass mix) and N application rate (0, 40, 80, 120 kg N/ha) on the fungal: bacterial ratios were tested. The fungal: bacterial ratios were higher in the grass only plots, however, decreased with increasing nitrogen (de Vries *et al.* 2006).

Organic fertilisers

Since most organic fertiliser are waste products, their application rate is often determined by availability rather than demand. Most amendments are applied primarily to benefit plant growth. The duration of observed increases in soil organisms depends on the amount and proportions of readily decomposable carbon substrates added and the availability of nutrients, particularly nitrogen (Hatrz *et al*., 2000; Adediran *et al*., 2003). However, microbial characteristics of amended soils often return to their baseline within a few years (Speir *et al*., 2003; Garcia Gil *et al*., 2004). Sustained changes in microbial biomass,

diversity and function are more likely where organic amendments are ongoing, as is the case in organic and biodynamic farms (Mader *et al*., 2002; Zaller and Kopke, 2004). Ryan (1999) argues however that an increase in microbial populations may not be seen when the productivity system is limited by nutrient input or water supply.

The principle indirect effects of humic substances on soil organisms are through increased plant productivity. Kim *et al*., (1997a) found no effect of commercial humate applied at 8.2t/ha on microbial activity or microbial functional groups in sandy soils used to grow bell peppers. Similarly, after 5 years of annual application of 100 L/ha liquid humic acid to a horticultural soil, Albiach *et al*., (2000) found no effect on microbial activity or enzyme activity.

Elfstrand *et al*., (2007) also compared the fungal: bacterial ratios of a maize crop which had been a source of manure for the past 47 years. The manure treatments included a clover free ley, farmyard manure and sawdust which were applied every second year in autumn at a rate of 4t C ha^{-1}. The samples collected showed that the crop and crop was bacterially dominated and in both sampling times (June and September). The ratio was significantly higher in the green manure, which contained higher nitrogen content, compared to farmyard manure.

The following table **(Table 2)** describes the effects of mineral and organic fertilisers on soil organisms;

• Plant	• Fertiliser	• Effect of soil organisms	• Reference and country of experimentation
• Pasture	• 0-120 P kg/ha	• No change in microbial P or earthworms; increase fungi.	• Sarathchandra et al., 1993) • New Zealand
• Pasture	• 40 N kg/ha	• No change in microbial C and N	• Lovell and Hatch, 1997, UK
• Wheat rotation	• 0-80 N kg/ha	• C and N mineralisation	• Ladd et al., 1994

			• Australia
• Pasture	• 27 P, 17 N kg/ha	• Negative clover and grass root length colonised by fungi	• Ryan et al., 2000 • Australia
• Soil	• Poultry manure, gypsum	• Higher microbial C	• Trochoulias et al., 1986, Australia
• Pasture	• Biosolids (30-120 kg/ha)	• Increased earthworm abundance	• Baker et al., 2002, Australia
• Rice	• 3 yrs poultry manure	• Increase in microbial biomass, activity, diversity and C turnover	• Dinesh et al., 2000, India
• Pasture	• Compost of biosoild, wood waste and green waste	• Microbial C and mineralisable N increased	• Speir et al., 2003, New Zealand
• Vegetables	• Compost of woody material with manure or sewerage sludge	• Increased microbial C	• Australia

Table 2: Effect of mineral and organic fertilisers on soil organisms.

NB Soil = no plant grown

Chemical pest and disease protection (herbicides/insecticides/ fungicides)

Among the pesticides, few significant effects of herbicides on soil organisms have been documented, whereas negative effects of insecticides and fungicides are more common. Copper fungicides are among the most toxic and most persistent fungicides, and their application warrants strict regulation.

Organophosphate insecticides (eg. chlorpyrifos, quinalphos, dimethoate, diazinon) had a range of effects including changes in bacterial and fungal numbers in soils (Pandey and Singh, 2004), varied effects on soil enzymes (enzymes are defined as proteins which aid or accelerate a biochemical reaction) (Menon *et al.*, 2005; Singh and Singh, 2005) and

reduction in earthworm reproduction (Panda and Sahu, 1999). Carbamate insecticides (carbaryl, carbofuran and methiocarb) also had a range of effects on soil organisms including a significant reduction of earthworms (Pandey and Singh 2004), mixed effects on soil enzymes (Sannino and Gianfreda, 2001).

The effect of herbicide on vineyard soil microbial populations is likely to involve not only the direct effect of the herbicide but also the indirect effect of reduction in rhizosphere exudates and organic material due to lack of vegetation after repeated herbicide applications (Whitelaw-Weckert, 2004). Root exudates are the plant substances (sugars, amino acids) that leak out of the roots of plants. These substances provide nutrition for both favorable and unfavorable microorganisms that live in the root zone. Root exudates help establish the rhizosphere, A common herbicide is glyphospate, has shown mixed impacts to soil biota. In wheat soils (Mekwatanakarn and Sivasithamparam, 1987) glyphosphate reduced soil bacterial populations, whereas Haney *et al*. (2002) reported increased soil biomass with its use, or no change at all in microbial populations long-term (Busse *et al*. 2001). In a large field trial in Wagga Wagga (warm irrigated region) and Tumbarumba (cool region) Australia, the effects of herbicides and permanent swards on soil microbial populations in Chardonnay vineyards were monitored. Three-floor management systems were imposes, a complete herbicide spray out, herbicide under row only, or slash only (no herbicide). Herbicides were applied approximately fives time throughout the year. The results showed that the populations of soil cellulolytic bacteria (52%), Pseudomonas spp. and fungi (31%) were significantly lower in the inter-rows that were sprayed out, indicating a significant effect on soil microbial biodiversity. It was also more severe in the cool climate region possible due to unfavourable soil conditions which lead to reduced soil biota activity.

Fungicides generally had even greater effects than herbicides and insectides on soil organisms. As these chemical are applied to control fungal diseases, they will also affect beneficial soil fungi and other soil organisms. Very significant negative effects were found for copper based fungicide, which caused long-term reductions of earthworm populations in avocado and vineyard soils respectively (Van Zwieten *et al*., 2004; Eijsackers *et al*., 2005). Merrington *et al*., (2005) further demonstrated significant reductions in microbial biomass, while respiration rates were increased, and showed conclusively that copper residues resulted in stressed microbes.

To summarise, the results from this literature survey on the effects of selected pesticides on soil organisms are shown in **Table 3**.

Plant	Pesticide	Effect of soil organisms	Reference and country of experimentation
Soil	Atrazine (H)	Altered community structure of bacteria	Seghers *et al*. 2003, Belgium
Soil	Glyphosphate (H)	Bacteria reduced, fungi increased microbial activity increased	Araujo *et al.* 2003, Brazil
Forestry	Glyphosphate (H)	Increased microbial activity, short-term community structure change.	Busse *et al*. 2001, USA
Soybeans	Glyphosate (H)	No effects on soil macroarthropod number or activity until late in the season where species were most abundant under weedy, no-tillage conditions.	House *et al*. 1987, USA
Soil	Carbaryl (I)	Significant reduction in earthworm	Ribera *et al*. 2001, France
Groundnut	Chlorpyrifos (I)	Reduced bacterial numbers, increased fungal numbers	Pandey and Singh, 2004, India
Ex cattle yards, contaminated soils	DDT, arsenic (I)	Bacterial and fungal numbers, and biomass C reduced	Edvantoro *et al*. 2003, Australia
Grains	Dimethoate (I)	Short-term reduction in microarthropods	Martikainen *et al*. 1998, Finland
Cultivated soils	Captan (F)	Fungal length and density reduced, microbial C and N significantly reduced	Hu *et al*. 1995, USA
Avocado	Copper (F)	Earthworm populations reductions.	Van Zwieten *et al*. 2004, Australia
Avocado	Copper (F)	Significantly reduced microbial biomass and ratio of microbial biomass to organic C	Merrington *et al.* 2002, Australia
Laboratory – soils	Mancozeb (F)	Reduction in nitrification	Kinney *et al*. 2005, USA

Table 3: Effect of herbicides on soil organisms. NB Soil means no plants grown. H=herbicide, I-insecticide, F=fungicide.

Cultivation/ Stubble retention/Tillage

Soil tillage or cultivation has long been an integral part of soil management within vineyards. However, tillage can also have negative impacts on soil health. Tillage can alter many aspects of the soils physical environment including soil water, temperature and porosity, can lead to a decline in OM content, as well as increasing the loss of top-soil through wind and water erosion. In addition, tillage can also negatively impact the wide diversity of invertebrates, many of which reside within the soil, thus, rendering them vulnerable to tillage. Soil communities are among the most important and species-rich components of agro-ecosystems, and thus are a valuable source of biodiversity for any agroecosystem. This is important as high diversity can be correlated with increased soil health.

The effect of a change of tillage and crop residue management practice on the chemical and microbiological properties of a cereal-producing red duplex soil was investigated by superimposing each of three management practices (conventional cultivation, stubble burnt, crop conventionally sown; direct-drilling, stubble retained, no cultivation, crop direct-drilled; stubble incorporated with a single cultivation, crop conventionally sown), for a 3-year period (Pankhurst *et al.*, 2002). A change from direct drill to conventional cultivation or stubble incorporated practice resulted in a significant decline, in the top 0-5 cm of soil, in organic C, total N, electrical conductivity, NH_4-N, NO_3-N, soil moisture holding capacity, microbial biomass and CO_2 respiration as well as a decline in the microbial quotient (the ratio of microbial biomass C to organic C). In contrast, a change from stubble incorporated to direct drill or conventional cultivation practice or a change from conventional cultivation to direct drill or stubble incorporated practice had little impact on soil chemical properties. However, there was a significant increase in microbial biomass and the microbial quotient in the top 0-5 cm of soil following the change from conventional cultivation to direct drill or stubble incorporated practice and with the change from stubble incorporated to direct drill practice. A change from direct drill practice to stubble incorporated or conventional cultivation practice was associated with a significant decline in the ratio of fungal to bacterial fatty acids in the 0- to 5-cm soil. The results show that soil microbiological properties are sensitive indicators of a change in tillage practice.

In corn, tillage regime, cover crop, and nitrogen on various sol organisms inhabiting a sandy soil were determined (Reeleder *et al*., 2006). Soil was collected for three consecutive years. Populations of several of the soil organisms studied were significantly affected by one or more agronomic treatments. Worm populations were low. Spring-sampled

populations were significantly higher in no-till plots than in conventionally tilled plots. Autumn samples were not affected as greatly by tillage, but were generally higher in no-till plots not receiving additional N or a rye cover crop. Soil microbial biomass, as represented by extractable soil DNA, was higher in the spring than autumn. Higher rates of nitrogen increased populations of total soil fungi, but nitrogen had little effect on mites, however mite levels were higher in no-till or cover crop treatments (Reeleder *et al*., 2006). In maize, grown in sub-tropical conditions, the three year effects of no tillage, or reduced tillage and water regime on soil profile distribution of organic matter and physical and microbiological soil quality indicators were examined (Roldan *et al*., 2005). Residue on the soil surface was about 20-fold increased in the no-tilled plots. In the topsoil (0-5cms), OM decreased with increasing tillage and was increased by two flood irrigations. The water regime had no effect on soil structural stability or total microbial activity.

Different tillage practices can strongly influence the abundance and biomass of soil micro-organism. In a study by Frey and colleagues (1999), two experimental plots were compared; grass sod and continuous cultivation with corn rotation. Temperature was the same, however, rainfall varied significantly; with site one having a maximum of 473mm compared to site 2 which receives 1140mm annual rainfall. Fungal biomass and the proportion of the total biomass composed of fungi increased in surfaces soil in response to reduced soil moisture, whereas bacteria remained constant across a range of moisture levels. No-till soils, in addition to be moisture, tended to have higher OM, higher bulk densities and lower temperatures.

In another field trial in South Australia in the grains industry, Pankhurst *et al*. (1995) the detection and characterised changes in soil biological properties were evaluated as the consequence of different agricultural management. The properties examined were total bacteria, fungi, actinomycetes, total pseudomonads, cellulytoic bacteria and fungi, mycorrhiza, plant root pathogens, bacteria feeding protozoa, earthworms, microbial biomass, C and N mineralisation, *in situ* CO_2 respiration, cellulose decomposition, soil enzyme activity. The sensitivity of these biological properties was assessed to tillage, stubble management, crop rotation, and N fertilisation. All management practices significantly affected C mineralisation and microbial biomass. Tillage with stubble management significantly affected root pathogenic fungi, protozoa, earthworms and cellulose decomposition. Crop rotation affect mycorrhiza fungi, protozoa, soil peptidase activity and N fertiliser had a significant effect on mycorrhiza fungi, protozoa and cellulose decomposition. As these biological are responsive to agricultural management, they may have potential as bioindicators. Total bacteria, fungi and actinomycetes, cellulose

decomposing bacteria and fungi and N mineralisation were less affected by these treatments and may therefore have limited potential as bioindicators.

On a field site situated in a table grape property in Mildura, the effects of tillage on beneficial soil invertebrates (Sharley and Thomson, 2005). Between November and February, invertebrate abundance was compared between uncultivated and cultivated plots. Results suggest that cultivating the inter-row does reduce invertebrate abundance and is having a detrimental impact on the beneficial organisms in the soil, particularly in the topsoil. Invertebrates have been shown to increase the permeability of soil and can reduce soil compaction through their daily activities of burrowing and tunnelling. The reduction in soil health brought about by the reduction in invertebrate numbers and can lead to the vineyard manager having to increase inputs into the farming system, such as fertiliser, and rely mainly on other forms of pest control (eg chemical control) other than natural enemies. Careful management between cultivation, and the use of direct drill cover crops as minimum tillage least disrupts beneficial organisms.

Paoletti *et al* (1998) and Paoletti *et al.*, (1995) observed a negative correlation between copper and earthworms in vineyards of northeastern Italy. Cultivation operations in between orchard rows reduced earthworm mean biomass by 42% in peach orchards, 36% in apple orchards, 20% in kiwi orchards, and 34% in vineyards; earthworm mean abundance was reduced by 47%, 37%, 21%, and 64% respectively (Paoletti *et al.*, 1998). A significant, negative regression with copper content in the soil and the natural loss of earthworm abundance was also found in this study.

An ongoing study investigated the effects of cultivation on the food-web in annual (maize) and perennial (asparagus) cropping systems (Wardle *et al.*, 1995). Soil biota in the perennial system was more responsive to cultivation. Cultivation in this site caused large increases in bacterial-feeding nematodes, probably due to the high weed levels which developed during the winter months under that treatment.

Water

Water is becoming an ever increasing and important limitation in viticulture in the Murray Valley region. An important aspect of increasing the sustainability of agricultural production is decreasing water use. The implications of reduced water on soil biota can lead to difficulties in achieving and sustaining soil health. There is generally no or negative effects on species quantity due to reduced water application.

In a study in Australian vineyards, Thomson (2006) investigated the effects of partial rootzone drying on invertebrate species. The results showed that earthworms were significantly reduced under conditions of water stress, although over the two years of the study, species diversity was not affected when compared. When no water stress was applied, the numbers obtained was comparable with those of Buckerfield and Webster, (1996), i.e. earthworm numbers were up to four times higher, 40 earthworms/m^2 compared to 10 earthworms/m^2.

