Hort Innovation

Final Report

Improving fruit quality and consistency in cherries through maximized nutrient availability

Project leader:

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Delivery partner:

Tasmanian Institute of Agriculture, University of Tasmania

Project code:

CY12002

Project:

Improving fruit quality and consistency in cherries through maximized nutrient availability CY12002

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Content

Content 3
Summary 4
Keywords 4
Introduction 5
Methodology 6
Outputs 10
Outcomes 11
Recommendations 12
References 13
Intellectual property, commercialisation and confidentiality 14
Acknowledgements 14
Appendices 15

Summary

It has been established that synthetic fertilisers and pesticides/herbicides can have serious environmental impacts, and as a consequence interest in alternate farming systems has increased in recent years. However, there is uncertainty as to whether fruit quality in alternate systems can be maintained. There is also the question of whether a move from synthetic fertilisers to the use of organic based fertilisers such as manures, composts, humates and bio-fertilisers will increase soil biology and be able to provide sufficient nutrients.

This project compared the impact of conventional fertiliser/herbicide and alternate management regimes using humates and targeted minerals. Two trial sites were established in southern Tasmania on cultivars Sweetheart and Lapin. The project examined a range of soil physical, biological and fruit quality parameters over the 5-year study. Organic amendments applied in the alternative treatments were Ferbon™ (lignite-based soil conditioner, Interstate Energy Group, Bacchus Marsh, Victoria) and humified compost (Foundation Aerobic Compost, Pure Living Soils). Effective microbes (EM1, VRM Pty Ltd) were also applied as a monthly soil amendment throughout the study period, commencing in October 2012.

The alternate regime resulted in a higher fruit set than the conventional in most years, but EM had no effect. There was a general trend for increase in percentage of A-grade fruit in the alternate regime compared with the conventional in most years. EM application showed a significant increase in A-grade fruit in years 2, 3 and 4. Sweetheart fruit diameter was 1-2mm smaller in the alternate regime in most years. Overall the alternate regime showed increased fruit set and pack-out, and a reduction in percentage reject fruit in most years. Lapin were more responsive to treatments than Sweetheart, but this may be due to soil type.

Fruit cracking was significantly reduced in the alternate regime in years 3 and 4, while EM application reduced the incidence of cracking in every season. Monthly application of EM was effective at reducing the incidence of fruit cracking under both alternate and conventional regimes. Cracking incidence was lowest in 2015/16, a relatively dry summer, and very high in 2016/17 (> 50% in the conventional regime), a season that had high rainfall leading up to harvest. In this season the alternate regime reduced cracking by 37%.

Other quality parameters measured showed variation between years, but within each year treatments had little effect on most parameters. What is worth noting is that, in the alternate regime fruit quality attributes of firmness, TSS and stem retention force met Australian ‘export finest’ standards with a higher percentage of A-grade fruit. This means that results from this study have demonstrated that humate based nutrition programs are capable of yielding high quality fruit with good pack outs.

Soil assessments demonstrated a healthier soil in the alternate treatments with reduced soil compaction, improved water infiltration and a higher abundance of mycorrhizal fungi.

Keywords

Cherry; soil organic matter; microbial amendment; effective microbes, fruit quality;

Introduction

Inconsistent yields, poor fruit quality and short shelf-life are of major concern for the Australian cherry industry, which is increasing its focus on export. Modern orchardists operate to rising standards of production using a range of best management practice systems, and orchardists are becoming increasingly aware that an ecologically balanced soil system is essential for maintaining healthy crops.

Fertile soils normally hold all the nutrition required for healthy crop growth, but rely on the right combination and volume of microbial populations to digest and transform these minerals to compounds readily available for plant uptake (Francis 2005). When soils are truly fertile, plant health is maximised and reflected in fruit quality and shelf life. Sotiropoulos et al (2010) stress that adequate mineral nutrition is a pre-harvest factor affecting fruit quality.

The importance of soil microbes in a healthy system is outlined by Kausadikar (2010). He summarises the following roles of soil microbes:

- conversion of complex organic nutrients into simpler inorganic forms (mineralisation) which are readily absorbed by the plant for growth;
- production of a variety of substances like indole acetic acid (IAA), gibberellins, antibiotics etc. which directly or indirectly promote plant growth;
- synthesis of polysaccharides, lignins and gums which have an important role in cementing/binding of soil particles to produce stable aggregates;
- degradation of organic matter;
- humus formation;
- biological nitrogen fixation - conversion of atmospheric nitrogen into ammonia and nitrate.

Lovel (2009) has suggested that microbial diversity in the soil at the root surface is crucial for plants to have available all required nutrition. Initially, to restore overworked soils to healthy condition requires mineral inputs to rebalance the biochemical sequence (where elements are deficient in totality), and also microbial inoculation to re-introduce the diversity of species that die out under monoculture orchard conditions.

Monoculture systems, particularly in combination with bare-earth orchard floor management, disrupt the diversity of soil biology and impact on tree health and fruit quality by impairing the capacity of soil to provide all the nutrients required by the tree, which in turn impairs the tree's capacity for nutrient uptake.

There is anecdotal evidence to suggest that boron, silicon and calcium are important in the hierarchy of plant chemistry, and without these nutrients in readily available form, the plant is unable to optimise use of nitrogen, magnesium, phosphorous, carbon, potassium and trace elements in the metabolic pathways involved in growth, flower initiation and fruit development. Yamaguchi et al (1986) discuss the cooperative role of boron and calcium in the building of the plant cell wall. Dick (2009) states that boron is required to activate silicon.

In his review, Epstein (1994) reports ample evidence that when readily available to plants, silicon plays a large role in growth, mineral nutrition, mechanical strength, and resistance to fungal diseases, herbivory, and adverse chemical conditions of the growing medium. Husby (1998) reported that silicon has been shown to ameliorate abiotic stresses, and also concluded that it has the potential to significantly decrease the susceptibility of plants to disease. Julien (2000) states silicon affects the absorption and translocation of several macro- and micronutrients. Fruit firmness in both strawberry and plum has been shown to increase following foliar application of silicon (Grajkowski et al. 2006; Ochmian et al. 2006).

Studies by Tasmanian and South Australian researchers in apples (DAFF Projects NLP20917, NLP28101 and NLP64548) and citrus (HAL Project CT06007) have demonstrated that improved soil health can improve fruit size and quality, and assist in reducing tree stress under drought conditions.

The aim of this project was to examine the impact of different nutrient strategies on (i) fruit quality at harvest, (ii) soil health, and (iii) the long-term soil microbial and invertebrate biomass and diversity, thus providing Australian cherry growers with knowledge on how to optimise soil biota and nutrient availability and uptake to enable them to maximise crop yields and fruit quality, particularly fruit firmness.

Methodology

The program was composed of three integrated components:

1. Review of scientific literature;
2. R&D: examination through field trials of cherry yields and fruit quality with respect to soil biology and nutrient availability; and
3. D&E: development of practical recommendations and extension to growers and extension personnel to raise the consistency of high quality cherry yields.

Review of literature

A review of available scientific literature on fruit quality, soil microbial activity and impact on nutrient availability/uptake and plant metabolic pathways was undertaken. Knowledge gained from this review was incorporated into the field trials and included in extension material developed as part of this project. The full literature review is presented in Appendix 9.

Research trials

Trial sites were established on commercial orchards in southern Tasmania (see table below). The Hansen Orchards and Grove Research Station sites were set up in October 2012, however because of lack of irrigation at the Grove site resulting in severe tree stress and lack of fruit, this site had to be abandoned in January 2013. An alternate site was established at Huon Park Orchard, Nicholls Rivulet in March 2013.

Site	**Hansen Orchards**	**Grove Research Station**	**Huon Park Orchard**
Location	Rosegarland (Derwent Valley)	Grove (Huon Valley)	Nicholls Rivulet (Huon Valley)
Trial established	October 2012	October 2012	March 2013
Cultivar	Sweetheart	Lapin	Lapin
Rootstock	Colt	F12/1	Colt
Age	planted 2007	planted 2003	planted 2008
Row orientation	east/west	north/south	north/south
Tree structure	KGB	V-axe	KGB
Spacing	5m x 2m	4.5m x 1m	4m x 1.8m
Soil type	dolerite/clay	sandy loam	sandy loam
Plot size	5 trees	7 trees	5 trees

The same treatments were applied to all sites. Treatments consisted of two nutrient regimes split into sub-plots with and without effective microbes (EMs) to give a total of four treatments (see below). Four replicates of each treatment were applied to multi-tree plots.

(i) control: conventional fertiliser and herbicide applied (as determined by the orchard manager in normal production)

(ii) alternative regime as developed in conjunction with consultant Hugh Lovel

(iii) as for (i) plus application of effective microbes (EMs)

(iv) as for (ii) plus application of effective microbes (EMs)

Note: the alternative regime was a dynamic program changing over time depending on the results of regular soil testing – aiming to rebalance available soil minerals and promote soil biology, with the long-term aim of reducing nitrogen inputs.

(a)  (b) 

(c) 

Figure 1: Trial sites. (a) Derwent Valley; (b) Grove (Huon Valley), (c) Nicholls Rivulet

Soil mineral analysis: To establish baseline soil nutrient levels, soil samples were collected from each plot prior to treatment application. A total of 15 cores were taken in a zigzag pattern across the trial site. Soil cores were homogenised and a subsample of 200 g sent to Environmental Analysis Laboratory (EAL) in Lismore for total and available mineral content. Samples were then collected annually in autumn of each year for the duration of the project and forwarded to EAL for analysis. Results from the analyses were used to determine the mineral requirements for the alternative plots each year (see Appendix 7).