The effects of soil moisture changes on bacteria, fungi, protozoa, and nematodes and changes in oxygen consumption were studied in a field experiment (Schnürer, 1986). In one plot the soil was drip-irrigated daily for 10 days, while an adjacent plot experienced one rainfall and was then allowed to dry out. Oxygen consumption was the parameter measured which responded most rapidly to changes in soil moisture content. Total hyphal length (i.e. length of fungal branching structures) was not affected by one rainfall but increased from 700 mg^{-1} dry weight soil to more than 1,600 m in less than 10 days in the irrigated plot. In the rain plot, bacterial numbers doubled within 3 days and declined during the following period of drought. In the irrigated plot, numbers increased by 50% and then remained constant over the duration of the study.

Furthermore, Zaman and Chang (2004) also report that moisture content affected the microbial biomass C:N ratios which varied from 4.6 (100% field capacity) to 13.0 (50% field capacity of two pastures (lucerne and ryegrass grown as an understorey to pine), which yielded similar trends contrast to bare soils.

In summary, water plays an important role in the soil in terms of facilitating the movement of microbial organisms. Water not only carries bacteria (and predators) it carries dissolved gasses, moves ions and nutrients and prevents desiccation. The fundamental relationship between the physical and chemical activities or processes that modulate soil water and biological activity include nutrient diffusion and mass flow, mobility, temperature and pH, and when considering the interaction of water and biological activity, all the above listed processes contribute and need to be discussed when considering water effects.

Temperature/ CO_2 levels

Elevated CO_2 levels will have little if any direct abiotic effect on soil structure and is also unlikely to have any direct impact on soil biota. This is because the CO_2 concentration in the soil is already very high (due to biotic respiration) compared with that of the atmosphere. Micro-organisms living very near, or on the soil surface may be affected to some degree, but this is still uncertain (Young *et al*., 1998). The major limitation with the

results presented in the literature below is that the environment is artificially modified, and thus, may not bare the same outcomes in field conditions.

The relationship between the fungal: bacterial biomass ratio and the metabolic quotient was studied in three different soils. In addition, the effect of the fungal: bacterial biomass ratio on the relationship between CO_2 evolution and the size of the soil microbial biomass was examined (Sakamoto and Oba, 1994). The range of the fungal:bacterial biomass ratio in two of the three soils was small (1.54–2.24 and 1.11–1.71, respectively), but it was large in the third soil (1.18–3.75). There was a high negative correlation between this ratio and the metabolic quotient (qCO_2=2.10–0.361 (fungal:bacterial biomass ratio) in the soil. Therefore, it can be suggested that qCO_2 decreases with an increase in the fungal:bacterial biomass ratio, which may be due to a higher efficiency of substrate C use by fungal flora in comparison with bacterial flora. In the former two soils, there was a high positive correlation between CO_2 evolution and total microbial biomass.

In a study by O'Neill, (1994), she reports that the responses of soil biota to CO_2 enrichment and the degree of experimental emphasis on them increase with proximity to, and intimacy with, roots. Total plant mycorrhization increases with elevated CO_2. VAM fungi increase proportionately with fine root length/mass increase. ECM fungi, however, exhibit greater colonization per unit root length/mass at elevated CO_2 than at current atmospheric levels. Microbial results to date suggest that metabolic activity (measured as changes in process rates) is stimulated by root C input, rather than population size (measured by cell or colony counts). Preliminary data on foliar litter decomposition suggests that neither nutrient ratios nor decomposition rates will be affected by rising CO_2. This is another important area that may be better understood as the number of longer term studies with more realistic CO_2 exposures increase. Evidence continues to mount that C fixation increases with CO_2 enrichment and that the bulk of this C enters the belowground component of ecosystems.

Kandeler *et al*., (1998) investigated the response of soil micro-organisms to atmospheric CO_2 (ambient plus 200 ppm) and temperature (ambient plus 2 °C) change within model ecosystems. The model communities consisted of four plant species (*Cardamine hirsuta, Poa annua, Senecio vulgaris, Spergula arvensis*), four herbivorous insect species (two aphids, a leaf-miner, and a whitefly) and their parasitoids, snails, earthworms, woodlice, soil-dwelling *Collembola,* nematodes and soil microorganisms (bacteria, fungi. Each experiment ran for 9 months and soil microbial biomass (C_{mic} and N_{mic}), soil microbial community (fungal and bacterial phospholipid fatty acids), basal respiration, and enzymes

involved in the carbon cycling were measured at three soil depths of 0–2, 0–10 and 10–20 cm. The results indicate that elevated temperature under both ambient and elevated CO_2 did not show consistent treatment effects. Elevation of air temperature at ambient CO_2 induced an increase in microbial C of the 0–10 cm layer, while at elevated CO_2 total phospholipid fatty acids (PLFA) increased after the third generation. Root biomass and C:N ratio were not influenced by elevated temperature in ambient CO_2.

Zaman and Chang (2004) also report that other than moisture content, temperature is the dominant influence on soil microbial activities, including microbial biomass C and N. Temperature was compared at 5, 25 and 40 °C in the laboratory of soil collected from plant environments described previously. With increasing temperature, regardless of soil moisture content there was an increase in microbial biomass C:N ratios; which was more pronounced in the bare soil compared to the lucerne and ryegrass ground cover in which the changes in biomass were only reported in soil at 50% field capacity.

The response of above-ground plant and ecosystem processes to climate change are likely to be influenced by both direct and indirect effects of elevated temperature on soil biota and their activities. Bardgett *et al*., (1999) examined the effects of elevated atmospheric temperature on the development of the soil microbial community in a model ecosystem facility. The model system was characterized by a soil of low nutrient availability. The experiment was run over three plant generations, broadly mimicking the early stages of a plant succession, and showed that microbial biomass, measured using phospholipid fatty acid analysis, increased significantly in response to elevated temperature during the first generation only. This increase was unrelated to changes in plant productivity or soil C-availability, and was largely due to a direct effect of elevated temperature on fast-growing Gram-positive bacteria. Slow growing soil microorganisms such as fungi were unaffected by elevated temperature throughout the experimentation. Measures of microbial biomass, microbial respiration and N-mineralization were also unaffected by elevated atmospheric temperature over the three generations. The lack of effects on the soil microbial community is thought to be due to the fact that elevated temperature did not influence root biomass or soil C-availability. In contrast, total microbial biomass declined during the last plant generation. Reductions in the diversity of PLFAs in later plant generations appeared to be associated with an increase in the proportion of fatty acids associated with fungi, relative to those from bacteria. These changes are likely to be related to increased competition for resources within the soil, and an associated reduction in N- and C-availability. Overall, elevated atmospheric temperature has little effect on the development of below-ground microbial communities and their activities in soils of low nutrient status.

Soil structure, pH, cropping sequence and organic matter

Soil health and microbial diversity have become vital issues for the grape growing industry. Continuous plant cover results in increases in the soil organic matter, leading to improved vineyard soil structure, nutrient storage capacity, water infiltration, water holding capacity and microbial density (Gulick *et al*., 1994; Bugg and van Horn, 1997; Pinamonti *et al*., 1996; Whitelaw *et al*., 1997; Whitelaw, 2000).

Changes in soil structure and in microbial populations were recorded in a long term field experiment over the growing season of maize (Guidi *et al*., 1988). Determinations were made on samples from plots which had received for two years the following treatments; mineral fertilisers, farmyard manure and three rates of compost. Seasonal variations were observed for the stability of the soil aggregates, total porosity, pore size distribution, mycorrhiza infection, and aerobic cellulolytic microorganisms. The stability of the soil aggregates changed in a similar way to that found for both mycorrhiza inflection and the number of aerobic cellulolytic microorganisms. Physical characteristics were not affected in any instance by the organic dressings and microbiological populations were generally influences only by the higher doses of compost.

The effect of low quality wheat residue and high quality wheat residue (based on C:N ratios) on macro aggregate formation and fungal and bacterial populations was tested. After 14 days, aggregation, microbial respiration, and total microbial biomass were not significantly different between the two treatments. However, fungal biomass was higher for the low quality residue treatment. In contrast, bacterial populations were favoured by the high quality residue treatment. Addition of N in the low quality residue treatment resulted in reduced macro aggregate formation and fungal biomass, but had no effect on bacterial biomass. These observations are not conclusive for the function of fungal and/or bacterial biomass in relation to macro aggregate formation (Bossuyt *et al*., 2001).

In broccoli (Stamatiadis *et al*., 1999) selected in field physical, chemical and biological indicators were measured for the rapid assessment of soil quality changes as a result of compost and ammonium nitrate application. Plots were laid out in a randomised complete block design with four replications of 0, 22 and 44 Mg ha^{-1} compost which were split to include fertiliser (165 kg N Ha^{-1}) and no fertiliser. Surface application of ammonium nitrate initially stimulated soil nitrification and acidification processes in the topsoil, as evidence by an 80-fold increase in nitrate N and accumulation of nitrite, a 1.5-unit increase in EC and a 1.4-unit decrease in pH. Nitrification was positively correlated to soil respiration and negatively correlated to soil water content. The detected short-term

beneficial effects of compost application were the stabilization of pH and the decrease of water infiltration rate. Stabilisation of pH prevented acidification effects due to fertiliser application. The high soil EC of plots receiving compost probably resulted from a high compost salt content, other than nitrates, and warns against repeated use of high EC composts that may result in N depletion, reduced nutrient cycling and impaired crop growth.

A field study was conducted to determine the influence of a short-term (2 year) cessation of fertiliser applications, liming, and sheep-grazing on microbial biomass and activity in a reseeded upland grassland soil (Bardgett and Leemans, 1995). The cessation of fertiliser applications (N and NPK) on limed and grazed grassland had no effect on microbial biomass measurements, enzyme activities, or respiration. Withholding fertiliser and lime from a grazed grassland resulted in significant reductions in both microbial biomass C by approximately 18 and 21%, respectively. The removal of fertiliser applications, liming, and grazing resulted in even greater reductions in microbial biomass C, and significant reductions in microbial biomass N. The abundance of culturable bacteria and fungi and the soil ATP content were unaffected by changes in grassland managements. With the cessation of liming soil pH fell from 5.4 to 4.7, and the removal of grazing resulted in a further reduction to pH 4.5.

In a survey of 42 farm sites in The Netherlands, comprising grasslands (23 farms) and two types of horticultural farms (vegetables (n=12) or flower bulbs (n=12)), earthworm communities were sampled by digging 15cm deep soil and hand-sorting earthworms, and identifying by type, and a number of soil physico-chemical conditions recorded. Abundance, biomass and species richness were significantly higher in grassland soils than in horticultural soils, and within the horticultural farms significantly higher in vegetable than in flower-bulb farms. No epigeic species were found in horticultural soils. The differences between the various farms types were probably related to the intensity of management practices, such as soil tillage, harvesting and crop protection measures such as pesticide and weedicide use, that results in less soil organic matter of lower quality; 2.78% compared with 6.4% in grasslands, that was present in the horticultural properties. Although diversity and abundance of earthworms was clearly highest in the grassland farms, even here diversity and number of species was apparently low (on average 0.48 and 2.09 respectively, measured over individual sample units) when these figures are compared with data from Australia on pasture soils (Baker *et al.*, 1992, 1997), they are in the same

magnitude. Species was related to soil factor in that study, but the present study relates the species types to climatic distribution (Didden, 2001).

The effects of eight lime application rates on corn/soybean crop rotations assessed the activities of 14 enzymes involved in C, N, P, and S cycling in soils (Acosta-Martinez and Tabatabai, 2000). The enzymes were assayed at their optimal pH values. Lime was applied at rates ranging from 0 to 17,920 kg effective calcium carbonate equivalent (ha^{-1}), and surface samples (0-15 cm) were taken after 7 years. Results showed that organic C and N were not significantly affected by lime application, whereas the soil pH was increased from 4.9 to 6.9. The significant increase in soil pH by lime applications may stimulate the microbial population and diversity, resulting in an increase in soil enzyme activities and thus affecting nutrient cycling. With the exception of acid phosphatase activity, which decreased with increasing soil pH, the activities of all other enzymes increased with increasing pH. The results support the view that soil pH is an important indicator of soil health and quality.

Variations in soil microbial biomass C concentration and in activity of extracellular enzymes were investigated in a field experiment of crop cereal and legume crop rotations after eight years of cultivation with either low organic matter input or high organic matter input (Debosz *et al.*, 1999). The cultivation system differed in whether their source of fertiliser was mainly mineral or organic, in whether a winter cover crop was grown, and whether straw was mulched or removed. Sampling occurred at monthly intervals over a two-year period. Distinct variations in microbial biomass C concentration and activity of extracellular enzymes were observed, such as biomass C, cellobiohydrolase activity, endocellulase activity and B-glucosidase activity, and were higher in the high OM treatment. It appears that these variations were driven more by environmental factors such as temperature and moisture and crop growth, rather than the OM status.

Following long-term cereal cropping, soil was subjected to a 16 month treatment period consisting of either a mixed cropping sequence of vetch, barley and clover or a continuous grass/clover ley which was continuously mowed and mulched (Bending *et al.*, 2000). Neither treatment had an effect on microbial N or respiration of microbial population. Also, after the experiment, there were no changes to OM and C:N ratios.

Soil organic matter level, soil microbial biomass C, C mineralization, and dehydrogenase and alkaline phosphatase activity were studied in soils under different crop rotations for 6 years. Inclusion of a green manure crop in the rotation improved soil organic matter status

and led to an increase in soil microbial biomass, soil enzyme activity and soil respiratory activity. Microbial biomass C increased from 192 mg kg^{-1} soil in a pearl millet-wheat-fallow rotation to 256 mg kg^{-1} soil in a pearl millet-wheat-green manure rotation. Inclusion of an oilseed crop such as sunflower or mustard led to a decrease in soil microbial biomass, C mineralization and soil enzyme activity. The results indicate the green manuring improved the organic matter status of the soil and soil microbial activity vital for the nutrient turnover and long-term productivity of the soil (Chander, 1997).

The effects on soil condition of increasing periods under intensive cultivation for vegetable production were compared with those of pastoral management using soil biological, physical and chemical indices of soil quality (Haynes and Tregurtha, 1999). The majority of the soils studied had high pH, exchangeable cation and extractable P levels reflecting the high fertilizer rates applied to dairy pasture and more particularly vegetable-producing soils. Soil organic C content under long-term pasture (>60 years) was in the range of 55 g C kg^{-1} to 65 g C kg^{-1}. With increasing periods under vegetable production, soil organic matter declined linearly to 15-20 g C kg^{-1}. The microbial quotient (C_{mic}/C_{org}) decreased from 2.3% to 1.1% as soil organic matter content declined from 65 g C kg^{-1} to 15 g C kg^{-1}. With decreasing soil organic matter content, there was an associated decline in earthworm numbers, soil aggregate stability and total clod porosity, however, this was not recorded until soil organic C content fell below about 45 g C kg^{-1}. It can be concluded that soils under continuous vegetable production, practices that add organic residues to the soil should be promoted and that extending routine soil testing procedures to include key physical and biological properties will be an important future step in promoting sustainable management practices in the area.