Treatment application: Following discussion of the soil nutrient analysis results with consultant Hugh Lovel, humate sources and minerals were applied to the alternative treatments in spring (September/October) of each year, with a follow up application in autumn (March/April). Effective microbes were applied on a monthly basis as a soil drench.

(a)  (b) 

Figure 2: (a) PhD student Abdelsalam Abobaker taking soil samples;
(b) soil profile to 50cm depth at Derwent Valley site.

The conventional regime was a synthetic fertiliser program based on the commercial practice used in the orchard including herbicide application (Basta) twice per year. The alternative regime was a soil conditioner sold as FF 50 Bio-humate (Ferbon®, Interstate Energy Group, Bacchus Marsh, Australia) or compost (Foundation Aerobic Compost, Pure Living Soils) blended with targeted minerals. Ferbon was applied at the rate of 300 kg ha^{-1}, compost at 800 kg ha^{-1} with soluble humate granules (water soluble potassium humate 75 %, solubility 85 %) at 20 kg ha^{-1}. Details of nutrient content of the organic amendments and the amounts of amendments and minerals applied are provided in Appendix 7.

The effective microbes (EM, purchased as EM1, Vital Resource Management Pty Ltd. Qld) were activated by brewing in a 30 L fermentation vat under anaerobic conditions. Stock solutions were prepared by adding 30 ml EM1 and 30 ml molasses per litre of de-chlorinated water. This was left to brew for at least one week at ambient conditions in the headhouse of the glasshouse complex. EM was applied monthly at a rate of 75 mL activated EM solution and 5 g Acadian soluble seaweed extract (SSE) in 10 L non-chlorinated water for each plot. All soil EM applications commenced at the start of the 2012-13 season.

A change to the orchard management practices at the Rosegarland site in the Derwent Valley in 2015 following the installation of a new fertigation system meant that all trees were receiving fertigation as applied by the grower as it is was no longer possible to quarantine the trial trees. The decision was made to continue with the study as it provided an opportunity to examine the impact of humates and effective microbes in conjunction with a full fertigation program, so providing additional information.

Soil health and quality parameters, including soil organic carbon, soil nitrogen, electrical conductivity, pH, bulk density, soil compaction and water infiltration rates were assessed in the final year. Soil micro-biology (0-20 cm) was assessed in year 3 by sending samples to the Soil Foodweb Institute, Lismore for analysis of bacteria to fungi ratios, and mycorrhizal colonisation (VAM) microbial activity. Other soil fauna assessments were taken by the project team in year 3 to determine earthworm and soil invertebrate population diversity.

To determine microbial diversity at the end of the project, DNA was extracted from soil samples collected in December 2016 using a Powersoil DNA extraction kit (MoBio) and from EM preparations using the method of Yuskianti et al 2014. Amplification and DNA sequencing was performed on an Illumina MiSeq platform by Research and Testing Laboratory, Lubbock, Texas, using primers targeting the bacterial 16S rDNA and fungal rDNA internal transcribed spacers. Sequence reads were denoised, checked for chimers and clustered according to their standard methodology (https://static1.squarespace.com/static/5807c0ce579fb39e1dd6addd/t/5813af0fd482e97e5eb4fcb5/1477685010205/Data_Analysis_Methodology.pdf).

Trial harvests: Trials were harvested at normal commercial harvest times for each block.

Cultivar	Season 1	Season 2	Season 3	Season 4	Season 5
Lapin	-	16 Jan 2014	20 Jan 2015	13 Jan 2016	23 Jan 2017
Sweetheart	25 Jan 2013	28 Jan 2014	20 Jan 2015	18 Jan 2016	18 Jan 2017

Fruit was picked from two tagged limbs on each tree, placed into labelled bags and returned to the laboratory for sorting. Fruit from each limb was weighed to determine a bulk weight for each tagged limb. Fruit was then sorted to determine numbers for A-grade, B-grade, reject and cracked fruit. For each tree, the A-grade fruit from the two limbs was pooled and a sub-sample of 25 fruit taken at random for quality assessments. A further subsample for each tree was bagged into Peakfresh bags, sealed and placed into cool storage at 1°C for postharvest assessments. Postharvest assessments were completed at 35 days after harvest for all cultivars.

In season 4 (2015/16) postharvest assessments were undertaken at 14, 28, 42 and 56 days after harvest as part of an Honours student project.

Fruit quality: Quality assessments included fruit weight, diameter, skin colour, flesh colour, compression firmness, flesh firmness, skin puncture force, stem retention force, dry matter content (DMC), total soluble solids content (TSS) and malic acid content.

Laboratory assessments:

- Fruit was weighed to 1 decimal place and then diameter measured with calipers.
- The Australian Cherry Colour Guide was used to determine skin colour.
- Compression firmness with a BioWorks FirmTech II and fruit skin puncture force and flesh firmness were measured using a GÜSS Fruit Texture Analyser model GS-20, fitted with a 2mm penetrometer probe.
- Stem retention was determined by measuring the force required to break free the stem from the fruit using a 'Manual Force Test Gauge' with a purpose designed stand (Mark 10, IDM Instruments) to remove human error.
- 10 fruit from each sample were pipped and flesh placed into paper bags, weighed and oven dried at 60°C. The dried fruit was then weighed and dry matter content calculated.

- The remaining fruit were juiced and the juice used for determination of total soluble solids and titratable acidity. Malic acid content was calculated from the titratable acidity results.
- Total soluble solids was measured with an Atago digital refractometer.
- Titratable acidity was measured on duplicate samples using a Mettler Toledo G20 compact titrator.

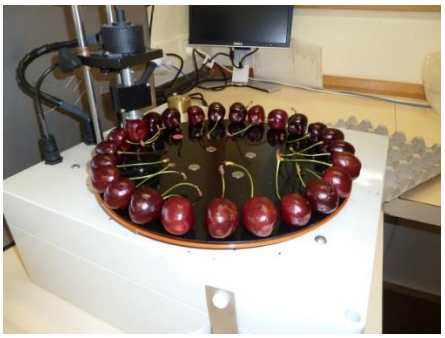
(a)  (b) 

Figure 2: (a) Samples ready for laboratory assessment;
(b) Measuring fruit firmness with BioWorks FirmTech machine

Leaf and fruit mineral analysis: Leaf and fruit samples were collected after harvest each season and forwarded to the Environmental Analysis Laboratory (EAL), NSW, for mineral analysis.

Data analysis: all data were collated and analysed by analysis of variance using Genstat 17.1 (VSN International Ltd.). Data are presented a mean values for each treatment and/or main effect (see Appendix 8). Significance was calculated at P=0.05 and least significant difference (LSD) was used for comparison of mean values.

For the DNA data, statistical analyses including PERMANOVA, non-metric multidimensional scaling and principal co-ordinate analysis were performed using Primer v6 (Quest Research ltd, Auckland). Treatment effects were tested using PERMANOVA analysis based on relative abundance of molecular operational taxonomic units (MOTUs, regarded as equivalent to species) as well as presence/absence of taxa. Reduced datasets consisting of those taxa with an overall abundance greater than predefined values (0.01 to 0.1%) were also tested. Bacterial data was also analysed at the genus and family level.

Project extension

Results were presented at industry seminars and in articles published in the Cherry industry newsletter.

A field day was conducted in the final year of the project aimed at growers and agronomists.

Surveys of growers were conducted midway through the project and participants attending the field day were asked what they had gained from the field day.

Outputs

1. **Industry presentations** (see Appendix 1)
   (i) Presentation to Cherry Industry Advisory Panel, June 2015
   (ii) Presentation at Fruit Growers Tasmania conference on 17 June 2016
   "Soil health in cherry orchards"

2. **Field days** (see Appendix 4 for report)
   (i) Orchard Soil Health field day at Huon Park Orchard, Nicholls Rivulet, Tas.
   Conducted on Tuesday 26th September 2017.
   Target audience: growers and agronomists
   Attendees: 35 attendees

3. **Industry articles** (see Appendix 2)
   (i) Bound, S & Buntain, M (2014) 'Healthy soils for premium quality sweet cherries' Australian Cherries, No. 17, Spring 2014.
   (ii) Bound, S (2016) 'Cherry soil health, how does this affect fruit quality' Australian Cherries, No. 22, Summer 2016.

4. **Other publications** (see Appendix 3)

Fact sheets available on the TIA website:

   (i) Improving fruit quality and consistency in cherries
   http://www.utas.edu.au/__data/assets/pdf_file/0006/978153/Cherry-soil-health_May-2016_17-5-2016.pdf
   (ii) Can improved soil biology increase nutrient availability
   http://www.utas.edu.au/__data/assets/pdf_file/0006/563541/2014-Can-improved-soil-biology-increase-nutrient-availability-.pdf
   (iii) Cherry soil health fact sheet
   http://www.utas.edu.au/__data/assets/pdf_file/0016/1030525/Cherry-soil-health-update-_25-8-2017.pdf

5. **Surveys** (see Appendix 5)

6. **Field trial data** (see Appendix 8)

7. **Literature review** (see Appendix 9)

Outcomes

The project has successfully achieved its aim of demonstrating that it is feasible to achieve high quality fruit with alternate nutrition regimes rather than conventional fertilisers and herbicide use.

Cultivar response

Lapin was more responsive to the alternate management regime and effective microbe application than Sweetheart, but this may be due to site factors and soil type.

Fruit set and packout improved

The alternate regime resulted in a higher fruit set than the conventional in most years, but EM had no effect. There was a general trend for increase in percentage of A-grade fruit in the alternate regime compared with the conventional in most years. EM application showed a significant increase in A-grade fruit in years 2, 3 and 4. Sweetheart fruit diameter was 1-2mm smaller in the alternate regime in most years. Overall the alternate regime showed increased fruit set and pack-out, and a reduction in percentage reject fruit in most years.

Fruit cracking reduced

There was significantly less fruit cracking in the alternate regime in years 3 and 4, while EM application reduced the incidence of cracking in every season. Monthly application of EM was effective at reducing the incidence of fruit cracking under both alternate and conventional regimes. Cracking incidence was lowest in 2015/16, a relatively dry summer, and very high in 2016/17 (> 50% in the conventional regime), a season that had high rainfall leading up to harvest. In this season the alternate regime reduced cracking by 37%.

Other quality parameters

Other quality parameters measured showed variation between years, with firmness and sugar content increased in some years, but not others. It is worth noting is that, in the alternate regime, fruit quality attributes of firmness, TSS and stem retention force met Australian 'export finest' standards with a higher percentage of A-grade fruit. This means that results from this study have demonstrated that humate based nutrition programs are capable of yielding high quality fruit with good pack outs with no loss of quality.

Soil quality improved

Soil assessments demonstrated a healthier soil in the alternate treatments with reduced soil compaction, improved water infiltration and a higher abundance of mycorrhizal fungi. Analysis of fungal species based on presence/absence was significantly affected by fertiliser treatment but not by EM application.

The majority of the bacterial and fungal species in the EM inoculum were not found in the soil and those that were detected were at extremely low levels. However application of EM had a beneficial effect on fruit quality, perhaps through stimulation of other organisms – further work is needed to clarify this response.

Grower awareness increased

While most growers are aware of the importance of soil organic matter, very few are aware of the vital role played by soil microbes. This project has helped to raise awareness of this and stimulate discussion on holistic soil management and how beneficial organisms can be increased in the soil.

The field day was particularly valuable for raising awareness of holistic soil management. All participants indicated interest in future workshops focussing on soil health and alternative management. The learning outcomes from the field day included:

- Microbial activity is good – grow the soil to grow the crop
- Aeration of soil important for good soil structure
- Use herbicides strategically
- Use your spade for physical soil inspections

Environmental benefits

As well as the potential economic benefit to growers through improved yields and packouts, improving grower knowledge on how to optimise soil biota and increase mineralisation of organic matter to provide available nutrient is likely to have environmental benefits through a reduction in application of synthetic fertilisers and herbicides.

Recommendations

This project has helped to raise awareness of the vital role of soil biota, not only on physical soil structure, but also in the contribution to the nutrient cycle through breakdown of organic matter and mineralisation, and stimulate discussion on holistic soil management and how beneficial organisms can be increased in the soil.

Moving away from the application of synthetic fertilisers and herbicides that are resulting in degradation of our soils towards a softer approach requires a change in mind set that can only be brought about through increased knowledge. While most growers are aware of the importance of soil organic matter, very few are aware that the soil ecosystem is an interdependent life-support system, with soil biota playing a vital role in the availability of nutrients through conversion of complex organic nutrients into simpler inorganic forms (mineralisation) which are readily absorbed by the plant for growth.

Recommendations arising from this project include:

1. Further studies to examine different cultivars on one soil type and/or the same cultivars on different soil types;
2. An examination of different humate sources to determine whether all humate sources have the same effect;
3. Establishment of demonstration plots in each growing region to enable growers to observe first hand the effect of soil biota over a period of several years;
4. Funded workshops and field days in all growing regions to raise grower knowledge of the importance and benefits of balanced healthy soils and the role of soil biota in nutrient mineralisation;
5. Examination of the use of mites as an indicator of soil health and correlation with crop yield and quality.

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Intellectual property, commercialisation and confidentiality

No project IP, project outputs, commercialisation or confidentiality issues to report.

Acknowledgements

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Mr Stephen Paterson provided technical support for the project and Michele Buntain assisted with project extension.

Thanks should also go to Kym Green for his encouragement to put the project up for consideration.

Appendices

1. Industry presentations
   (i) Presentation to Cherry Industry Advisory Panel, June 2015
   (ii) Presentation at Fruit Growers Tasmania conference on 17 June 2016 "Soil health in cherry orchards"

2. Industry articles
   (i) Bound, S & Buntain, M (2014) 'Healthy soils for premium quality sweet cherries' Australian Cherries, No. 17, Spring 2014.
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3. Other publications

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   (ii) Can improved soil biology increase nutrient availability http://www.utas.edu.au/__data/assets/pdf_file/0006/563541/2014-Can-improved-soil-biology-increase-nutrient-availability-.pdf
   (iii) Cherry soil health fact sheet http://www.utas.edu.au/__data/assets/pdf_file/0016/1030525/Cherry-soil-health-update-_25-8-2017.pdf

4. Field days
   (i) Orchard Soil Health field day at Huon Park Orchard, Nicholls Rivulet, Tas. Conducted on Tuesday 26th September 2017.

5. Surveys

6. Site plans

7. Soil amendments and soil analyses

8. Data analysis and results interpretation

9. Literature review

Appendix 1 – Industry presentations

(i) Presentation to Cherry Industry Advisory Panel, June 2015

CY12002

Improving fruit quality and consistency in cherries through maximised nutrient availability

5 year project commenced October 2012

Aims: to examine how alternative nutrient management influences soil health and ultimately fruit quality

Field sites:

1. GRS, Huon Valley (Lapins)
   - established Oct 2012, aborted Jan 2013
2. Rosegarland, Derwent Valley (Sweetheart/Staccato)
   - established Oct 2012
3. Nicholls Rivulet, Huon Valley (Lapins)
   - established April 2013

Treatment regimes:

1. Conventional nutrition and herbicide program
2. Alternative nutrient regime - humates combined with minerals
   dynamic program changes over time depending on soil/leaf test results - working towards rebalancing available soil minerals and promoting soil biology, with the aim of reducing N inputs over the life of the project.
3. Conventional plus 'effective microbes' (EM's)
4. Alternative plus EM's

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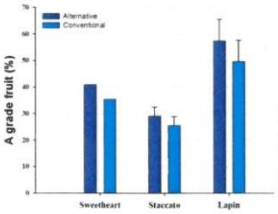
CY12002

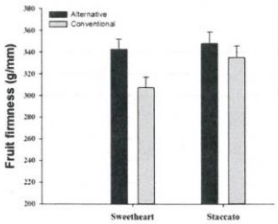
Outcomes to date:

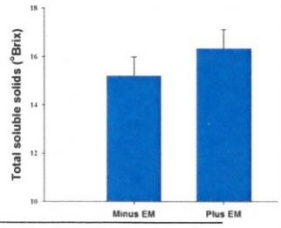
After 15 months

1. Proportion A-grade fruit 17-20% higher under alternatively managed regime compared to conventional plots
2. Reject fruit reduced in Lapins:
   13% in conventional vs 4% in alternative treatment
3. Application of EMs reduced cracking incidence in Lapins by 33%
4. Firmer fruit from alternative regime
5. Higher TSS in EM treated Sweetheart fruit
6. Increase in worm numbers at Rosegarland site
7. PhD student (Abdelsalam Abobaker) using sites to study impact of treatments on mycorrhizal colonisation

2014/15 harvest & fruit quality data currently being analysed







Publications to date:

1. Fact sheet: S Bound & P Domeny (2012) Improving fruit quality and consistency in cherries
2. Article in Australian Cherries: S Bound & M Buntain. Healthy soils for premium quality sweet cherries. *Australian Cherries*, No 17, 2014
3. Fact sheet: S Bound & M Buntain (2014) Can improved soil biology increase nutrient availability?

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(ii) Presentation at Fruit Growers Tasmania conference on 17 June 2016 “Soil health in cherry orchards”

FGT Conference 17 June 2016

Soil health in cherry orchards

Sally Bound
Perennial Horticulture Centre
Tasmanian Institute of Agriculture (TIA)
University of Tasmania

Background

1. Improved soil health can improve fruit quality
2. Diverse soil biology assists in maintaining balanced nutrient supply
3. Increasing use of humates and biofertilisers,
   - mostly anecdotal evidence as to effectiveness
4. Need scientific rigour – critical examination

CY12002 Improving fruit quality and consistency in cherries through maximised nutrient availability

5 year project commenced October 2012

Aims: to examine how alternative nutrient management influences soil health and ultimately fruit quality

Field sites:

1. GRS, Huon Valley (Lapins)
   - established Oct 2012, aborted Jan 2013
2. Rosegarland, Derwent Valley (Sweetheart/Staccato)
   - established Oct 2012
3. Nicholls Rivulet, Huon Valley (Lapins)
   - established April 2013

Treatment regimes

1. Conventional nutrition and herbicide program
2. Alternative nutrient regime - humates combined with minerals *
3. Conventional plus ‘effective microbes’ (EM**)
4. Alternative plus EM

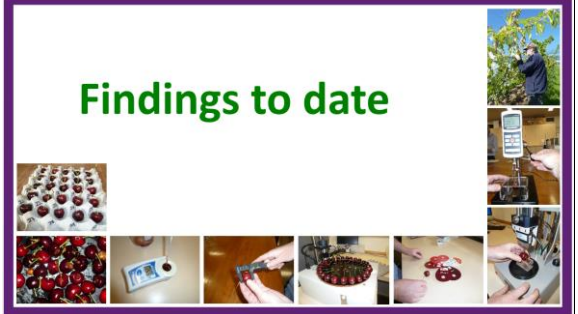
* dynamic program - working towards rebalancing available soil minerals and promoting soil biology, with the aim of reducing N inputs over the life of the project.