To conclude, land management practices alter the number of functional groups in the soil. Crop selections, tillage practices, residue management, pesticide use, mineral inputs and irrigation alter the habitat for soil organisms, and thus, alter the structure and diversity in the soil of the food web. Although not specific to viticulture, the summary above provides information of the changes in soil biota population types and numbers due to management practices and environmental conditions. It is not surprising that bacteria and fungi numbers in each sample vary according to these management practices (nutrient availability, temperature, moisture, pH, and other environmentally influenced factors, however, whether these outcomes will be achieved in vineyard soils are still unclear. Care must also be taken in interpreting the research data as an abundance of information compared the effects of the management on soil structure, and does not correlate to soil biota levels, therefore, it remains unclear where the management practice alone impacts on the soil

structure or whether the role of soil biota assist in the overall changes to the soil. This ultimately affects what occurs above ground, in our case the grapevine, and the changes in soil structure will undoubtedly affect for example nutrient and water uptake.

4. Effects of soil biota on soil health, vine health and fruit quality

Microbial population aims to increase fertility in attempt to produce a living, healthy and balanced soil and vines. Biological complexity of a soil system can affect processes such as nutrient cycling, the formation of soil structure, pest cycles and decomposition rates. Researchers have yet to define how much and what kind of food web complexity in managed ecosystem is optimal for these soil functions and processes to occur efficiently.

Functions and processes of beneficial micro-organisms:

1. Fixation of atmospheric nitrogen and carbon from the air for plant uptake;
2. Decomposition of organic wastes and residues;
3. Suppression of soil-borne pathogens;
4. Recycling and increased availability of plant nutrients;
5. Degradation of toxicants including pesticides;
6. Production of antibiotics and other bioactive compounds;
7. Production of simple organic molecules for plant uptake;
8. Solubilisation of insoluble nutrient sources; and
9. Production of polysaccharides to improve soil aggregation.

Below provides a snapshot of how some of these processes and functions work.

Nutrient cycling

When organisms consume food, they create more of their own biomass and they release wastes. The most important waste for crop growth is ammonium (NH_4^+). Ammonium and other readily utilised nutrients are quickly taken up by other organisms, including plant roots. When a large variety of organisms are present, nutrients may cycle more rapidly and frequently among forms the plants can and cannot use.

Nutrient cycling and retention

Most of the nutrients contained in soil organic matter are in complex organic forms that have to be mineralised to an inorganic form before they can be used by the plant. Soil micro-organisms play a dominant role in the decomposition of organic material such as cellulose, polysaccharides, lignins, proteins and amino acids, and are responsible for nearly all nitrogen and carbon transformations in the soil. They are also important in transforming nutrients such as phosphorus, sulphur, iron, potassium, calcium, magnesium, manganese, aluminium and zinc into forms that can be used by the plant. Soil micro-organisms therefore have a beneficial impact on plant health by releasing nutrients that would

otherwise be ‘locked away’ in dead plant and animal tissue. In addition to mineralising or releasing nitrogen to plants, the soil food web can immobilise or retain nitrogen when plants are not rapidly growing. Nitrogen in the form of soil organic matter and organism biomass is less mobile and less likely to be lost from the rooting zone than inorganic nitrate (NO_3^-) and ammonium (NH_4^+).

Improved structure

Many soil organisms are involved in the formation and stability of soil aggregates. The binding substances that hold soil particles together have both mineral and organic origins. Some of the organic binding agents are contributed by soil biota. Bacterial activity, organic matter, and the chemical properties of clay particles are responsible for creating micro-aggregates from individual soil particles. Earthworms and arthropods consume small aggregates of mineral particles and organic matter, and generate larger faecal pellets coated with compounds from the gut. These faecal pellets become part of the soil structure. Fungal hyphae along with fibrous roots bind soil particles and small aggregates together into larger units. Polysaccharides (sugars) produced by micro-organisms act as the gums that bind and stabilise aggregates. Plant residues are also broken down by soil biota to create soil aggregates. Improved aggregates stability, along with the burrows of earthworms and arthropods, increase porosity, water infiltration and water holding capacity.

Disease suppression

Soil borne disease problems are common in soils that have been intensively cropped. Such soils are said to be conducive to disease. They have lost much of their microbial diversity and biological buffering capacity, so many competitors of fungal pathogens and root-feeding nematodes have disappeared. In contrast, a disease suppressive soil has a full complement of beneficial organisms, and the pathogens that cause disease are unable to increase to levels that will cause damage. The organisms involved in disease suppression act in many different ways. Fungi and bacteria are able to displace each other by competing for nutrients. Bacteria can either inhibit the growth of pathogens, produce antibiotics that are detrimental to pathogens. Fungi can parasitise, whereas some of the larger organisms consume pathogens. Suppression is improved by agronomic practices such as stubble retention, spraying liquid microbe cultures on the soil and plants, slashing grass cover (including weeds) and minimising grazing. The greatest implication for disease suppression is the long duration to achieve.

Although each of these functions and/or processes are important, the most important function is to build soil structure, so oxygen, water and nutrients can easily move into the soil and into deep, well-structured root systems. Current concepts of plant root systems as being at the surface of the soil is the result of current agricultural and urban practices. Roots should go down into the soil for at least 10 feet, but the compaction that humans impose on soil results in toxic materials being produced, preventing good root penetration. The only way to deal with this is to have the proper biology build the structure in the soil again, so oxygen and water can move into the soil. When the biology is functioning properly, water use is reduced, the need for fertiliser is reduced, and plant production, vine health and fruit quality is increased.

5. Measuring soil biota populations in the vineyard

The soil food web can be very complex due to the diversity of soil biota present. It is not feasible to try and measure all biota population types / numbers and activity levels throughout the season. Instead, a measurement of fungi, bacteria and fungal – bacterial ratio can be used as an indication of vineyard soil health.

Soil biota activity is dependent on seasonal and daily conditions. In temperate systems, the greatest activity occurs in late spring when temperature and moisture conditions are optimal for growth; this is so for the Murray Valley region. However, certain species are most active in winter, others during dry periods, and still others in flooded conditions. Not all organisms are active at a particular time. Even during periods of high activity, only a fraction of the organisms are eating, respiring, and altering their environment. The remaining portions are barely active or even dormant.

To ensure accurate results it is important that a representative sample of the soil food web / soil biota is taken for analysis. In order to maintain a viable soil food web, there must be an availability of food, therefore, the soil biota is generally found concentrated in one of the following four locations:

1. Around roots – the rhizosphere is the narrow region of soil directly around the roots. It is teaming with bacteria that feed on necrotic plants cells and the proteins and sugars released by roots. The protozoa and nematodes that graze on bacteria are also concentrated near roots. Thus, nutrient cycling and disease suppression needed by plants occurs immediately adjacent to roots.
2. On humus – fungi are most common here. Much organic matter in the soil has already been decomposed many times by bacteria and fungi and/or passed through the stomach of earthworms or arthropods. The resulting humic compounds are complex and have little available nitrogen. Only fungi make some of the enzymes needed to degrade the complex compounds in humus.
3. On the surface of soil aggregates – biological activity, in particular that of aerobic bacteria and fungi, is greater near the surface of soil aggregates than within aggregates. Within large aggregates, processes that do not require oxygen, such as denitrification can occur. Many aggregates are actually the faecal pellets of earthworms and other invertebrates.
4. In spaces between soil aggregates – those arthropods and nematodes that cannot burrow through soil move in the pores between soil aggregates. Organisms that are sensitive to desiccation, such as protozoa and many nematodes live in water-filled pores.

In Murray Valley vineyards the extent of the soil food web would depend on irrigation practices, the potential to sustain vegetation and, organic matter in the soil. Organic matter is generally low in Murray Valley soils, therefore, sampling from the soil around the root zone would produce the best indication of soil biota present and thus soil health. It is important to note that while the vineyard soil food web will be most concentrated around the root zone, the treatment of the inter-row area will impact on the diversity and population levels of the overall vineyard soil food web.

Samples can be taken periodically throughout the season, at any time of the day, to develop a baseline specific to a particular vineyard. This is especially important when supplementing the soil food web with extra soil biota to boost the soil food web and thus vineyard performance. However, as stated above, only a fraction of the soil biota present is active at one time, therefore, the optimal times to be testing biota population types and numbers is during times of optimal plant growth. In the viticulture industry, active root growth is in spring, however, autumn soil testing is proving to be of benefit to ensure that the corrections required can be implemented in time for budburst. It is also important to ensure that the sample you collect is moist as dry conditions cause in micro organisms to be dormant.

The procedure for representative sampling is similar to soil sampling for nutrient content and can be summed up by the following points:

- Take approximately 10 representative 2-2.5cm diameter cores from the top 10cm of soil.
- Core samples should be taken from the area of the vineyard that is to be analysed for soil biota population types, numbers and activity levels.
- Mix the samples together and put approximately 500g in a zip-lock bag. Clearly label the sample(s).
- The bag should be only slightly bigger than the sample to maintain sample viability during postage to the laboratory.
- Store sample in a cool / dry area until packaged for postage. Do not leave the sample in a hot area exposed to the sun; this may change the outcome of the analysis.
- Package sample in a solid box for postage ensuring that it can not move about. Remember to include the analysis requirements with the sample.
- Send the sample / s in overnight express post to ensure the soil biota is still alive when it reaches the laboratory for analysis.

- Samples should not be sent on a Thursday or a Friday to ensure that samples reach the laboratory in timely manner and optimal condition for analysis.
- Avoid taking samples immediately after an irrigation / rainfall event or fertiliser application, unless measuring biota changes caused by these events.

The sampling procedures are simple to follow, however, before taking a sample it is important to check with the agent through which the sample is sent to the laboratory to make sure any specific requirements are addressed. It is imperative that your soil sample reaches the laboratory within three days to ascertain the true status of your soil. Activity will be affected if prolonged longer than three days when following this sampling protocol.

6. Soil biota testing facilities – Australian laboratories

When your soil sample is tested, the minimum assessment the laboratory will measure is the total and active bacteria and fungus levels otherwise known as the soil foodweb status, however, many laboratories will and can measure additional soil organisms including protozoa, nematodes and mycorrhizal fungi at an additional cost.

Requesting fungal and bacterial biomass allows for a good preliminary assessment for your soil health. Active biomass is a measure of the organisms that are metabolising or "doing the work". Fungi and bacteria are active when food resources are available and conditions are favourable.

The following list of laboratories in Australia offers the service of measuring and reporting on the status of soil biota in your vineyard, at a fee. The fee varies depending on number of samples and the specific tests requested, and best to discuss with the supplier.

Soil Foodweb Inc.

1 Crawford Rd, East Lismore NSW 2480

p. 02 6622 5150

f. 02 6622 5170

w. www.soilfoodweb.com.au

Australian Soil Additive and Products Pty Ltd

PO Box 121 Bangalow NSW 2479

p. 02 6688 2324

w. www.asap.com.au

YLAD Living Soils

p. 02 6382 2165

w. www.ylad.com.au

BioAg Pty. Ltd.

22-24 Twynam St, Narrandera NSW 2700

p. 02 6959 9911

f. 02 6959 9922

w. www.bioag.com.au

Environmental Responsible Agriculture (ERA) Sustainable Farming Company Pty Ltd

PO Box 1644 Canning Vale WA 6155

p. 08 94552 2184

f. 08 9455 4269

w. www.erafarming.com

7. Interpretation of results

While the theory of a soil web is relatively easy to understand, that is, different soil biota classes interacting to produce different outcomes as described above, the concept of sustaining a balanced soil web is a difficult one. The diversity of soil biota in the soil food web and the factors that affect population type, numbers and activity level makes it difficult to know which indicators to concentrate on. There are a number of tests available to determine microbial populations, but the ones which are the most meaningful to the viticulturalists include; fungal:bacterial ratio and the C:N ratio. These two main methods can be determined by chloroform fumigation incubation or by phospholipid fatty acids methods. Below defines how these two methods are used to determine the soil microbial biomasses, including more advance microbiological techniques that can also be used.

The measurement techniques which will allow for these rapid assessment to characterise a food web include (Parkinson and Coleman, 1991; Pankhurst *et al*., 1996; Dalal, 1998; Vancow, 2001; Schloter *et al*., 2003):

- Microscopic methods – estimated bacteria and fungi to determine biomass. Difficulties exist in identifying living and non-living microbes.
- Measuring activity levels – activity is determined by measuring the amount of by-product such as CO_2, generated in the soil, or the disappearance of substances such as plant residue or methane used by a large portion of the community or by specific groups of organisms. These measurements reflect the total "work" the community can do. Total biological activity is the sum of activities of all organisms, though only portions are active at a particular time.
- Respiration – measuring CO_2 production. This method does not distinguish which organisms (plants, pathogens, or other soil organisms) are generating the CO_2.
- Nitrification rates – measuring the activity of those species involved in the conversion of ammonium to nitrate.
- Decomposition rates – measuring the speed of disappearance of organic residue or standardised cotton strips.
- Measuring cellular constituents – The total biomass of all soil organisms or specific characteristics of the community can be inferred by measuring components of soil organisms such as the following: Biomass carbon, nitrogen or phosphorus – measure the amount of nutrients in living cells, which can then be used to estimate the total biomass of organisms. Chloroform fumigation is a common method used to eliminate the amount of carbon or nitrogen in all soil organisms. C:N ratios can then be calculated.

- Enzymes – measured enzymes in living cells or attached to soil. Different enzymes are identified depending on the microbe being assessed.
- Assays can be used to estimate potential activity or to characterise biological community.
- Phospholipids and other lipids - provide a “fingerprint” of the community and quantify the biomass of groups such as fungi. The fungi fingerprint; of 18-C chain constitutes 43% of the total phospholipid fatty acid in soil fungi together with ergosterol, specific to fungal membranes, which have a strong correlation in soil, thus, indicating estimate fungal biomass. That ratio between fungal and bacterial can be calculated based on the number of ratio of carbon chained fatty acids, where bacterial based microbes exists in phospholipids greater than 20-Carbon units.
- DNA and RNA – provide a “fingerprint” of the community and can detect the presence of specific species or groups. This latter method for assessing the composition and diversity of soil microbial communities has been extensively reviewed by Hill and colleagues (2000).

The use of these methods described above in agricultural situations have contributed to increasing our knowledge of soil quality. For comparative purposes soil microbial biomass and its derived indices have been successfully used to measure changes induced by land use practices. As a routine analytical tool, it is limited by the cumbersome and time consuming measurement, lack of benchmarking values and interpretation, ambiguous relationship with productivity and cost effectiveness. With our increasing demand to monitor soil quality and protection of the environment, improved and rapid techniques will be required.

The following table **(Table 4)** quantifies the biomass levels of micro organisms regardless of soil type or soil organic matter level assuming no crop is grown;

• Microbial Diversity	• “Best” Quantity (g/ dry soil)
• Active Bacterial Biomass	• 50 ug
• Total Bacterial Biomass	• 100ug
• Active Fungal Biomass	• 50ug
• Total Fungal Biomass	• 100ug

Table 4: The minimum quantities of bacteria and fungi required in soils.

Highly productive agricultural sandy loam soil best yields often occur with a 1:1 fungal bacterial biomass ratio. However, grapevines have been classified as a fungal dominated plant, i.e. feed on fungi more than bacteria. The ratio which has been determined is 5:2, or in simpler terms 5 fungi to every 2 bacteria (www.soilfoodweb.com.au). Therefore, a soil with a greater fungal dominance often has the ability to build up its organic matter status because of the management practices which favour organic matter levels in the soil whether it is from a grass cover crop or soil-chemical reactions which are continuously occurring. It is also important to have high diversity, i.e. the number of different species or types of organisms present in the soil sample.