** EM – mix of ~80 species of co-existing beneficial micro-organisms; predominantly lactic acid bacteria and yeasts, plus photosynthetic bacteria and actinomycetes that exist symbiotically and are purported to suppress pathogenic micro-organisms and convert natural resources into forms that can be absorbed by the plant.

What are we measuring?

1. Crop load and packout (A-grade fruit, cracking etc)
2. Fruit quality
   - size, firmness, TSS, stem retention, acidity
3. Soil properties
   - pH, cation exchange capacity, OM content, compaction
4. Soil nutrient levels
   - total and available
5. Soil fauna
   - worms, invertebrates, microbiology
6. Leaf nutrient levels

Findings to date



Rosegarland site – soil properties

	Baseline 2012	2013 Conv	2013 Alt	2014 Conv	2014 Alt	2015 Conv	2015 Alt	Ideal
Soil pH	6.6	6.2	6.3	6.5	6.7	6.5	7.3	~6.5
Conductivity (dS/m)	0.36	0.44	0.58	0.23	0.25	0.18	0.30	0.2-0.6
CEC (M.E./100g)	21.4	20.6	21.4	21.1	23.8	17.2	23.9	<15
Organic matter (%)	5.1	5.2	5.3	5.8	6.1	5.7	6.2	4-10
Labile carbon (%)	0.74	0.68	0.63	0.70	0.78	0.61	0.74	0.8-1.2

- Soil pH variable
- CEC increased in alternative plots, reduced in conventional
- SOM greater increase in alternative plots

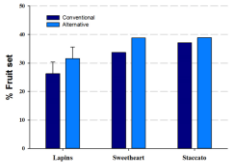
Worm counts (Dec 2013)

	Rosegarland	Nicholls Rivulet
(a) Treatment regime		
conventional	3.3[a]	4.1[a]
alternative	8.1[b]	18.1[b]
(b) Effective microbes		
no EM	6.5	13.9
plus EM	5.0	8.4

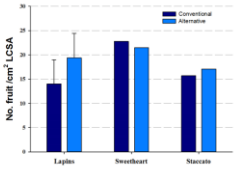
- Increase in worm numbers in alternative treatment plots
- EM no effect

Fruit set

2014/15



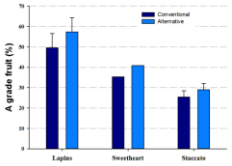
2015/16



- increased set in Lapins
- no significant effect in Sweetheart or Staccato

Packout - % A-grade fruit (regime)

2013/14



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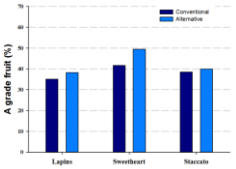
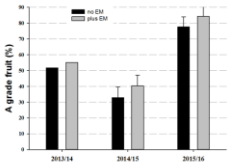


- increased packout in Lapins
- variable effects in Sweetheart & Staccato

Packout - % A-grade fruit (EM)

Lapins



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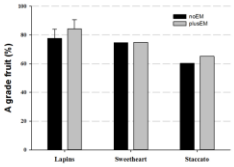
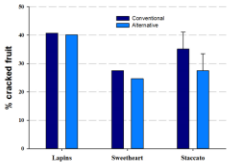


- EM improved packout in Lapins
- no significant effect in Sweetheart or Staccato

Cracking – effect of regime

2014/15



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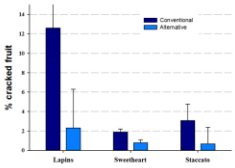
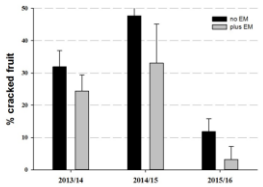


- differences across years and cultivars
- general trend for reduction in cracking in alternative regime
  - Lapins higher CL in alternative treatment plots, but no CL difference in Sweetheart or Staccato

Cracking – effect of EM

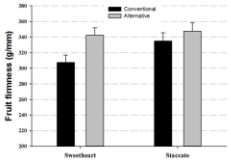
Lapins



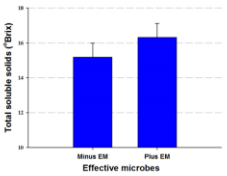
- EM reduced cracking in Lapins in 3 consecutive years (no difference in CL)
- no effect in Sweetheart or Staccato – soil type?

Firmness / TSS

2012/13



2012/13 (Sweetheart)



- firmer fruit from alternative regime
  - note: Sweetheart no difference in CL; Staccato alternative treatment lower CL
- EM increased soluble solids content
- no differences in some years, BUT no negative effects

Conclusions

- Overall positive effect on fruit set, packout and quality with alternative regime
- Reduction in cracking with EM application
- Lapins influenced more that Sweetheart or Staccato
  - but is this really a soil type effect?
- Further studies to answer questions raised:
  - Study different cultivars on same soil type and/or same cultivars on different soil types
  - How important is humate source?

Thanks to...

- John & Peta Cenin, Howard Hansen & Ryan Hankin for use of their trees and working with us
- Steve Paterson for technical support
- Michele Buntain and CGA for assistance with project extension
- Kym Green for his encouragement with the project
- HIA and the cherry industry for provision of funding

Appendix 2 – Industry articles

(i) Bound, S and Buntain, M (2014) Healthy soils for premium quality sweet cherries. Australian Cherries, No 17, Spring 2014

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Healthy soils for premium quality sweet cherries

Dr Sally Bound and Michele Buntain

Mention cherry fruit quality and our first thoughts fly to images of luscious fruit and valiantly protecting it from cracking and rots. This project, under the leadership of TIA's Dr Sally Bound, takes a more fundamental approach to cherry fruit quality, literally from the ground up. It's not a simple nutrition project, but looks at alternative nutrient management designed to promote biological activity in the soil and compares this to conventional orchard nutrition. Alternative nutrient regimes, supplementary microbes and humates have been around for some time with little scientific rigour to support their claims. This project aims to add the science in a critical look at how alternative nutrient management influences soil health and ultimately fruit quality.

The idea is that a healthy soil includes a diverse micro and macro biological population that assists in maintaining a balanced nutrient supply to the plant with small peaks and troughs. The desired impact of this biological diversity and balanced soil nutrition is a healthy tree with consistent fruit quality.

The project, funded by Horticulture Australia Limited, runs for 5 years to look at the longer term impacts of alternative nutrient regimes on soil biology and cherry fruit quality. Test sites are commercial cherry orchards in the Derwent Valley and Huon Valley and include the cultivars 'Sweetheart', 'Staccato' and 'Lapins'.

The alternative nutrient regime is based on soil and leaf analysis that indicate the balance of soil minerals required to promote soil biology. It is supplemented with the regular addition of humates during the growing season. Additional treatments include the application of a commercial blend of 'effective microbes' (EM's) to both conventional and alternative plots (Figure 1).

Figure 1: Application of effective microbes (EM's) to cherry trees

The first cherry harvests are completed with some favourable results emerging. The proportion of A-Grade fruit harvested was 17-20% higher for all cultivars under the alternative regime compared to conventionally managed cherries (Figure 2). Treatments did not affect most fruit quality parameters, but the alternative regime produced firmer fruit than the conventional regime (Figure 3). Monthly addition of effective microbes (EM's) to the soil increased fruit sugar content in 'Sweetheart' (Figure 4). In 'Lapins', there was less reject fruit from the alternative regime (4%) compared to 13% from conventionally managed trees. Application of EM's reduced 'Lapins' fruit cracking by 33%.

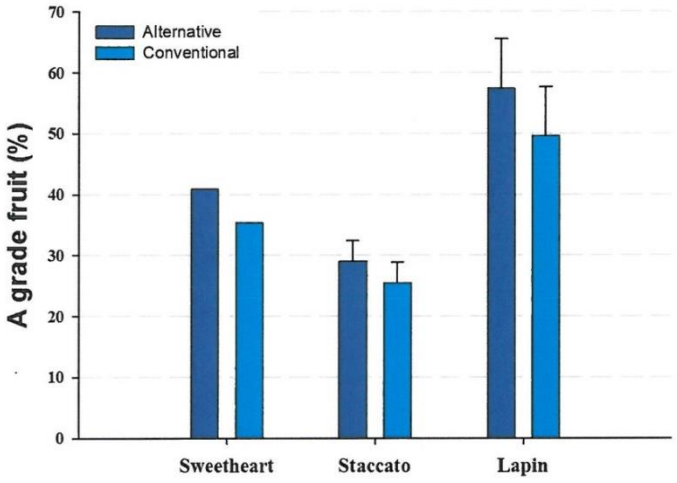

Figure2: The effect of management treatment on proportion of A-Grade cherry fruit

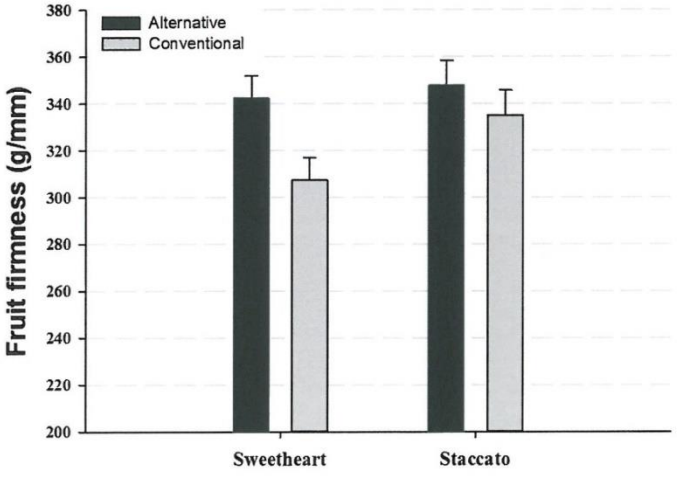

Figure3: The effect of management treatment on fruit firmness of sweet cherry fruit at harvest

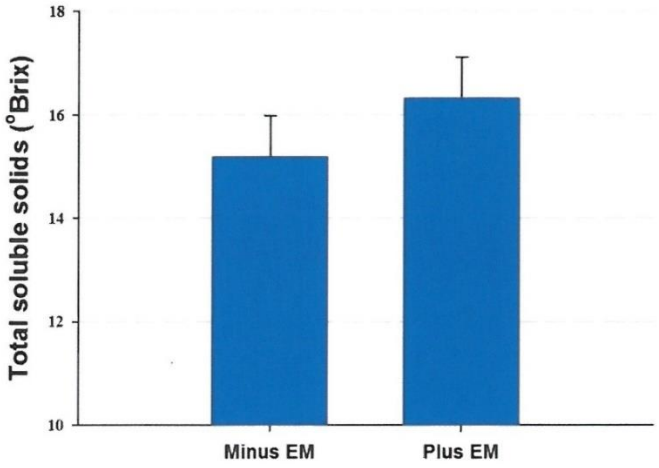

Figure 4: The effect of monthly application of Effective Microbes (EM's) on the sweetness of 'Sweetheart' cherry fruit at harvest

This project is complemented by research being conducted by PhD researcher Abdelsalam Abobaker funded by UTAS. His studies look at how bio fertilisers and humate based products affect soil physical properties, mycorrhizal colonisation as well as tree growth and development.

The project is in its early stages and is planned to run for another three years. This will enable the longer term effects of alternative nutrient management practices to be more fully evaluated. We will continue to monitor the living and non-living components that underpin soil health, including soil organic carbon, nitrogen, EC, pH, bulk density, soil compaction and water infiltration rates; diversity and ratios of microorganisms (bacteria and fungi) and macro-organisms (invertebrate and earth worms). The ultimate test will continue to be consistency in sweet cherry fruit yield and quality.

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Horticulture Australia

UTAS TIA is a joint venture of the University of Tasmania and the Tasmanian Government Tasmania

(ii) Bound, S (2016) Cherry soil health, how does this affect fruit quality?. Australian Cherries, No 22, Summer 2016

Cherry soil health, how does this affect fruit quality?

Dr Sally Bound Senior Research Fellow, Tasmanian Institute of Agriculture

The HIA funded project *'Improving fruit quality and consistency in cherries through maximised nutrient availability'* or as we call it for short, ***Cherry Soil Health Project*** has the long term goal of improving soil health and ultimately fruit quality through an alternative nutrient management regime.

Soil health has different meanings to different people and situations. Most define soil health as being fit for a purpose, in this case cherry production, whilst sustaining soil biodiversity and the soil ecosystem. At the same time a healthy soil maintains or enhances water and air quality. It's a complex system that is complex to measure. What we can do is measure how different management practices affect indicators of soil health and how these impact on longer term tree productivity and fruit quality. Trial sites are commercial cherry orchards in the Derwent Valley and Huon Valley and include the cultivars 'Sweetheart', 'Staccato' and 'Lapins'.

Fruit set, pack out and cracking

In our 2015 harvest, there were some encouraging results from the alternative nutrient regime and supplementation with microbes. Interestingly, the variety 'Lapins' proved to be the most responsive of the 3 varieties tested. Good fruit set underpins yield. At this harvest, we recorded small but positive increases in fruit set from the alternative nutrient regime compared to conventionally managed trees (Figure 1). This improved fruit set was backed up by improvements in pack out and a reduction in reject and cracked fruit. The percentage of A-grade fruit for Lapins increased by 7% with Effective Microbe (EM) application and there was a trend across all cultivars for a greater percentage of A-grade fruit from the alternative nutrient regime (Figure 2). There was also less cracked fruit from EM treated 'Lapins'.

Post harvest fruit quality

Treatments had no effect on the fruit quality parameters: stem retention force, total soluble solids content (brix) malic acid content and flesh colour. However, there were indications that the alternative nutrient regime was having some effect on fruit quality. Skin puncture force of 'Lapins' fruit was higher under the alternative regime compared with conventional. 'Lapins' also exhibited a lighter skin colour in the EM treatments compared to conventional.

After 5 weeks in cool storage the results were similar, with skin puncture force of both 'Lapins' and 'Sweetheart' fruit higher under the alternative regime compared to conventional.

What's next?

Soil health is not a quick fix or instant response but is the result of complex relationships between physical, chemical and biological soil properties. During the coming winter we will monitor some of these indicators of soil health including soil organic matter, total and active bacteria and fungi, protozoa and nematodes, cation exchange capacity, soil compaction and water infiltration to see just how far we have come.

Special thanks to Howard Hansen and Ryan Hankin (Hansen Orchards) and John and Peta Cenin (Nicholls Rivulet) for being so accommodating of our research intervention in their orchards.

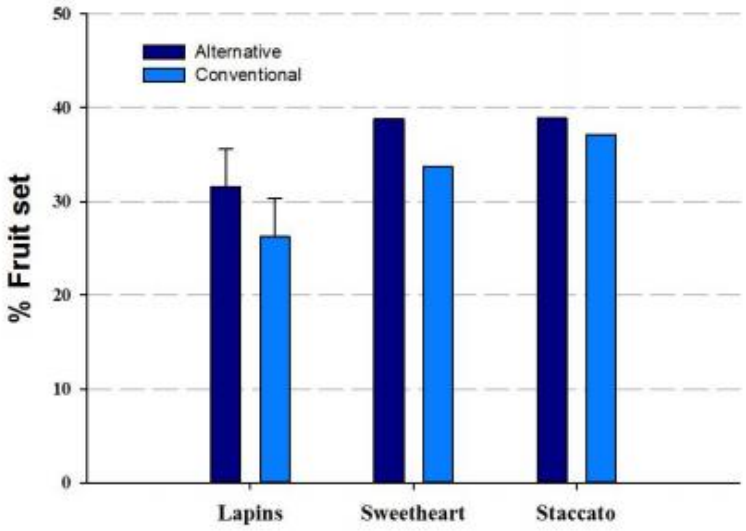

Figure 1: Effect of nutrient management regime on fruit set in 'Lapins', 'Sweetheart' and 'Staccato' cherry trees.

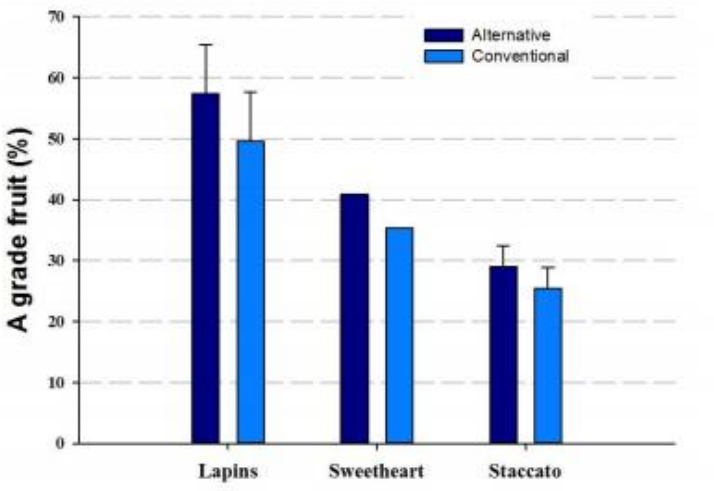

Figure 2: Effect of nutrient management regime on the percentage A-grade fruit in 'Lapins', 'Sweetheart' and 'Staccato' cherry trees.

Contact:

Dr Sally Bound | sally.bound@utas.edu.au

Appendix 3 – TIA fact sheets

(i) Improving fruit quality and consistency in cherries

Improving fruit quality and consistency in cherries

S Bound[1] and P Domeney[2]
[1]TIA — New Town, [2]TIA - Cradle Coast Campus

Key Words: Cherry, fruit quality, fruit firmness, soil management, cherry production

Take home messages

- *researching the links between crop yields and quality, with specific aspects of the soil, to optimise soil microbiology for nutrient availability and uptake*
- *project is collecting baseline data*

Introduction

Consistency in premium quality cherries is of economic concern to Australian cherry growers as the proportion of cherries grown for export continues to rise. This project researches the links between good crop yields and fruit quality (particularly fruit firmness) by working with soil mineral and organic content to optimise soil microbiology for nutrient availability and uptake.

Objectives

To learn more about the organic and mineral aspects of soil that drive fruit quality and how these aspects can be managed to positively influence fruit quality in cherries.

What is being done

Specific mineral and biological amendments will be added to the orchard soils after initial base measurements. Changes in the soil life and structure will be measured annually. After each harvest the soil measurements will be correlated with a wide range of fruit quality aspects, including size, firmness, sugar levels, colour, stem retention and cracking incidence.

Results and Discussion

The first year of this project gathers baseline information for comparison in soil and fruit quality changes as the project continues. The first harvest is yet to occur and preliminary results will be available after March 2013.