It is difficult to present outcomes from these testing procedures, and relate them to viticulture. There is an abundance of literature in forest soils and compared to general agricultural soils e.g. pastures and cereal crops. However, the ratios of fungi to bacteria differ in these plants; thus, caution is required in interpreting the research findings. For example, row and vegetable crops are generally bacterial dominated, compared to forests and tree crops which are more fungal dominated. The table below lists the preferred ratios **(Table 5)**. The first four species are more bacterially dominated, that is a greater number of bacteria are generally present or are required for optimal growth compared to fungi. The latter four species are fungal dominated where fungi are required in greater amounts for optimal growth.

Plant species	Ratio
Lawn	0.5: 1 (bacteria dominated)
Carrots	0.5:0.8
Tomato	0.8:1.0
Wheat	0.8:1.0
Grape	2-3:5 (fungal dominated)
Apple	10:50
Eucalyptus	10:100
Conifers	100:1000

Table 5: Ratio of bacteria: fungi of different crop species Source: www.soilfoodweb.com.au

The role of earthworms in promoting soil fertility is important (Lee, 1985; Werner and Dindal, 1989). Because of their strong interaction with soil, earthworm populations are profoundly affected by agricultural practices, such as soil tillage, crop residues, the use of fertilisers and pesticides etc. (Edwards 1983; Daugbjerg *et al.*, 1988). Knowledge of the

effect of each agricultural practice on earthworms is necessary in order to adopt appropriate soil management. Earthworms may also be used as bioindicators of soil management because they are easy to rear and classify and are sensitive to both chemical and physical soil parameters (Paoletti *et al.*, 1991) prove earthworms to be good bioindicators of microclimate, and nutritional and toxic conditions of vineyard soils.

Each laboratory offers the service of report interpretation for each sample, and it is in the grower's interest to discuss their results individually with the supplier of your choice, so the laboratory can decide on the best action to improve your soil biota status. Your results will include a written description of biomass, desired results and phone consultation. The level of consultation varies upon service provider and additional advice may be available depending on service provider, with or without a fee. Based on the bacteria and fungal assessments, the desired ranges and units calculated for grapevines (according to the soilfoodweb organisation) are;

Organic biomass data	Units	Desired range
Dry weight of 1 gram fresh material	NA	0.45-0.85
Active Bacterial Biomass	µg/g	1-10
Total Bacterial Biomass	µg/g	100-300
Active Fungal Biomass	µg/g	10-25
Total Fungal Biomass	µg/g	200-600
Hyphal Diameter	µm	*Varies dependent on community dominance 2-3+
Protozoa- Flagellates	Number/g	5000+
Protozoa- Amoebae	Number/g	5000+
Protozoa- Ciliates	Number/g	50-100
Total nematode	Number/g	10-20
Percent Mycorrhizal Colonization of root	%	40-80

Table 6: *Hyphal diameter of 2.0 = actinobacteria hyphae, 2.5 = ascomycete (typical soil fungi for grassland), 3.0+ basidiomycete fungal community

Your results will present data on these organic biomass parameters. As a grape grower your soil should have the active levels of bacteria and fungi in the desired ranges, and also at the ratio of 2-3:5. For example if the biomass results was returned with the active bacteria being 6, we would hope that the associated fungal levels would be 12.

Why it is important to carefully discuss your results is because management practices play a role in the biota levels, and it is the decision of the grower to decide if any changes in management will be adopted. If organisms are missing, i.e. the bacteria and fungal species are not present, the anticipated action would be to replace or put them into your soil system, and many laboratories would recommend addition of composts or microbial teas that contain lots of organisms. However, if the organisms are there (Total biomass level), but not active, a substance to “wake them up” may be all that’s required. It is important to note that at certain times of the year, the activity status of these microbes vary dependant on healthy soil moisture levels as described earlier.

If you feel that your laboratory is presenting biased information, and encouraging the use of particular products, it is recommended to talk to an independent soil microbiologist. Recently, the viticulture team at the National Wine and Grape Industry Centre (NWGIC), Wagga Wagga NSW; phone 02 6933 2113; has researched soil biota levels in field trials in both warm irrigated (Griffith) and cool climate (Tumbarumba) regions. The staff members involved would be available to assist in further interpretation of your results and answer further queries relating to your results.

8. Techniques to increase soil biota activity

The following section of this review describes the various techniques to increase soil biota. Some of the methods listed have not been investigated scientifically in viticulture; therefore, the transfer of the reported benefits to increase biota levels should be considered at your own discretion.

Cover crops

Cover cropping has been used to limit soil erosion, contribute to reducing and even eliminating the use of herbicides and other chemicals for pest and disease control (Pardini *et al*. 2002). In addition, cover cropping plays a key role in guaranteeing sustainable production through the maintenance of soil fertility (Porter, 1998). Viticulture in Australia and the Murray Valley has been using cover cropping as a popular method for reduced heat exchange and more importantly soil improvements. Only recently are the biological benefits of cover cropping being high-lighted such as the associated increases in beneficial organisms and organic matter.

In a study, with five year-old Merlot/5BB field-grown vines, several cover crops were planted to test their effects on vine growth, production, juice composition, soil microbial ecology and gopher activity over a three-year period. Under vine was maintained by herbicide. The mixes used were native perennial grass (no till), annual clover (no-till) green manure (disced), cereals (disced) and disced control. Cover cropped soils had greater microbial biomass than disced or tilled soils, and the no-till mix had greater microbial biomass (determined by phospholipid fatty acid analysis) than the disced mixes (Ingels *et al*., 2005) and was important in improving soil physical qualities and nutrient cycling. In other systems, no-till management practices have had a positive effect on microbial biomass relative to conventional-till management practices ((soybean/wheat, maize/wheat, cotton/wheat [Balota *et al*., 2003], cotton (Feng *et al*., 2003), even though in intensive vegetable production, the effects of tillage on microbial biomass were not found (Jackson *et al*., 2003).

After three years of investigation, permanent swards increased labile organic carbon levels, both in the inter-row and the under-vines soils in a warm- irrigated vineyard and cool climate vineyard in NSW. At the same time, the populations of soil bacteria were markedly higher in the sward than the bare soil and the total fungal populations were increased in the sward inter-row soil. Beneficial nematodes, namely bacteria feeders, fungal feeders and predators, were more abundant in the top 10cm soil inter-row than under vine positions

(Hutton *et al*., 2006). Higher plant-parasitic nematodes were recorded from the under-vine positions, and were highest in the 10-20cm soil profile.

The following table **(Table 7)** discusses the main effects of cover cropping in vineyards in relation to increasing soil biota activity;

• Effect on soil	• Mechanism	• Authors
• Increased Organic Matter (OM) content thus providing greater food supply for fungi and bacteria to feed.	• Cover crop mulch is left to decompose. Roots of annual species die off leaving OM in the soil.	• Mitham, 1999 • Porter, 1998 • Warner, 1999b •
• Reduced number of specialised parasites and increased ecological stability.	• Higher ratio between beneficial and parasitic insect species.	• Daane and Costello, 1998 • Jutzi, 1997

Table 7: Main effects of cover cropping

Another benefit for cover crops other than those listed above, are the provisional habitat for beneficial arthropods. Additionally, cover crops augment soil organic matter, which can improve soil physical, biological and chemical conditions in the vineyard rooting zone. Cover crops create macropores either by displacing soil during taproot formation or granulation of soil particles into aggregates (sod-forming species). During cover crop decomposition into stable humates, fungi and bacteria further aggregate soil particles by secreting organic substances. In the process, change in soil structure occurs as macropores and aggregation improve infiltration, water storage, and soil gas exchange. In warm, sunny dry climates, frequent tillage and high soil temperatures cause net losses of SOM, even when planting cover crops annually. Organic matter may accumulate more rapidly under grass/root culture. Cover crop composition and floor management can influence the fate of soil carbon. Because of its high cation exchange capacity per unit weight, increases in SOM can significantly improve soil fertility. As SOM increases, nutrient retention and nitrogen availability increases. Microbial biomass, activity and community composition respond to changes in soil management, which can affect the rate at which SOM accumulates. Changes in microbial composition and soil fauna may confer improvements in soil quality (McGourty *et al*., 2004).

Manures and composts

In a New Zealand study, the effects of organic mulch on soil and grapevine were investigated in four Sauvignon blanc vineyards local to the Marlborough wine region (Agnew *et al.*, 2003; Mundy and Agnew, 2002; Agnew *et al*., 2002). The mulch consisted of varied combinations and quantities of vineyard pruning and marc, green waste, pine bark, animal manure and crushed mussel shells and were compared to vines with no mulch over a three-year period. The application of this mulch resulted in significant changes in soil nutrient status including an increase in pH, soil OM, rapid release of P and K in year one, and then no further significant change, and a slight increase in sodium.

To summarise the key results from the New Zealand study, the key benefits from using mulches were soil OM increases, soil temperature buffering, i.e. more constant soil temperature around roots at 10cm depth, with temperature varying by $0.5^{O}C$ compared to 10 degrees in bare soil and a maximum soil temperature between 5-10 degrees cooler in the summer months in the mulched vines. The increases in soil fungi populations, thus improvements in soil structure through aggregate formation were reported, no effects on yield, however, even though a benefit was not seen, no detrimental effects to grapevines were noted, such as bunch rots; considering grape pruning were used; nor excessive vine vigour and juice composition such as total soluble solids and titratable acidity.

A wide range of municipal and commercial /industrial organic waste material can be composted with source separated green and food waste being the most common input material. Biosolids can be co-composted relatively easily with green waste. However, when using these, you must prescribe to compost quality standards, which vary from states and territories, and consultation of the Biosolids standards are available from the EPA, i.e., Quality control of organic waste products such as municipal composts and biosolids is likewise mandatory to avoid accumulation of elements that are toxic to soil organisms.

The use of compost in viticulture can, as in other agricultural/ horticultural applications result in a wide range of positive effects. However, there is also scope for potentially detrimental effects. The following table **(Table 8)** lists these advantages and disadvantages.

• Positive effects	• Negative effects
• Supply of humus – replenishes soil humus, which is reduced by soil	• Oversupply of nutrients – knowledge of OM status and or when large

cultivation • Supply of plant nutrients • Improvement of soil physical, chemical and biological properties (indirect effects) • Increase OM after long term use • Crop yield and quality effects?? Long term studies are required.	quantities of compost supplied • Heavy metals • Governed by legal regulations.

Table 8: Effects of using composts in viticulture.

Two composts were tested as mulching materials in a vineyard (Pinamonti, 1998). One was sewage sludge and bark compost with low metal, the other was a municipal solid waste compost with a higher concentration of metals. Both compost mulches increased organic matter content, available phosphorus and exchangeable potassium of soil and improved the porosity and water retention capacity of the soil. They also reduced soil temperature fluctuations, reduced evaporation of soil water, and influenced some nutrients measured in leaf samples. These latter characters were also observed in the Viticare trials mulching trial in Swan Hill where oaten straw was placed under Merlot vines (Dimos, 2006).

Zaller and Kopke (2004) studied the effects of applications of traditionally composted cattle farm manure and two types of biodynamically composted manure over nine years as a fertiliser on soil chemical properties, microbial biomass and respiration, dehydrogenase and saccharase activities, decomposition rates and root production under grass-clover, activity and biomass of earthworms under wheat, and yields in a grass-clover, potatoes, winter wheat, beans, spring wheat, winter rye crop rotation. The experiment was conducted in Germany in a completely randomised block design. The results showed that plots which received either prepared or non-prepared manure at a rate of 30 Mg ha^{-1} yr^{-1} had significantly increased soil pH, P and K concentrations, microbial biomass, dehydrogenase activity, decomposition, earthworm cast production and altered earthworm community than those plots without cattle manure application. Crop yields were not affected by either application. The biodynamic preparations of manure significantly decreased microbial basal respiration, but did not affect soil microbial biomass, dehydrogenase activity or decomposition during the first 60 days. However, after 100 days, decomposition was significantly faster in these prepared manure plots, furthermore significantly leading to higher biomass and abundance of endogeic earthworms, i.e., those to be important in the establishment and maintenance of soil structure. This is in contrast to those finding of

Carpenter-Boggs *et al*., (2000), however, this latter study was short-term in comparing organic and biodynamic farms.

Elfstrand *et al*., (2007) looked at soil enzyme activities, microbial community composition and function after 47 years of continuous green manuring. Green manuring practices can influence soil microbial community composition and function and there is a need to investigate the influence compared with other types of organic amendments. The study reports the long-term effects of green manure amendments, applied at a rate of 4 t C ha^{-1}, every second year, on soil microbial properties, based on a field experiment started in 1956. Phospholipid fatty acid analysis (soil microbe analysis method identifying fungi or bacteria based on carbon chain lengths) indicated that the biomass of bacteria, fungi and total microbial biomass, generally increased due to green manuring compared with soils receiving no organic amendments. Minor differences in abundance of different microbial groups were also found compared with other organic amendments (farmyard manure and sawdust) such as a higher fungal biomass and consequently a higher fungal/bacterial ratio compared with amendment with farmyard manure.

In a study on apples orchards, the comparison on organics to conventional practices were compared (Werner, 1997). Microbial respiration was higher in organic plots, increased colonisation from mycorrhiza fungi resulted in increased tissue P levels, and earthworm abundance, however, the author claims that the three year timeline to convert to organic status were barely adequate to create changes in the soil characteristics which were measured.

Compost Teas

Compost teas are becoming more popular amongst growers as a way to boost the diversity, abundance and activity of microbial communities in the soil. Compost teas are used for two reasons;

1. To inoculate microbial life into the soil or onto the foliage and
2. To add soluble nutrients to feed the organisms and the plant present.

The use of compost tea is suggested any time when the organisms in the soil are not at optimal levels. Compost tea is a liquid produced by leaching soluble nutrients and extracting bacteria, fungi, protozoa and nematodes from compost. It differs from compost in that teas are brewed with a microbe food source such as molasses, specifically to allow the microbes to reproduce and build in numbers. Specific conditions are required to

produce effect compost teas, particularly regarding aeration (a constant temperature is reuired). Aerobically brewed teas are the best understood and are most commonly used by growers. These require careful management to ensure that the tea is well aerated to support the growth of desirable microbe species. Compost teas can be applied four ways. These include foliar applications, soil drenches applied in spring and autumn, seed treatments or aeration by filling soil core with tea, compost and sand. The reported benefits of using compost tea containing the whole foodweb include those listed above for cover crops and mulch/composts (www.soilfoodweb.com.au, 2008), however, the is no known scientific evidence of their effectiveness in the viticulture industry. It is recommended that you consult with local growers to share knowledge and outcomes gained by use of this product.

Commercial inoculants and additives

In a recent American study, Merlot/5C wines were produced from biodynamically grown grapes (Reeves *et al*., 2005). In a concept similar to organic viticulture, biodynamics eliminates synthetic chemical fertilisers and pesticides. The primary difference between the two farming systems is that biodynamics uses a series of soil and plant amendments called preparations (plant inoculants) applied either as a field spray or compost, which stimulate the soil and enhance plant health and end-product quality. Whether these preparations actually augment soil or winegrape quality is unclear. Within the first six years of the study, no differences were observed in nutrient analyses or vine yield components, however, post six years, pruning weight to yield ratios were significantly different and indicated that the biodynamic treatment had ideal vine balance for producing high quality winegrapes.