Funding and Project Duration

Project funded by Horticulture Australia Ltd, using the Cherry industry levy and matched funds from the Australian Government. August 2012 — December 2017

Technology transfer and publications

- Project champions are included in the project from year 3.
- TIA web pages created and updated as new activities generate results

Additional Collaborators

- Abdelsalam Abobaker will conduct his PhD research into microbiological aspects of soils and their impacts on cherry quality.

Abdelsalam taking soil samples for benchmarking soil data in September 2012

(ii) Can improved soil biology increase nutrient availability?

Can improved soil biology increase nutrient availability?

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This HAL funded project is comparing the impact of conventional fertiliser regimes with an alternative regime of humates and minimal fertiliser application on fruit quality and soil microbiology. Two sites have been established. Site 1 in the Derwent Valley was established in November 2012 and has now been running for 1.5 growing seasons. Two cultivars, Sweetheart and Staccato, are being examined at this site. The second site in the Huon Valley was established in March 2013. The cultivar under study at this site is Lapin.

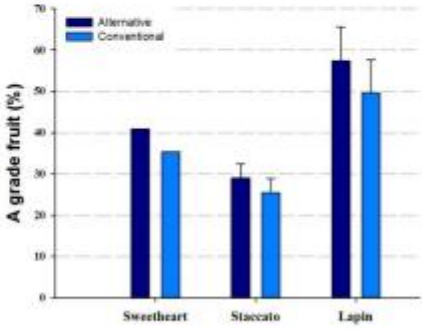
As well as examining soil life, fruit quality parameters being studied include: fruit weight, diameter, firmness, sugar content, juice pH or malic acid content, skin puncture force, colour, and stem retention force.

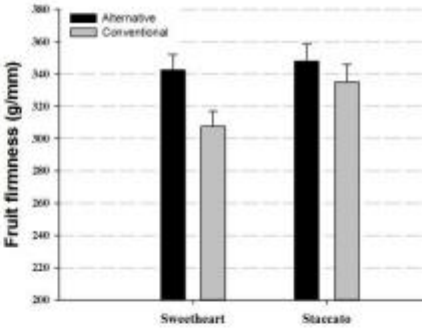
Results from the first harvest show that, in all cultivars, the proportion of A-grade fruit was 17-20% higher in the alternative regime compared with the conventional regime. There were no differences between treatments in most fruit quality parameters, but the alternative regime produced firmer fruit than the conventional regime. Monthly addition of effective microbes (EMs) to the soil increased fruit sugar content in Sweetheart.

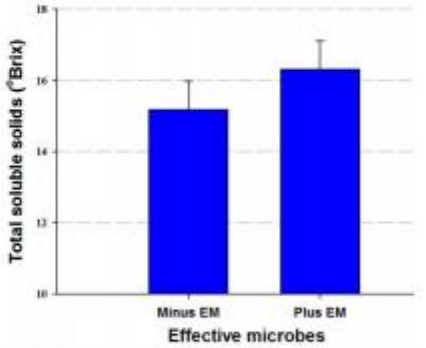
In Lapin, reject fruit was reduced from 13% in the conventional regime down to 4% in the alternative regime. EMs reduced fruit cracking by 33%.

Root samples have been collected from each site by PhD student Abdelsalam Abobaker and are currently being analysed for mycorrhizal colonisation.

This project is still in its early stages and is planned to run for another three years to enable evaluation of longer term effects of minimal fertiliser inputs combined with the application of organic matter in the form of humates.







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This project has been funded by HAL using the cherry industry levy and matched funds from the Australian Government.

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(ii) Cherry soil health fact sheet

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Cherry Soil Health Fact Sheet

Key Points

- The **alternative nutrient management regime** uses organic amendments and effective microbes as an alternative to conventional synthetic fertilisers and herbicides.
- **Fruit cracking** was reduced each season in plots treated with **effective microbes** with 37% less cracking in a high rainfall season. In years 3 and 4, there was also less fruit cracking in the **alternative nutrient regime** plots.
- **Fruit set** was higher for the alternative nutrient management plots with a small decrease in **fruit size** (1-2 mm) for Sweetheart and Staccato
- In the alternative regime fruit quality met **Australian 'export finest' standards**.

The Cherry Soil Health Project is a 5 year project with the goal of improving soil health through an alternative nutrient management regime. Soil health has many definitions but ultimately means the soil should be fit for purpose, in this case growing cherries, whilst sustaining soil biodiversity and the soil ecosystem. At the same time a healthy soil maintains or enhances water and air quality. It's a complex system that is difficult to meaningfully measure.

This project looks at how different management practices affect indicators of soil health and how these impact on longer term cherry tree productivity and fruit quality.

Alternative or conventional?

Alternative farming systems use organic based fertilisers such as manures, composts, humates and bio-fertilisers as an alternative to conventional systems that rely on synthetic fertilisers and herbicides. There has been a growing interest in alternate farming systems as a way of reducing environmental impact and enhancing soil health. However it is uncertain whether fruit quality in alternate systems can be maintained and whether these amendments increase soil biology and provide sufficient nutrients.

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TIA is a joint venture of the University of Tasmania and the Tasmanian Government

Our test orchards

The project has 2 trial sites: Hansen Orchards in the Derwent Valley, established in November 2012 on cultivars Sweetheart and Staccato; and Huon Park Orchards at Nicholls Rivulet, established in March 2013 on Lapins.

The alternative system

The alternative regime is a dynamic program that we modified each season based on annual soil test results. The aim was to rebalance available soil minerals and promote soil biology. Fertiliser amendment included **regular applications of bio-humates** blended with **targeted minerals**. The mineral component was made up according to levels of total and available minerals indicated by soil tests. Weeds were mown as an alternative to herbicide application.

Effective microbes (EM)

We also examined a commercial mix of effective micro-organisms (EM). EM is a mixture of beneficial microorganisms, predominantly lactic acid bacteria and yeasts purported to have beneficial effects on soil and plant growth.

Figure 1: Applying effective microbes in the cherry orchard

The test products

Organic amendments

- *Ferbon™* (lignite-based soil conditioner, Interstate Energy Group) applied at 300 kg/ha in years 1 & 2.
- *Humified compost* (Foundation Aerobic Compost, Pure Living Soils) at 800 kg/ha combined with soluble humate granules (Nutri-Tech Solutions) at 20 kg/ha from year 3 onwards.

The organic amendments were applied in spring and autumn. Targeted minerals were blended with the ferbon or compost and included potassium, manganese, zinc, copper and boron.

Microbial amendment - Effective microbes (EM) Soil EM amendment (EM1, VRM Pty Ltd) was applied monthly at the recommended rate (15 L activated EM/ha) throughout the experiment, from October 2012 to February 2017.

Impact on cherry fruit quality

- **Cultivar:** Lapins was more responsive to the alternative management regime and effective microbe application than Sweetheart or Staccato. However, this may be due to site factors and soil type with Lapins grown only at Huon Park Orchards, Nicholls Rivulet.
- **Fruit set:** The alternative regime resulted in a higher fruit set compared to fruit set in conventionally managed trees in most years.
- **Fruit size:** Sweetheart and Staccato fruit diameter was 1-2mm smaller in the alternative regime in most years.
- **A-grade fruit:** There was a general trend for more A-grade fruit from the alternative regime.
- **Fruit Cracking:** There was significantly less fruit cracking from the alternative regime in years 3 and 4. EM application reduced the incidence of cracking in every season. The 2016/17 season was notable for high levels of fruit cracking due to rain leading up to harvest. In this season greater than 50% of fruit from the conventionally managed trees cracked whilst there was only 18.5% cracking from alternatively managed trees.

Hort Innovation

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Appendix 4 – Field days

(i) Orchard Soil Health Field Day, Huon Park Orchard, Nicholls Rivulet, 26 Sept 2017

(ii) Field Day summary

35 attendees.

Bill Cotching discussed the four key requirements for productive soil in terms of soil health:

- Aeration – good drainage, water available
- Organic matter – needs to be in equilibrium
- Microbes / soil biology – needs to be active
- Nutrition – balance; no amount of fertiliser will fix water logging

Sally Bound talked about the impact of different nutrient sources and effective microbes on fruit yields and quality.

The group then toured the trial site and examined the soil structure in the different treatments.
Key points arising from the discussions were:

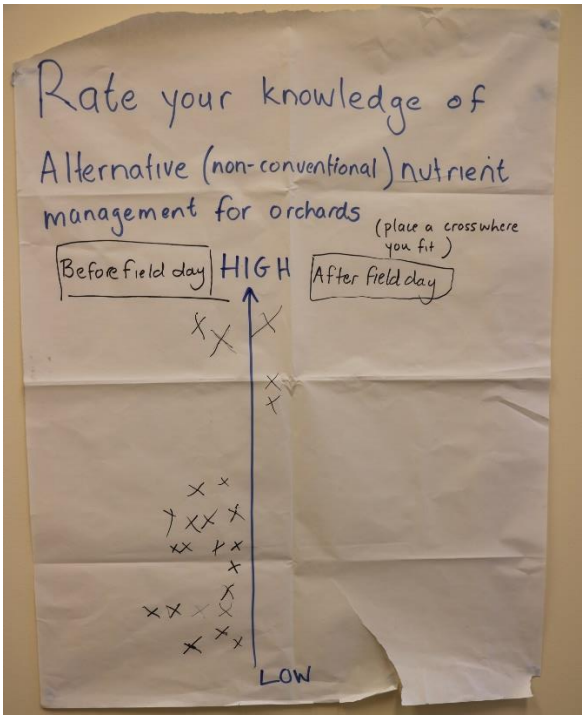
- Can have good soils in poor condition, and can also have poor soils in good condition
- Worms strong indicator of soil health. 10-12 per spadeful indicates good soil health
- Need actively growing roots (white vs brown)
- OM levels are influenced by rainfall and clay content. OM is 58% carbon, rest is other nutrients
- Plant roots exert pressure of 2,000 kilopascals
- Colour – grey and yellow indicate anaerobic
- Hydrogen sulphide also indication of lack of air
- Moss on surface is sign that soil is not very active
- Soil structure is as much about growing roots as the physical structure
- Clods indicate lack of biology / root material
- To reconstitute soil need actively growing roots
- Compost can increase OM but doesn't rejuvenate soil – can also put too much compost on as high levels of some nutrients can inhibit uptake of others
- Perennial situations fungi are predominant over bacteria because don't like being disturbed
- Plenty of native bacteria and fungi in Tas soils – just need to improve soil physical structure to increase numbers
- Physical conditions primarily control soil health ➡aeration

Without any knowledge of the treatments in the plots, soil expert, Dr Bill Cotching noted the differences in soil structure and health between the plots.