Conversely, Raupp and Konig (1996) found that biodynamic preparations only caused significant effects under poor yielding conditions. The biodynamic plots had 39% more earthworms, which are known to enhance soil structure, organic matter decomposition, and nutrient cycling (Edwards and Lofty, 1977).

Different companies are bringing out common applications of microbes that can be applied through the irrigation systems. Here are some examples of companies to consult in using these types of products; Spray Gro, Nutritech Solutions, BioAg. They concentrate on stimulating microbial populations through the addition of products such as humic acids, seaweed, and using often conventional inputs to produce healthy and balanced soils and vines. There are no known reports evaluating the effects of humic acids and seaweed products in viticulture, and the anecdotal evidence available is sourced from resellers, however, Kim *et al*., (1997), reports that the use or benefits of microbial inoculants are

short lived, however, this investigation was on tomato plants. It is, thus, recommended that you test the product to ensure its viability.

Seaweed and humic substances contain major and minor nutrients, trace elements, hormones and antibiotics which condition both the plant and soil. Viatmins are also present and act as a plant conditioner, however, is not found in the extract form of seaweed. Seaaweed and humic acids helps to produce a crumb structure in the soil, another of the ways in which soil structure helps retain moisture. This in turn leads to better aeration and capillary action, and these stimulate the root systems of plants to further growth, and also stimulate soil bateria to greater activity. These products will not increase soil organic matter. In terms of soil conditioning, bacteria activity in the presence of seaweed has two results;

1. secretion of substances which assist in further soil conditioning and stabilising
2. leads to a temporary diminuation of nitrogen and phosphorus available for the plant, then an augmentation of the nitrogen and phosphorus total.

Regardless of the technique to increase soil biota level, the food sources for the biota exist rely on enzymes (proteins) and hormones (sugars and / or proteins) and other good food resources eg plant growth promoting materials, which arer produced by bacteria and fungi, protozoa, nematodes and microarthropods. The greater the number of biota the more enzymes, hormones will be produced and consumed for growth by the soil biota, ultimately leading to a more healthy soil for your vineyard.

9. Recommendations for the Murray Valley.

In recommending soil health techniques in the Murray Valley, the single most important goal is to increase the soil organic matter status. This in turn will assist in the building up of microbe levels in the soil and allow for soil structural improvements and species diversity which promotes good plant health. Observations show that agricultural management practices and products to raise soil biota levels, such as those described earlier have a greater effect on soil biota. It is important that samples from the same region, same soil type under different management regimes will have variable soil biota levels and its important to assess your vineyard individually.

Agronomic practices that enhance soil organic matter include;

- Cover crops
- Reduced tillage/ soil disturbance
- Trialling alternative products

As these options aid root development, increased resistance to environmental stresses and increase the availability of nutrients to the vine.

Some soils would be able to buffer change better, e.g. medium textured-type. It would undoubtedly take longer to build a healthy soil food web in a sandy soil, due principally to the low organic matter status. As stated above, the main aim is to raise the organic matter content of any soil type to raise the soil biota, thus, health status of the soil. To raise the organic matter profile, it is important to have the organisms to decompose leaf litter and so on (eg prunings). Other common methods include the use of cover crops or the use of mulches and composts as they provide a good food source for the organisms. Current limitations in the research on these products is they seldom investigate the role or effects on the soil biota, as in the past has not been the principle focus. The recent use of microbial additions, actively aerated compost teas and seaweeds has had successful benefits in other agricultural crops, although has not been investigated in viticulture. However, we are now keen to investigate the use of these products and methods and make assessments specific to our grapegrowing region.

Therefore, sandy, light soils and pure clays have lower diversity, grapevines or any row crop would need an increase in organism diversity and the fugal to bacterial biomass ratios change to 5:2-3. The fewer disturbances imposed to the agricultural system, the lesser the affect on the soil food web, and the system will become less complex and possibly more bacterial. With increased productivity, the soil will become more fungal dominated. However, it may require time to achieve.

10. Conclusion

Soil health is an area of agricultural production has the potential to improve productivity and quality in vineyards of the Murray Valley. The idea of controlling and manipulating the soil environment, i.e. the biological, physical and chemical status to create a more favourable soil microbiological environment for optimum crop production and protection is not new. One advantage is that the viticulture industry is continually looking at environmental ways to sustain and correct soil quality and let a “natural system” assist in achieving our production goals. With our ultimate aim of increasing soil organic matter through the use of inoculants, organic amendments and cultural and management practices, it is envisaged shortly that our knowledge on the benefits of these products on soil biota levels will prove beneficial to the already known agronomic benefits such as improved water retention and disease suppression. Integrated vineyard programs typically incorporate a range of soil health techniques (manures, cover crops, composts, microbial solids and liquids), often in association with conventional inputs.

The functions of the food web are essential to plant growth and environmental quality. Good resource management will integrate food web enhancing strategies into the vineyard. Needed research will examine the food web functions within whole systems, and will support technology development. In the coming years, we can expect progress in answering soil biology such as the following, specifically to the winegrape industry;

1. What is a healthy food web? i.e., what measurements or observations can be used to determine whether a particular biological community is desirable for the intended land use and what levels of complexity is optimal for highly productive and sustainable crop?
2. Is it more useful to count species, or types of organisms? Organisms are divided into six groups in a soil food web. Achieving optimal balance of these groups of these groups is one approach to managing the food web. Alternatively, identifying the species and complexity present within a group may provide other useful information about the health and productive potential of a soil.
3. How should the biology of the soil be managed? In the future, farmers may be able to precisely predict the effect of management decisions such as timing of tillage, the application of certain kind of compost, or the use of particular pesticides. They may choose practices with the intent of making specific changes to the composition of the soil food web.
4. What are the costs and benefits for biological functions? The costs to achieve a highly diverse or complex soil community need to be identified. These can be compared to the benefits of biological services provided, such as nutrient cycling, diseases suppression, and soil structure enhancement.

By following such a program, growers in the Murray Valley can typically obtained the following gains in their vineyards;

- greater grape yields of consistently high quality,
- improved colour classification for reds grape varieties and
- the ability to reach target baumes earlier.

Also, there are reports of less dependence on fungicides and insecticides, reducing the possibility of delayed harvesting due to withholding periods. Irrigation intervals may be stretched and water use efficiency improved due to the greater root mass of the vines and the soil having a superior water holding capacity.

Generally, those studies described have reported little changes in yield and fruit composition, however, improvements to the soil biota levels regardless of management practice requires time to see any changes in the vineyard, and by understanding the processes of soil health, a sustainable approach to viticulture in the Murray Valley, delivering long-term fertility can be reached. Further investigations, however, are still required to confirm these suggested benefits.

A healthy soil effectively supports plant growth, protects air and water quality. The physical structure, chemical make-up and biological components of the soil together determine how well a soil performs. Organic matter is required in order to have the organisms performing their function in the soil and will result in an increase in microbe diversity, all while soil structure is being built. This will leads to an overall improvement in grape production. Thus, the benefits to the grapegrowers of the Murray Valley will be enormous, both environmentally and economically with sustainable production, product improvement in the field and potentially at end point, marketers' edge and personal fulfilment.

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APPENDIX 2

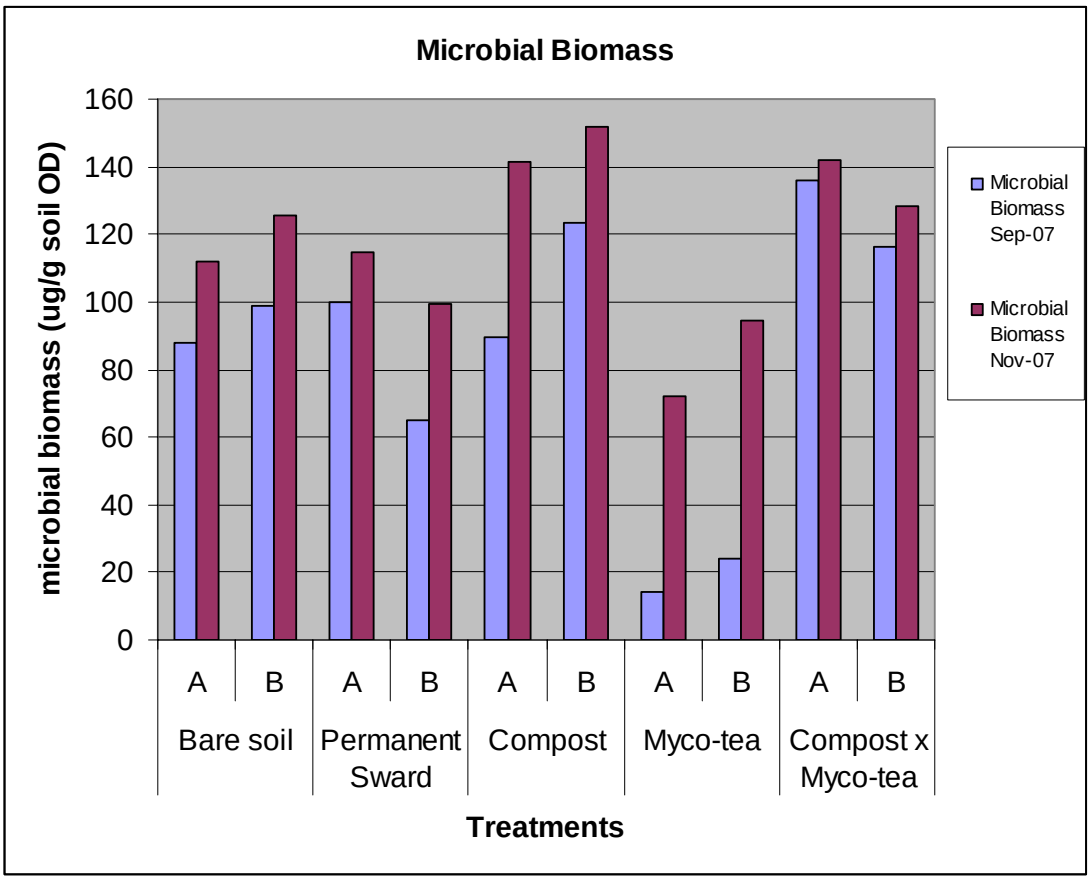
Soil Health Trial 1 – Trial Design

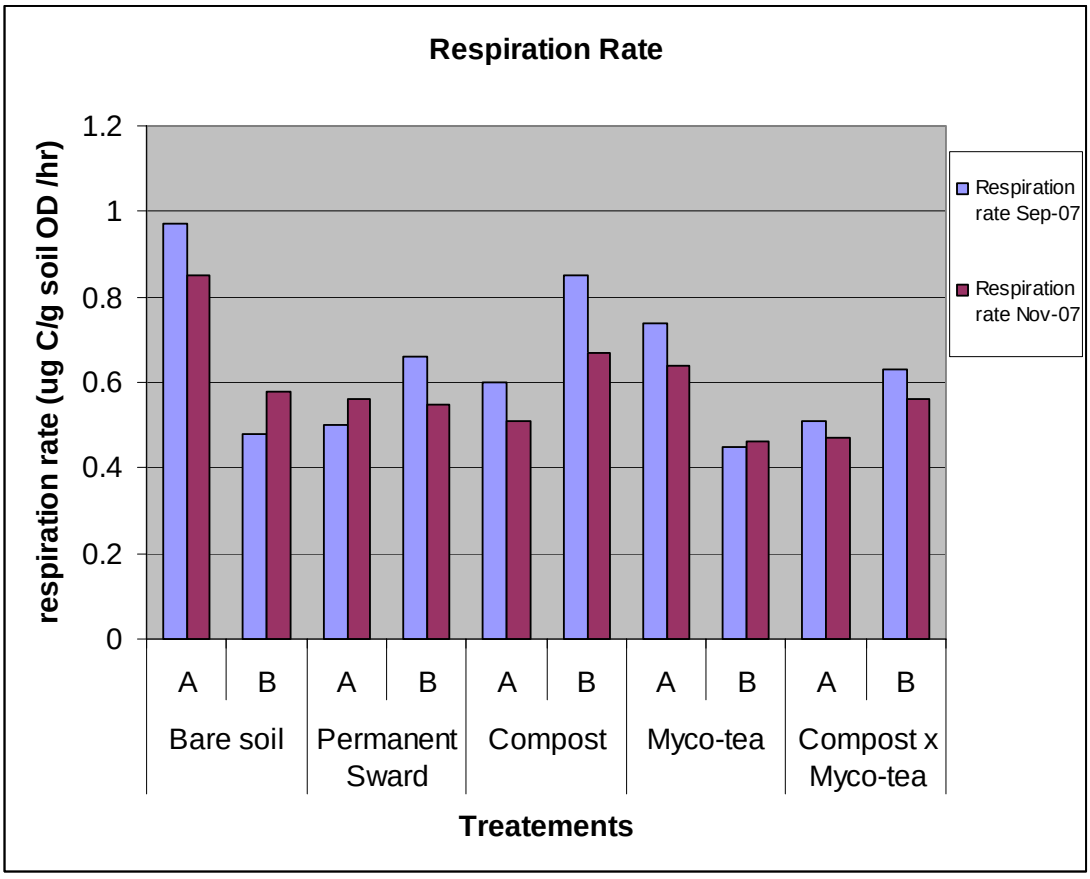
Soil Health Trial - Random Selection

Rows 4-6 Vines 140-185		Rows 8-11 Vines 125-190		Rows 13-15 Vines 130-180	
Treatment	**Location**	**Treatment**	**Location**	**Treatment**	**Location**
Section 1 -Permanent sward	R 4-6 V 143-145	Section 6 - Compost X MycoTea	R 9-11 V 128-130	Section 11 - Bare Soil	R 13-15 V 134-136
Section 2 - Bare Soil	R 5-7 V 149-151	Section 7 - MycoTea	R 8-10 V 137-139	Section 12 -Compost X MycoTea	R 13-15 V 140-142
Section 3 - Compost	R 4-6 V 155-157	Section 8 - MycoTea	R 8-10 V 155-57	Section 13 - MycoTea	R 13-15 V 146-148
Section 4 - Compost X MycoTea	R 4-6 V 161-163	Section 9 - Permanent sward	R 8-10 V 170-172	Section 14 - Permanent sward	R 13-15 V 164-166
Section 5 - Compost	R 4-6 V 182-184	Section 10 - Bare Soil	R 9-11 V 185-187	Section 15 -Compost	R 13-15 V 173-75

APPENDIX 3

Soil Health Trial 1 – Soil Microbial biomass and respiration rate results





Note: “A” results are indicative of the Vine bank and “B” results are indicative of the mid row.

Treatment	Sampling area	Mean microbial biomass (µg/g soil OD)		Mean respiration rate (µg C/g soil OD/hr)	
		September 2007 sampling	November 2007 sampling	September 2007 sampling	November 2007 sampling
Bare soil	Vinebank	88.15	112.10	0.97	0.85
	Inter row	98.69	125.77	0.48	0.58
Compost	Vinebank	89.49	141.32	0.60	0.51
	Inter row	123.44	151.82	0.85	0.67
Myco tea	Vinebank	14.17	72.05	0.74	0.64
	Inter row	24.05	94.55	0.45	0.46
Compost Myco tea	Vinebank	135.77	141.75	0.51	0.47
	Inter row	116.09	128.08	0.63	0.56
Permanent sward	Vinebank	99.85	114.67	0.50	0.56
	Inter row	65.03	99.30	0.66	0.55

APPENDIX 4

Soil Health Trial 1 – Fruit Quality Results

Baume: A measure of sugar content that can be used to predict the potential alcohol level that may be achieved.

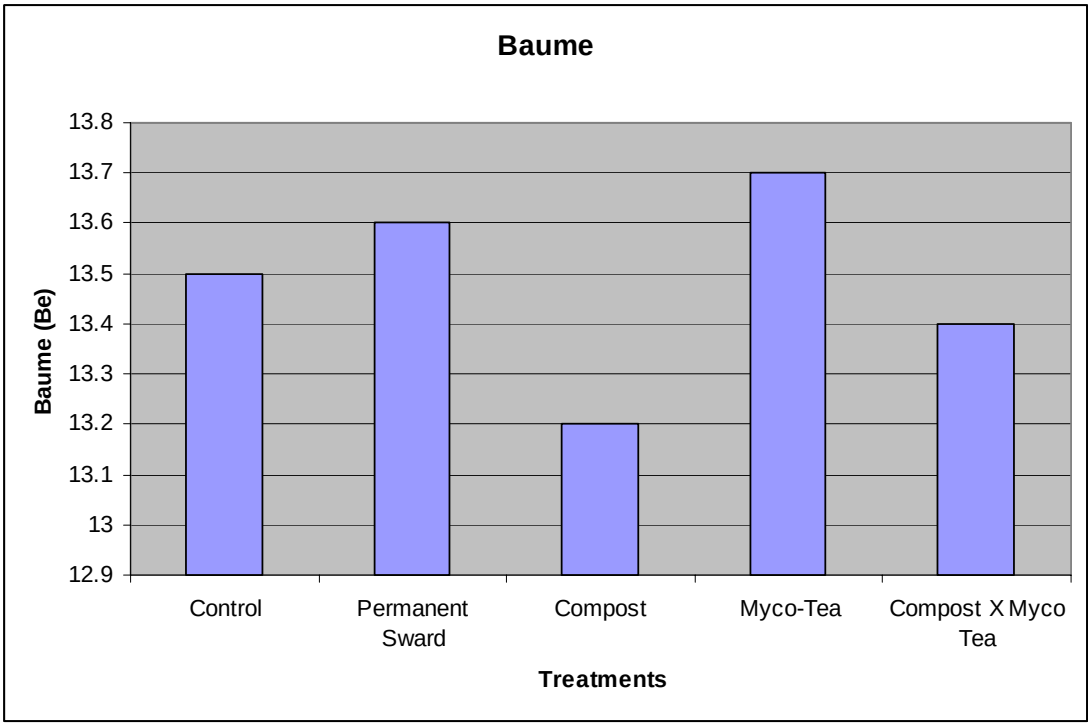
pH: A measure of acidity or basicity of a solution.

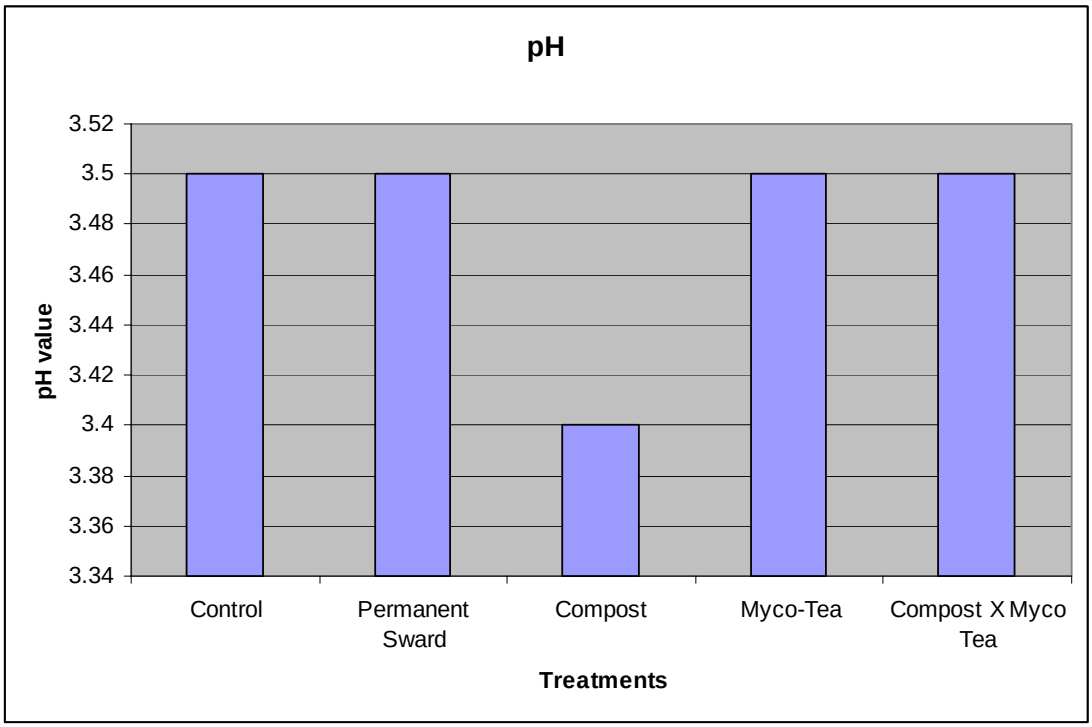
Titratable Acid: A measure of the total amount of organic acids available in juice or wine.

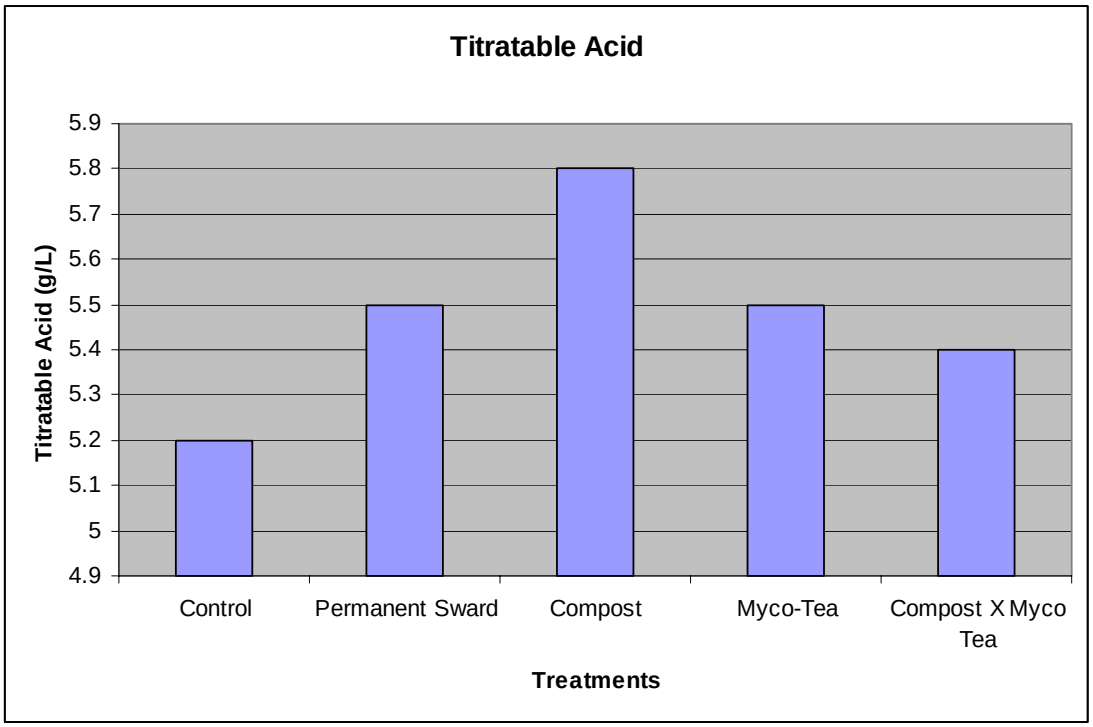
Anthocyanins: A measure of colour in fruit, juice or wine.

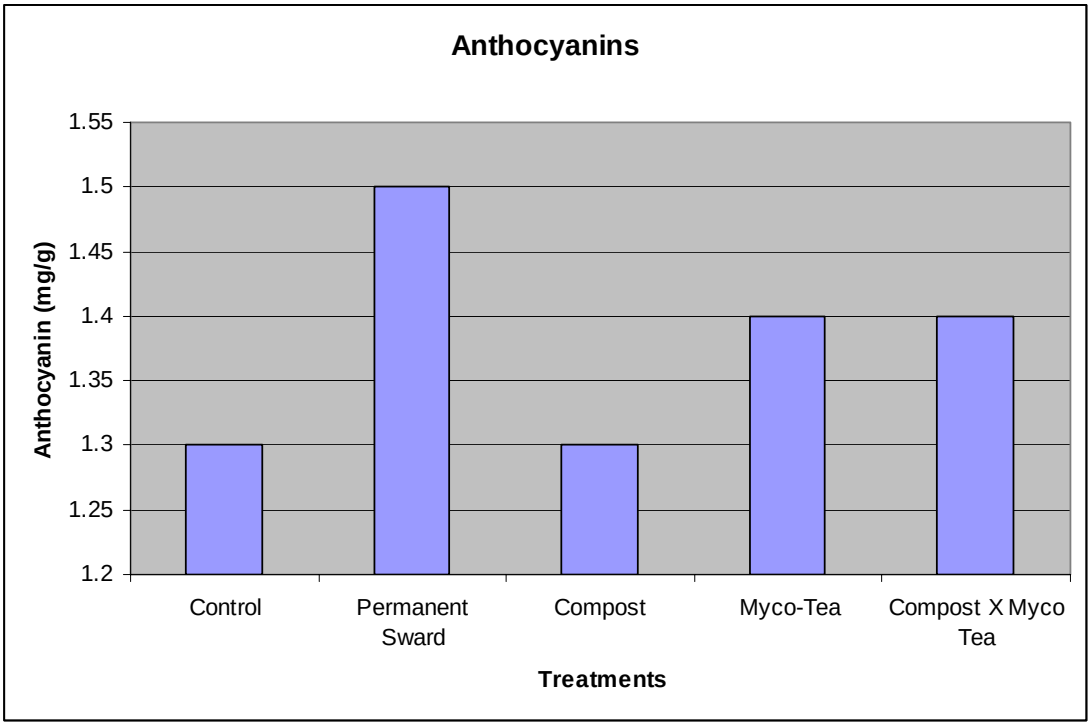
Phenolics: Are chemicals compounds found mainly in the skins and seeds of grapes.

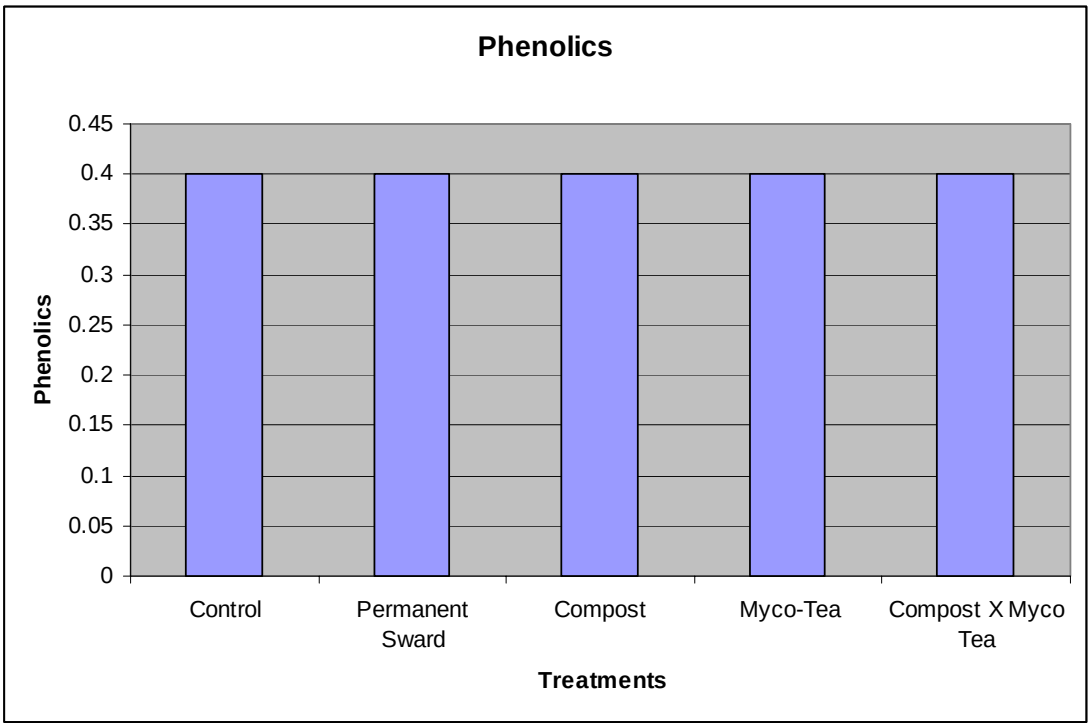
Tannins: Are astringent, bitter plant compounds that caused the dry feeling in the mouth when drinking red wine.