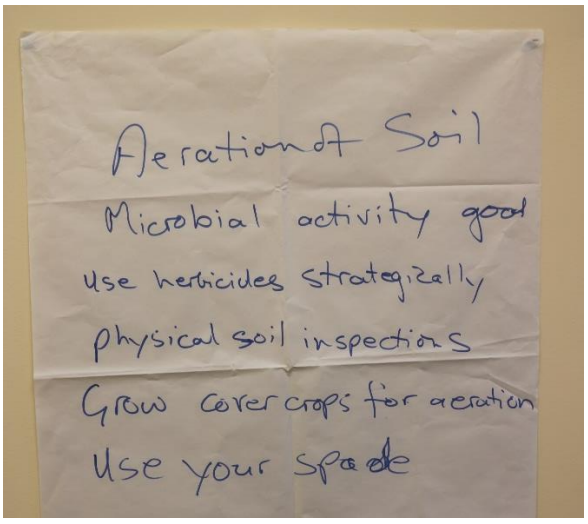
(iii) Field day review

Participants arriving at the 'Orchard Soil Health Field Day' were asked to self-rate their knowledge of alternative (non-conventional) nutrient management for orchards. This was repeated at the end of the field day.

The majority of participants gave a relatively low rating to their knowledge of alternative nutrient management for orchards prior to the field day. The responses after the field day demonstrated that participants completing this felt they now had a much improved knowledge of this topic.



At the end of the field day participants were asked for six key points on what they had learnt from the field day:



Post event On-line survey

Participants were invited to complete a short online survey about the Orchard Soil Health Field Day after the event. Only a small number of participants responded to the survey. Those who responded demonstrated a good understanding of some key messages from this day.

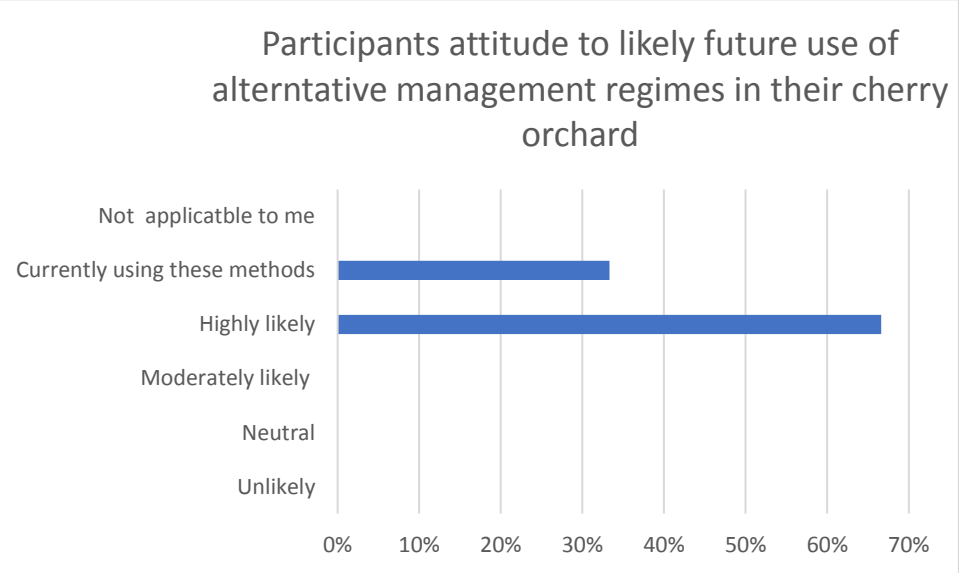
Q1: How would you describe yourself and what you do?

- 33% Cherry Grower
- 33% Orchardist including cherries
- 0% Orchardist (not including cherries)
- 33% UTAS student

Q2: What key message(s) do you remember from the orchard soil health day?

- Soil health influences cherry cracking
- Holistic soil management
- Microbes
- Grow the soil to grow the crop
- Water storage
- Differing management approaches have differing soil health characteristics
- Soil structure

Q3: How likely is it that you would use some form of alternative nutrient and/or herbicide management in your orchard?



Q4: Would you be interested in attending future workshops focusing on soil health and alternative management?

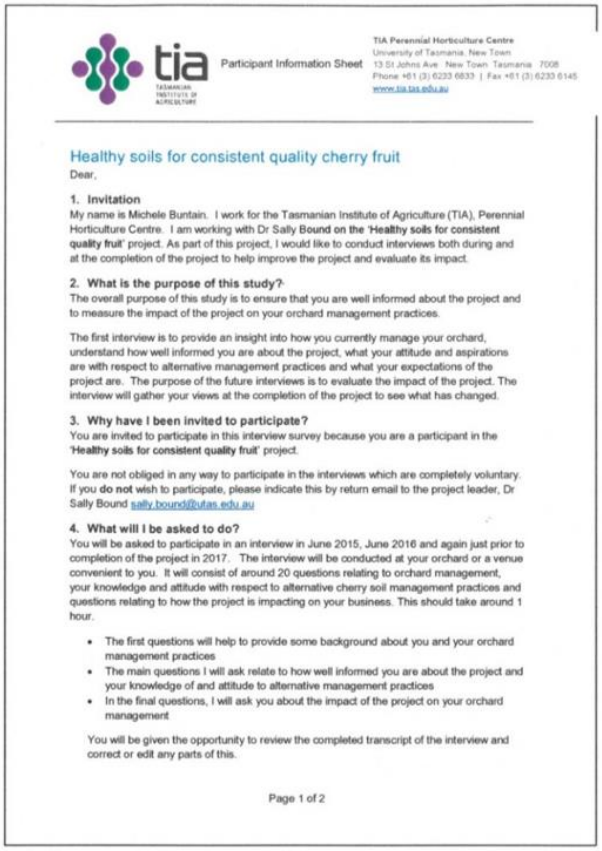
Yes 100%

Other topics

- Tree management – what type of wood to grow, how to prune to get it
- Different approaches/management practices and their effects. Topics such as differing species for under plantings. A show and tell of what is occurring internationally.

Appendix 5 – Surveys

(i) Survey documents – Invitation to participate



tia Participant Information Sheet

TIA Perennial Horticulture Centre
University of Tasmania, New Town
13 St Johns Ave New Town Tasmania 7008
Phone +61 (3) 6233 6833 | Fax +61 (3) 6233 6145
www.tia.tas.edu.au

Healthy soils for consistent quality cherry fruit

Dear,

1. Invitation
My name is Michele Buntain. I work for the Tasmanian Institute of Agriculture (TIA), Perennial Horticulture Centre. I am working with Dr Sally Bound on the '**Healthy soils for consistent quality fruit**' project. As part of this project, I would like to conduct interviews both during and at the completion of the project to help improve the project and evaluate its impact.

2. What is the purpose of this study?
The overall purpose of this study is to ensure that you are well informed about the project and to measure the impact of the project on your orchard management practices.

The first interview is to provide an insight into how you currently manage your orchard, understand how well informed you are about the project, what your attitude and aspirations are with respect to alternative management practices and what your expectations of the project are. The purpose of the future interviews is to evaluate the impact of the project. The interview will gather your views at the completion of the project to see what has changed.

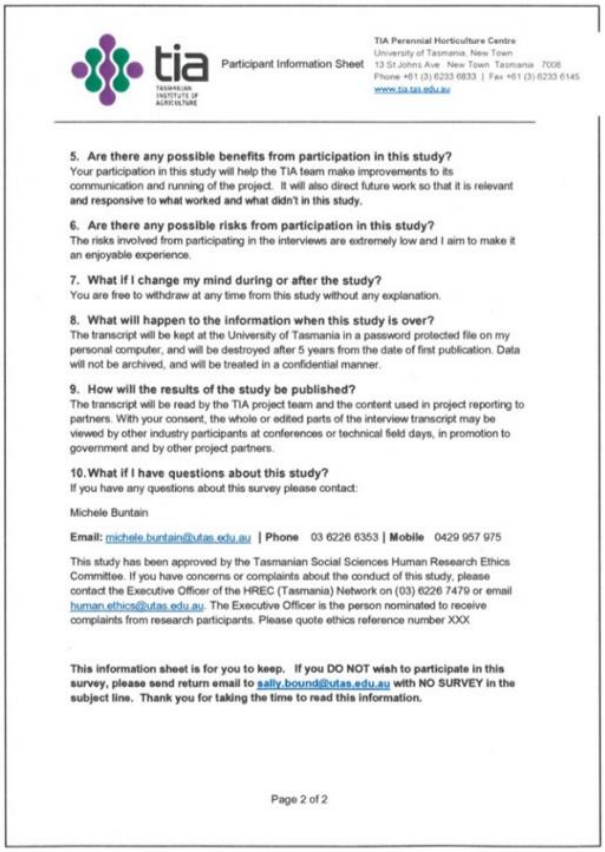
3. Why have I been invited to participate?
You are invited to participate in this interview survey because you are a participant in the '**Healthy soils for consistent quality fruit**' project.