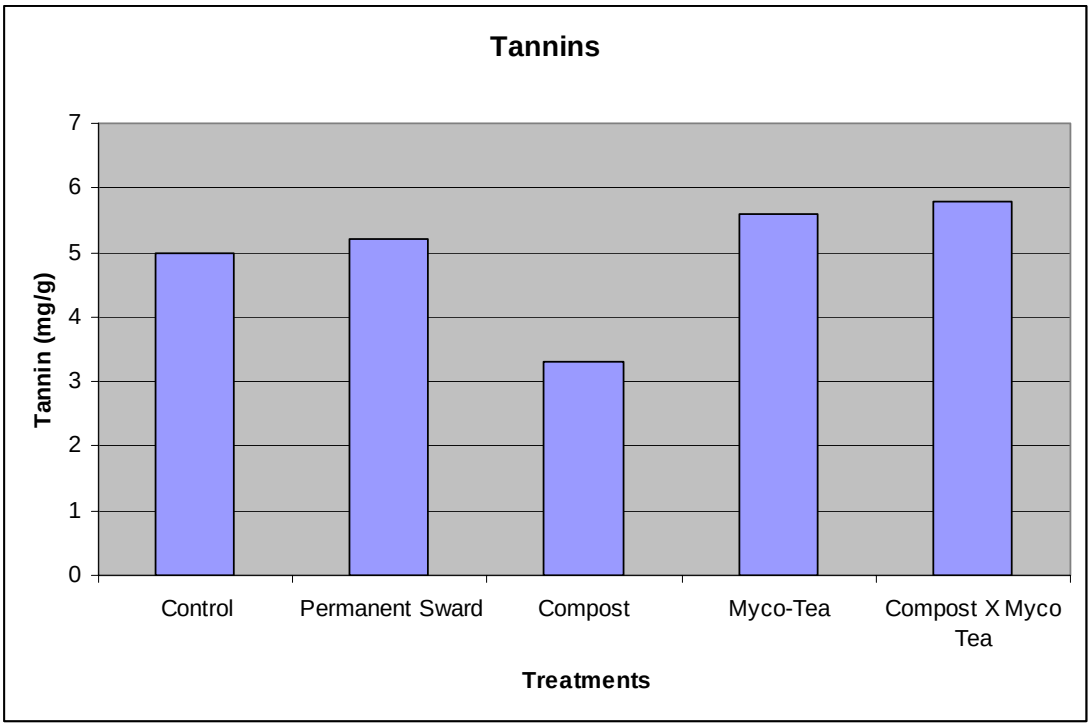

Baume
13.8
13.7
13.6
13.5
13.4
13.3
13.2
13.1
13
12.9
Baume (Be)
Control
Permanent Sward
Compost
Myco-Tea
Compost X Myco Tea
Treatments


pH
3.52
3.5
3.48
3.46
3.44
3.42
3.4
3.38
3.36
3.34
pH value
Control
Permanent Sward
Compost
Myco-Tea
Compost X Myco Tea
Treatments


Titratable Acid
Titratable Acid (g/L)
5.9
5.8
5.7
5.6
5.5
5.4
5.3
5.2
5.1
5
4.9
Control
Permanent Sward
Compost
Myco-Tea
Compost X Myco Tea
Treatments


Anthocyanins
Anthocyanin (mg/g)
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
Control
Permanent Sward
Compost
Myco-Tea
Compost X Myco Tea
Treatments


Phenolics
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Phenolics
Control
Permanent Sward
Compost
Myco-Tea
Compost X Myco Tea
Treatments


Tannins
7
6
5
4
3
2
1
0
Tannin (mg/g)
Control
Permanent Sward
Compost
Myco-Tea
Compost X Myco Tea
Treatments

Treatment	Date	Section	Baume	pH	Titratable Acid g/L	Anthocyanins mg/g	Phenolics	Tannin mg/g
Control	18-Feb	SH2	13.7	3.48	5.7	1.51	0.457	5.9
	18-Feb	SH10	14.1	3.50	4.6	1.25	0.372	7.2
	18-Feb	SH11	12.8	3.42	5.3	1.23	0.347	1.8
	Average		**13.5**	**3.5**	**5.2**	**1.3**	**0.4**	**5.0**
Permanent Sward	18-Feb	SH1	13.9	3.51	5.3	1.49	0.434	5.1
	18-Feb	SH9	13.3	3.49	6.2	1.49	0.435	4.9
	18-Feb	SH14	13.6	3.49	5.1	1.53	0.464	5.5
	Average		**13.6**	**3.5**	**5.5**	**1.5**	**0.4**	**5.2**
Compost	18-Feb	SH3	13.0	3.45	6.3	1.33	0.377	1.9
	18-Feb	SH5	13.9	3.46	5.4	1.52	0.443	6.5
	18-Feb	SH15	12.6	3.40	5.6	0.90	0.404	1.5
	Average		**13.2**	**3.4**	**5.8**	**1.3**	**0.4**	**3.3**
Microbial solution	18-Feb	SH13	13.1	3.48	5.0	1.29	0.465	5.9
	18-Feb	SH7	14.1	3.54	5.9	1.51	0.429	5.1
	18-Feb	SH8	13.9	3.50	5.5	1.42	0.427	5.9
	Average		**13.7**	**3.5**	**5.5**	**1.4**	**0.4**	**5.6**
Compost & Microbial solution	18-Feb	SH4	13.1	3.48	5.7	1.46	0.480	6.0
	18-Feb	SH6	14.2	3.55	5.4	1.46	0.371	7.8
	18-Feb	SH12	12.9	3.46	5.2	1.16	0.351	3.7
	Average		**13.4**	**3.5**	**5.4**	**1.4**	**0.4**	**5.8**

APPENDIX 5

Soil Health Trial 2 – Biology Results

1. Soil Sample No. 1 – September 2008 – Control & Treatment
2. Compost Biology results – September 2008
3. Soil Sample No. 2 – April 2009 – Control & Treatment

1. Soil Samples No.1 – September 2008 – Control & Treatment

Soil Foodweb Analysis

Report prepared for:

Murray Valley Winegrowers Inc
Liz McGuire
PO Box 2745
Mildura, Vic 3502 Australia
liz.mcquire@murrayvalleywinegrap

Report Sent: 30/09/2008
Sample#: 02-009153 | Submission:02-004737
Unique ID: Cab Sav - Control
Plant: Grapes
Invoice Number: 5128
Sample Received: 11/09/2008

For interpretation of this report please contact:
Local Advisor: or regional lab:
Soil Foodweb Institute Pt
contact@soilfoodweb.co
0266225150
Consulting fees may apply

Organism Biomass Data		Dry Weight	Active Bacterial (µg/g)	Total Bacterial (µg/g)	Active Fungal (µg/g)	Total Fungal (µg/g)	Hyphal Diameter (µm)
Results		**0.870**	24.7	1009	**5.43**	**115**	2.75
Comments		Too Dry	Excellent	Excellent	Low	Low	
Expected Range	Low	0.45	10	150	20	300	
	High	0.85	20	300	40	600	

Nematodes per Gram of Soil
Identification to genus

		Protozoa Numbers/g			Total Nematodes #/g	Percent Mycorrhizal Colonization	
		Flagellates	Amoebae	Ciliates		ENDO	ECTO
Results		--	Not Ordered	--	Not Ordered	Not Ordered	Not Ordered
Comments							
Expected Range	Low	20000	20000	50	30	40%	40%
	High			100	50	80%	80%

Organism Biomass Ratios		Total Fungal to Total Bacterial	Active to Total Fungal	Active to Total Bacterial	Active Fungal to Active Bacterial	Plant Available N Supply (lbs/acre)
Results		**0.11**	**0.05**	**0.02**	**0.22**	
Comments		Low	Low	Low	Low	
Expected Range	Low	2	0.25	0.25	1	
	High	5	0.95	0.95	2	

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Dry Weight: Add organic matter to improve soil biology, build soil structure, increase water holding capacity.

Active Bacteria: Bacterial activity above expected levels; Bacterial biomass will increase as long as nutrients are available.

Total Bacteria: Higher than normal bacterial biomass suggests high bacterial species diversity.

Active Fungi: Need to improve active biomass; Add 20 to 40 litre/ha of liquid humic acids, or 2.5 to 12.5 tonnes/ha fungal compost or woody mulch, or 200 litre/ha fungal compost tea.

Total Fungi: Need to improve total fungal biomass. Add fungal compost (2.5 to 12.5 tonnes/ha or more), or multiple applications of 200 litres/ha fungal compost tea as soil drench.

Hyphal Diameter: Good balance of disease suppressive and normal soil fungi.

Protozoa:

Total Nematodes

Mycorrhizal Col. Endo: | Ecto:

TF/TB: Too bacterial- dominated for grapes. Will lack disease suppression, nutrient retention, ability to build soil structure. Need to improve beneficial fungi to balance bacterial biomass.

AF/TF: Low activity; need to add fungal foods to encourage fungi.

AB/TB: Low activity: add bacterial foods.

AF/AB: Soil is bacterial dominated, and becoming more bacterial; addition of fungal foods might help maintain balance.

Nitrogen Supply

Interpretation Comments

Soil Type: Clay, low organic matter, 0.8%, Irrigated: yes, Plant: Grapes, Notes:

Actinobacteria Biomass = 8.20 ug/g

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Soil
Foodweb Analysis

Report prepared for:

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Liz McGuire
PO Box 2745
Mildura, Vic 3502 Australia
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Report Sent: 30/09/2008
Sample#: 02-009154 | Submission:02-004737
Unique ID: Cab Sav - Treatment
Plant: Grapes
Invoice Number: 5128
Sample Received: 11/09/2008

For interpretation of this report please contact:
Local Advisor: or regional lab:
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Organism Biomass Data	Dry Weight	Active Bacterial (µg/g)	Total Bacterial (µg/g)	Active Fungal (µg/g)	Total Fungal (µg/g)	Hyphal Diameter (µm)
Results	**0.90**	31.6	895	**3.53**	**177**	2.75
Comments	Too Dry	Excellent	Excellent	Low	Low	
Expected Range Low	0.45	10	150	20	300	
Expected Range High	0.85	20	300	40	600	

Nematodes per Gram of Soil
Identification to genus

	Protozoa Numbers/g			Total Nematodes #/g	Percent Mycorrhizal Colonization	
	Flagellates	Amoebae	Ciliates		ENDO	ECTO
Results	--	Not Ordered	--	Not Ordered	Not Ordered	Not Ordered
Comments						
Expected Range Low	20000	20000	50	30	40%	40%
Expected Range High			100	50	80%	80%

Organism Biomass Ratios	Total Fungal to Total Bacterial	Active to Total Fungal	Active to Total Bacterial	Active Fungal to Active Bacterial	Plant Available N Supply (lbs/acre)
Results	**0.20**	**0.02**	**0.04**	**0.11**	
Comments	Low	Low	Low	Low	
Expected Range Low	2	0.25	0.25	1	
Expected Range High	5	0.95	0.95	2	

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Dry Weight: Add organic matter to improve soil biology, build soil structure, increase water holding capacity.

Active Bacteria: Bacterial activity above expected levels; Bacterial biomass will increase as long as nutrients are available.

Total Bacteria: Higher than normal bacterial biomass suggests high bacterial species diversity.

Active Fungi: Need to improve active biomass; Add 20 to 40 litre/ha of liquid humic acids, or 2.5 to 12.5 tonnes/ha fungal compost or woody mulch, or 200 litre/ha fungal compost tea.

Total Fungi: Need to improve total fungal biomass. Add fungal compost (2.5 to 12.5 tonnes/ha or more), or multiple applications of 200 litres/ha fungal compost tea as soil drench.

Hyphal Diameter: Good balance of disease suppressive and normal soil fungi.

Protozoa:

Total Nematodes

Mycorrhizal Col. Endo: | Ecto:

TF/TB: Too bacterial- dominated for grapes. Will lack disease suppression, nutrient retention, ability to build soil structure. Need to improve beneficial fungi to balance bacterial biomass.

AF/TF: Low activity; need to add fungal foods to encourage fungi.

AB/TB: Low activity: add bacterial foods.

AF/AB: Soil is bacterial dominated, and becoming more bacterial; addition of fungal foods might help maintain balance.

Nitrogen Supply

Interpretation Comments

Soil Type: Clay, low organic matter, 0.8%, Irrigated: yes, Plant: Grapes, Notes:

Actinobacteria Biomass = 0.41 ug/g

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e-mail: contact@soilfoodweb.com.au

Simple Foodweb Analysis

Murray Valley Winegrowers Inc
Liz McGuire
PO Box 2745
Mildura, VIC 3502

Sample Type: Soil
Sample Received: 11/09/08
Invoice Number: 5128

Sample #	Overal Rating	Comments 20 fields observed.	
9153 Cab Sav Control	Poor	**Bacteria:** **True Fungi:** **Active Protozoa:** **Nematodes:**	> 500 per field. Low diversity. Mostly cocci type bacteria. 40%. Low diversity. Opaque. Hyaline and brown fungi. Fungal diameter range 2.0 - 5.0µm. None observed. None observed.

Sample Information: Sample taken on 9/09/08 from irrigated cab sav vines growing in sandy clay loam, low organic soil. Organic matter 0.8%.

Overall rating of samples are based on the percentage of organisms observed in each category. Although high percentages of some organisms may suggest a good rating, the lack of other organisms will place the sample into a lower category.

Ratings: Excellent / Very Good / Good / Adequate / Poor / Bad

2. Compost Biology Results

Compost Foodweb Analysis

Report prepared for:

Australian Vermiculture
Brendon Price
PO Box 532
Broken Hill, NSW 2880 Austral
(088) 087-7682
brendonj@bigpond.net.au

Report Sent: 25/09/2008
Sample#: 02-009145 | Submission:02-004731
Unique ID: Vermicompost A/U
Plant:
Invoice Number: 0
Sample Received: 09/09/2008

For interpretation of this report please contact:
Local Advisor: or regional lab:
Soil Foodweb Institute Pt
contact@soilfoodweb.co
0266225150
Consulting fees may apply

Organism Biomass Data	Dry Weight	Active Bacterial (µg/g)	Total Bacterial (µg/g)	Active Fungal (µg/g)	Total Fungal (µg/g)	Hyphal Diameter (µm)
Results	0.620	124	4062	**11.1**	272	2.5
Comments	In Good Range	Excellent	Excellent	Low	Good	
Expected Range Low	0.45	15	100	15	100	
Expected Range High	0.85	25	3000	25	300	

	Protozoa Numbers/g			Total Nematodes	Percent Mycorrhizal Colonization	
	Flagellates	Amoebae	Ciliates	#/g	ENDO	ECTO
Results	22266	73980	**0**	**2.81**	Not Ordered	Not Ordered
Comments	High	High	Low	Low		
Expected Range Low	10000	10000	50	20		
Expected Range High			100	30		

Organism Biomass Ratios	Total Fungal to Total Bacterial	Active to Total Fungal	Active to Total Bacterial	Active Fungal to Active Bacterial	Plant Available N Supply (lbs/acre)
Results	**0.07**	0.04	0.03	**0.09**	100-150
Comments	Low	Good	Good	Low	
Expected Range Low	0.75	0.01	0.01	0.75	
Expected Range High	1.5	0.1	0.1	1.5	

Nematodes per Gram of Soil
Identification to genus

Bacterial Feeders	
Butlerius	1.09
Cuticularia	0.39
Diplogasteritus	0.18
Fungal Feeders	
Thonus	0.09

Australian Vermiculture
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Report Sent: 25/09/2008
Sample#: 02-009145 | Submission:02-004731
Unique ID: Vermicompost A/U
Plant:
Invoice Number: 0
Sample Received: 09/09/2008

For interpretation of this report please contact:
Local Advisor: or regional lab:
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Dry Weight:	Within normal moisture levels for compost.
Active Bacteria	Bacterial activity above expected levels; bacterial biomass will increase as long as nutrients are available.
Total Bacteria	Higher than normal bacterial biomass suggests high bacterial species diversity.
Active Fungi:	Fungi may have run out of food or oxygen; add fungal foods, consider turning when oxygen drops too low.
Total Fungi:	Aerobic fungal biomass in normal range for mature compost.
Hyphal Diameter	Good balance of disease suppressive and normal soil fungi.
Protozoa	Low ciliate numbers suggest lack of species diversity. Nutrient cycling will be limited. Need inoculum of protozoa to build populations, restore missing species.
Total Nematodes	Low numbers, low diversity, need to add beneficial nematodes.
Mycorrhizal Col.	Endo: | Ecto:
TF/TB:	More bacterial biomass than fungal biomass. Excellent for improving bacterial diversity and biomass.
AF/TF:	Fungal component is mature, meaning activity below 10%.
AB/TB:	Bacterial component is mature, which means bacteria will not compete with plants for nutrients.
AF/AB:	Bacterial-dominated compost is becoming more bacterial; addition of foods for preferred dominance might speed balance.
Nitrogen Supply	Low nutrient cycling and availability. Need more protozoa and beneficial nematodes to cycle nutrients.

Interpretation Comments

Compost age 2 months, compost from manures and greenwaste, reached 65*C for ? days, turned ? times, water added: 0 when needed times, for Not Indicated plant, Smell: ?. Notes: Client notes - smells great.

Actinobacteria Biomass = 14.6 ug/g

3. Soil Sample No. 2 – April 2009 – Control & Treatment

Soil Foodweb Analysis

Report prepared for:

Murray Valley Winegrowers Inc
Liz McGuire
PO Box 2745
Mildura, Vic 3502
(035) 023-2335
liz.mcquire@murrayvalleywinegrape

Report Sent: 01/05/2009
Sample#: 02-010094 | Submission:02-005085
Unique ID: K & J Bottrell Control
Plant: Grapes
Invoice Number: 5392
Sample Received: 22/04/2009

For interpretation of this report please contact:
Local Advisor: or regional lab:
Soil Foodweb Institute
contact@soilfoodweb.c
0266225150
Consulting fees may apply

Organism Biomass Data	Dry Weight	Active Bacterial (µg/g)	Total Bacterial (µg/g)	Active Fungal (µg/g)	Total Fungal (µg/g)	Hyphal Diameter (µm)
Results	**0.90**	10.1	197	0.60	147	3
Comments	Too Dry	Above range	In range	Below range	Below range	
Expected Range Low	0.45	1	100	10	200	
Expected Range High	0.85	10	300	25	600	

	Protozoa (Numbers/g)			Total	Mycorrhizal Colonization (%)	
	Flagellates	Amoebae	Ciliates	Nematodes #/g	ENDO	ECTO
Results	--	Not Ordered	--	Not Ordered	Not Ordered	Not Ordered
Comments						
Expected Range Low	5000	5000	50	10	40%	40%
Expected Range High			100	20	80%	80%

Organism Biomass Ratios	Total Fungal to Tot.Bacterial	Active to Total Fungal	Active to Total Bacterial	Active Fungal to Act.Bacterial	Plant Available N Supply (lbs/ac)
Results	**0.75**	**0.004**	**0.05**	**0.06**	
Comments	Low	Low	Low	Low	
Expected Range Low	2	0.15	0.15	1	
Expected Range High	5	0.2	0.2	2	

Nematode detail (# per gram or # per mL)
Classified by type and identified to genus.
(If section is blank, no nematodes identified.)

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PO Box 2745
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Report Sent: 01/05/2009
Sample#: 02-010094 | Submission:02-005085
Unique ID: K & J Bottrell Control
Plant: Grapes
Invoice Number: 5392
Sample Received: 22/04/2009

For interpretation of this report please contact:
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contact@soilfoodweb.c
0266225150
Consulting fees may apply

Dry Weight:	Add organic matter to improve soil biology, build soil structure, increase water holding capacity.
Active Bacteria	Bacterial activity above expected levels; Bacterial biomass will increase as long as nutrients are available.
Total Bacteria	Aerobic bacterial biomass in normal range for this plant group.
Active Fungi:	Need to improve active biomass; Add 20 to 40 litre/ha of liquid humic acids, or 2.5 to 12.5 tonnes/ha fungal compost or woody mulch, or 200 litre/ha fungal compost tea.
Total Fungi:	Need to improve total fungal biomass. Add fungal compost (2.5 to 12.5 tonnes/ha or more), or multiple applications of 200 litres/ha fungal compost tea as soil drench.
Hyphal Diameter	Good balance of disease suppressive and normal soil fungi.
Protozoa	
Total Nematodes	
Mycorrhizal Col.	Endo: | Ecto:
TF/TB:	Too bacterial dominated for grape vines. Will lack disease suppression, nutrient retention, ability to build soil structure. Need to improve beneficial fungi to balance bacterial biomass.
AF/TF:	Low activity; need to add fungal foods to encourage fungi.
AB/TB:	Low activity: add bacterial foods.
AF/AB:	Soil is bacterial dominated, and becoming more bacterial; addition of fungal foods might help maintain balance.
Nitrogen Supply	
Interpretation Comments	

Soil Type: Sand, low organic matter, Low, Irrigated: Yes., Plant: Grapes.
Actinobacteria Biomass = 0 ug/g

Soil
Foodweb Analysis

Report prepared for:

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Report Sent: 01/05/2009
Sample#: 02-010095 | Submission:02-005085
Unique ID: K&J Bottrell Treatment
Plant: Grapes
Invoice Number: 5392
Sample Received: 22/04/2009

For interpretation of this report please contact:
Local Advisor: or regional lab:
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Organism Biomass Data	Dry Weight	Active Bacterial (µg/g)	Total Bacterial (µg/g)	Active Fungal (µg/g)	Total Fungal (µg/g)	Hyphal Diameter (µm)
Results	**0.90**	38.7	219	0	257	3
Comments	Too Dry	Above range	In range	Below range	In range	
Expected Range Low	0.45	1	100	10	200	
Expected Range High	0.85	10	300	25	600	

Nematode detail (# per gram or # per mL)
Classified by type and identified to genus.
(If section is blank, no nematodes identified.)

	Protozoa (Numbers/g)			Total Nematodes #/g	Mycorrhizal Colonization (%)	
	Flagellates	Amoebae	Ciliates		ENDO	ECTO
Results	--	Not Ordered	--	Not Ordered	Not Ordered	Not Ordered
Comments						
Expected Range Low	5000	5000	50	10	40%	40%
Expected Range High			100	20	80%	80%

Organism Biomass Ratios	Total Fungal to Tot.Bacterial	Active to Total Fungal	Active to Total Bacterial	Active Fungal to Act.Bacterial	Plant Available N Supply (lbs/ac)
Results	**1.18**	**0**	0.18	**0**	
Comments	Low	Low	Good	Low	
Expected Range Low	2	0.15	0.15	1	
Expected Range High	5	0.2	0.2	2	

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Dry Weight:	Add organic matter to improve soil biology, build soil structure, increase water holding capacity.
Active Bacteria	Bacterial activity above expected levels; Bacterial biomass will increase as long as nutrients are available.
Total Bacteria	Aerobic bacterial biomass in normal range for this plant group.
Active Fungi:	Need to improve active biomass; Add 20 to 40 litre/ha of liquid humic acids, or 2.5 to 12.5 tonnes/ha fungal compost or woody mulch, or 200 litre/ha fungal compost tea.
Total Fungi:	Aerobic fungal biomass in desired range.
Hyphal Diameter	Good balance of disease suppressive and normal soil fungi.
Protozoa	
Total Nematodes	
Mycorrhizal Col.	Endo: | Ecto:
TF/TB:	Too bacterial dominated for grape vines. Will lack disease suppression, nutrient retention, ability to build soil structure. Need to improve beneficial fungi to balance bacterial biomass.
AF/TF:	Low activity; need to add fungal foods to encourage fungi.
AB/TB:	Good ratio of activity and total bacterial biomass for plant group and season.
AF/AB:	Soil is bacterial dominated, and becoming more bacterial; addition of fungal foods might help maintain balance.
Nitrogen Supply	
Interpretation Comments	

Soil Type: Sand, low organic matter, Low, Irrigated: Yes., Plant: Grapes.
Actinobacteria Biomass = 0 ug/g

APPENDIX 6

Recipe for microbial solution.

Example Recipe for Microbial Solution

The recipes used in this project vary slightly with the amount of compost used and the climatic conditions expected during the brewing process. However the products and volumes used were relatively similar each time and have to date produced reasonable results.

Recipe

Add to compost bag:

- 5kg of moist biologically tested compost – this will fill the compost bag.

Add to the brewer:

- 250ml Seaweed solution – Product used was Stimplex.
- 100ml Humic acid – Product used was Power Humate.
- 500ml Fish Hydrolysate – Product used was Sampi Fish.

Note: It is expected that as this project develops that other ingredients will used to achieve maximum success in regards to the multiplication of micro-organisms in the microbial solution.

APPENDIX 7

Definition of a good tea

Source: Compost Tea Quality: Light Microscope Methods, Soil Foodweb Institute, contact: (02) 66225150
www.soilfoodweb.com.au

Definitions of the Levels of Biological Tea Quality

Bad: None to very few organisms observed. When examining 10 to 20 fields, only bacteria are observed, and less than 25 bacteria observed in each field. See picture below of "bad" tea.

Poor: More than 25 but less than 500 bacteria seen in each field. If patchy clumps of hundreds of bacteria are seen, then this puts the tea into the poor category. The key is that nothing other than bacteria, but high numbers of bacteria, are observed in poor, but not bad, tea.

Acceptable: Somewhere in the first 10 fields, at least one fungal hypha should be seen, preferably a thick hyphal strand, that goes across the full field of view. If only bits of hyphae are seen, then the sample is still in the poor category. More than 500 bacteria per field should be observed, with a range of bacterial shapes, from rods to cocci to picket fences observed (see pictures of bacteria below to get an idea of the different sizes and shapes you might see; the more sizes and shapes the better). Protozoa should be observed skimming across the water sample. Remember to focus up and down in the water drop because flagellates and ciliates like to hang-out at the top of the water drop, while amoebae like to ooze across the solid slide surface.

Very good: In the first 5 fields, a fungal hypha should be seen, and preferably more than one in that volume of liquid. Again, remember to focus up and down through the sample. Bacteria should be so numerous that you would not want to consider counting them. Thousands per field should be present, around the organic matter, zipping around in the liquid. The smallest critters zipping back and forth are mobile bacteria. Not all bacteria are mobile, but if you see them zipping back and forth, then you know you have active organisms. Unfortunately, you can't tell if they are aerobic, or facultative anaerobes, or true anaerobes, since all three categories of bacteria have motile representatives. Lots of protozoa should be seen, preferably more than one kind of protozoan – such as several species of flagellate or amoebae.

Excellent: Each field of view should contain a strand of fungal hypha. Thick strands are better than the skinny ones. Just like very good tea, the bacteria should be everywhere, and too numerous to count easily. Protozoa should be dense, with several individuals observable per field. In EXCELLENT tea, nematodes will be found as well. This general requires compost with great levels of nematodes. Nematodes will not reproduce in compost tea. The brew time is too short. If nematode eggs were laid in the compost, they might wake up during an extended holding period for the tea.

Reasons for poor quality tea:
There are many reasons for a lack of biomass of bacteria, fungi or protozoa in compost tea. If fungal filaments are encased in a layer of bacteria, they have been attacked by anaerobic bacteria, and it indicates that the sample has dropped below 6 micrograms oxygen per liter. Generally, the anaerobic bacteria consume the "innards" of the fungi hyphae, leaving the outer wall remaining behind. Sometimes even that wall will disintegrate, leaving no sign that fungi were ever present in the tea.

Protozoa and nematodes also cannot tolerate reduced oxygen conditions, and will generally move into a dormant condition if the reduction in oxygen occurs slowly enough. If the drop in oxygen is too fast, or lasts for too long, the organisms may be killed.

APPENDIX 8

Oxygen, Temperature and Quality Records.

Microbial Solution 1		
Start : 18/02/2009 - 12pm		
Time	Oxygen (mg/L)	Temperature (oC)
12pm	7.7	24.9
1:00	10.7	24.7
2:25	9.5	25.5
3:15	10	25.3
5:02	10.8	25.8
7:31	6.3	26.2
8:54	5.3	26.3
8:15AM	10.6	26.8
10:15	10.5	27.5
1:20PM	10.5	28.8
3:15	10.1	30.1
5.05	10.5	30.4
6:40	9.5	30.1
7:20AM	10.5	23.1
9:15	10.5	22.9
10:15	10.8	23.2
11:15	9.6	22.9
11:25	8	26
No. of fields containing fungi = 0 / 81		
Quality of mcirobial Solution: **Bad**		

Microbial Solution 2		
Start : 4/03/2009 - 10:20AM		
Time	Oxygen (mg/L)	Temperature (oC)
10:20AM	10	19.6
12:45PM	11.6	21.7
4:45	10.5	22.6
7:30	9.7	23.4
8:50AM	10.9	20.9
11:25	9.7	21.9
1:18PM	10.7	22.6
3:18	8.5	23.4
6:38	7.7	24.4
9:30AM	10.9	22.1
11:35	10.8	23.3
No. of fields containing fungi = 2 / 81		
Quality of mcirobial Solution: **Bad**		

Microbial Solution 3		
Start : 13/3/2009 - 1:30PM		
Time	Oxygen (mg/L)	Temperature (oC)
1:50PM	11	25.4
3:40	10.7	23.2
5:50	11.1	23.5
8:15AM	10.3	21.7
10:30	10.7	21.8
1:50PM	10.6	22.5
3:40	10.6	22.9
6:15	10.6	23.3
8:55AM	10.9	20.6
10:12	9.6	21.2
1:55PM	7.3	22.6
No. of fields containing fungi = 10 / 81		
Quality of mcirobial Solution: **Adequate**		

Microbial Solution 4		
Start : 22/3/2009 - 11AM		
Time	Oxygen (mg/L)	Temperature (oC)
11:20AM	8.1	24.1
1:30PM	8	24.9
2:30	8.3	25.3
6:00	8.2	27.2
7:35	8	27.2
8:20AM	7	23.3
10:40	7.4	24
1:50PM	7.4	25.7
3:40	7.30	26.7
5:25	6.2	27
8:15AM	8	21.7
9:10	6.9	25.3
Very hot day		
No. of fields containing fungi = 12 / 81		
Quality of mcirobial Solution: **Adequate**		

Microbial Solution 5		
Start : 28/3/2009 - 1:05PM		
Time	Oxygen (mg/L)	Temperature (oC)
3:05PM	9.2	23.1
5.42	8.9	24.8
7:10	7	25
9:20AM	7.6	22.5
12:00	8	24.4
1:15PM	7.9	25
3:30	7.5	26.2
5:00	8	26.7
7:15	7.2	26.8
7:00AM	8.6	22.5
9:00	7.3	22.5
11:00	7.2	23.7
1:45PM	7.2	25.4
No. of fields containing fungi = 20 / 81		
Quality of mcirobial Solution: **Good**		

APPENDIX 9

Photos

1. Soil Health Trial 1
2. Soil Health Trial 2

2. Soil Health Trial 1









Top: All vegetation was removed from each trial plot at the beginning of the trial. This picture illustrates what the bare soil control, Myco-Tea and Permanent Sward treatments looked like on the vine bank during the trial.

Middle left: The compost on the vine bank.

Middle right: A closer picture of the compost used in the compost and compost / Myco-Tea treatments.

Left: Establishment of the Permanent Sward treatment.

2. Soil Health Trial 2







Above left: The “Dirt Simple” brewer in action. Air is pumped into the container through the bottom valve. Once the microbial solution is ready the air pump is removed from the bottom valve and the delivery pump is connected.

Above right: Looking inside the “Dirt Simple” brewer when oxygen is being pumped into the container.

Left: The compost bag used in the “Dirt Simple” brewer. This is the amount of compost that is left after a 24-48 hour period inside the brewer. This bag was full at the beginning of the cycle.



Left Below: The home made applicator. This applicator is a stainless steel tank that has been adjusted to deliver the microbial solution to the vineyard onto the vine bank approximately 10 cm from the vine row.

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Top Left: Use of the delivery pump with is a non-propeller pump to transfer the microbial liquid from the brewer to the applicator.

Top Right: Measuring oxygen and temperature to ensure the microbial liquid remains aerobic.



Middle: Applicator in action.

Bottom: Fungi photographed under the microscope during quality control.