You are not obliged in any way to participate in the interviews which are completely voluntary. If you **do not wish** to participate, please indicate this by return email to the project leader, Dr Sally Bound sally.bound@utas.edu.au

4. What will I be asked to do?
You will be asked to participate in an interview in June 2015, June 2016 and again just prior to completion of the project in 2017. The interview will be conducted at your orchard or a venue convenient to you. It will consist of around 20 questions relating to orchard management, your knowledge and attitude with respect to alternative cherry soil management practices and questions relating to how the project is impacting on your business. This should take around 1 hour.

- The first questions will help to provide some background about you and your orchard management practices
- The main questions I will ask relate to how well informed you are about the project and your knowledge of and attitude to alternative management practices
- In the final questions, I will ask you about the impact of the project on your orchard management

You will be given the opportunity to review the completed transcript of the interview and correct or edit any parts of this.



tia Participant Information Sheet

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www.tia.tas.edu.au

5. Are there any possible benefits from participation in this study?
Your participation in this study will help the TIA team make improvements to its communication and running of the project. It will also direct future work so that it is relevant and responsive to what worked and what didn't in this study.

6. Are there any possible risks from participation in this study?
The risks involved from participating in the interviews are extremely low and I aim to make it an enjoyable experience.

7. What if I change my mind during or after the study?
You are free to withdraw at any time from this study without any explanation.

8. What will happen to the information when this study is over?
The transcript will be kept at the University of Tasmania in a password protected file on my personal computer, and will be destroyed after 5 years from the date of first publication. Data will not be archived, and will be treated in a confidential manner.

9. How will the results of the study be published?
The transcript will be read by the TIA project team and the content used in project reporting to partners. With your consent, the whole or edited parts of the interview transcript may be viewed by other industry participants at conferences or technical field days, in promotion to government and by other project partners.

10. What if I have questions about this study?
If you have any questions about this survey please contact:

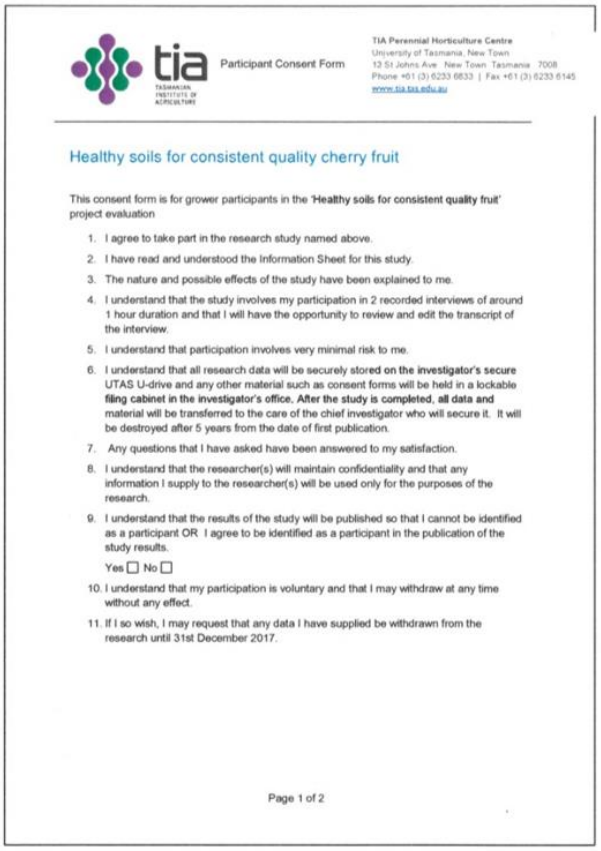
Michele Buntain

Email: michele.buntain@utas.edu.au | **Phone** 03 6226 6353 | **Mobile** 0429 957 975

This study has been approved by the Tasmanian Social Sciences Human Research Ethics Committee. If you have concerns or complaints about the conduct of this study, please contact the Executive Officer of the HREC (Tasmania) Network on (03) 6226 7479 or email human.ethics@utas.edu.au. The Executive Officer is the person nominated to receive complaints from research participants. Please quote ethics reference number XXX

This information sheet is for you to keep. If you DO NOT wish to participate in this survey, please send return email to sally.bound@utas.edu.au with NO SURVEY in the subject line. Thank you for taking the time to read this information.

(ii) Survey documents – Consent form



Participant Consent Form

TIA Perennial Horticulture Centre
University of Tasmania, New Town
13 St Johns Ave New Town Tasmania 7008
Phone +61 (3) 6233 6833 | Fax +61 (3) 6233 6145
www.tia.tas.edu.au

Healthy soils for consistent quality cherry fruit

This consent form is for grower participants in the **'Healthy soils for consistent quality fruit'** project evaluation

1. I agree to take part in the research study named above.
2. I have read and understood the Information Sheet for this study.
3. The nature and possible effects of the study have been explained to me.
4. I understand that the study involves my participation in 2 recorded interviews of around 1 hour duration and that I will have the opportunity to review and edit the transcript of the interview.
5. I understand that participation involves very minimal risk to me.
6. I understand that all research data will be securely stored **on the investigator's secure** UTAS U-drive and any other material such as consent forms will be held in a lockable **filing cabinet in the investigator's office. After the study is completed, all data and** material will be transferred to the care of the chief investigator who will secure it. It will be destroyed after 5 years from the date of first publication.
7. Any questions that I have asked have been answered to my satisfaction.
8. I understand that the researcher(s) will maintain confidentiality and that any information I supply to the researcher(s) will be used only for the purposes of the research.
9. I understand that the results of the study will be published so that I cannot be identified as a participant OR I agree to be identified as a participant in the publication of the study results.

   Yes ☐ No ☐
10. I understand that my participation is voluntary and that I may withdraw at any time without any effect.
11. If I so wish, I may request that any data I have supplied be withdrawn from the research until 31st December 2017.

Page 1 of 2

Participant Consent Form

TIA Perennial Horticulture Centre
University of Tasmania, New Town
13 St Johns Ave New Town Tasmania 7008
Phone +61 (3) 6233 6833 | Fax +61 (3) 6233 6145
www.tia.tas.edu.au

Participant's name: _____

Participant's signature: _____

Date: _____

Statement by Investigator

☐ I have explained the project and the implications of participation in it to this volunteer and I believe that the consent is informed and that he/she understands the implications of participation.

If the Investigator has not had an opportunity to talk to participants prior to them participating, the following must be ticked.

☐ The participant has received the Information Sheet where my details have been provided so participants have had the opportunity to contact me prior to consenting to participate in this project.

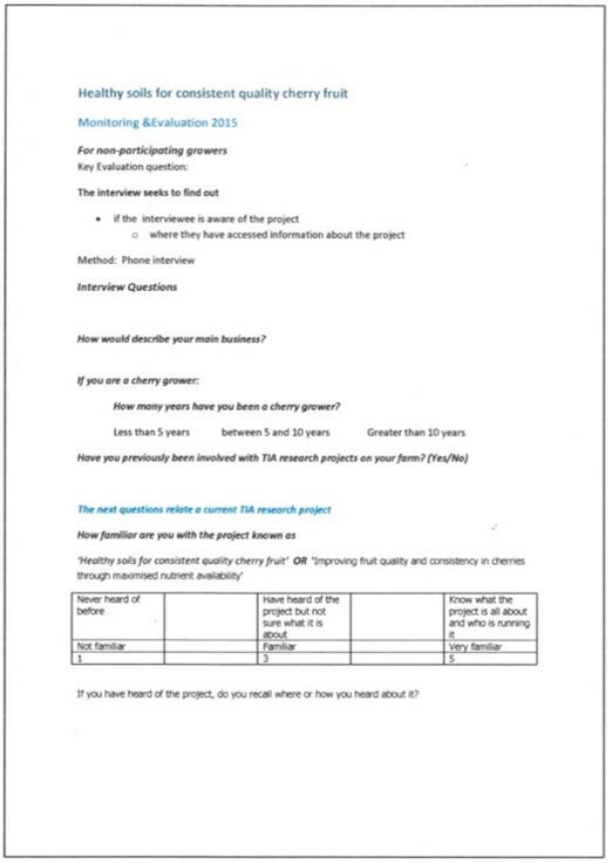
Investigator's name: _____

Investigator's signature: _____

Date: _____

Page 2 of 2

(iii) Survey documents – Non-participating growers questions



Healthy soils for consistent quality cherry fruit

Monitoring &Evaluation 2015

For non-participating growers

Key Evaluation question:

The interview seeks to find out

- if the interviewee is aware of the project
  - where they have accessed information about the project

Method: Phone interview

Interview Questions

How would describe your main business?

If you are a cherry grower:

How many years have you been a cherry grower?

Less than 5 years between 5 and 10 years Greater than 10 years

Have you previously been involved with TIA research projects on your farm? (Yes/No)

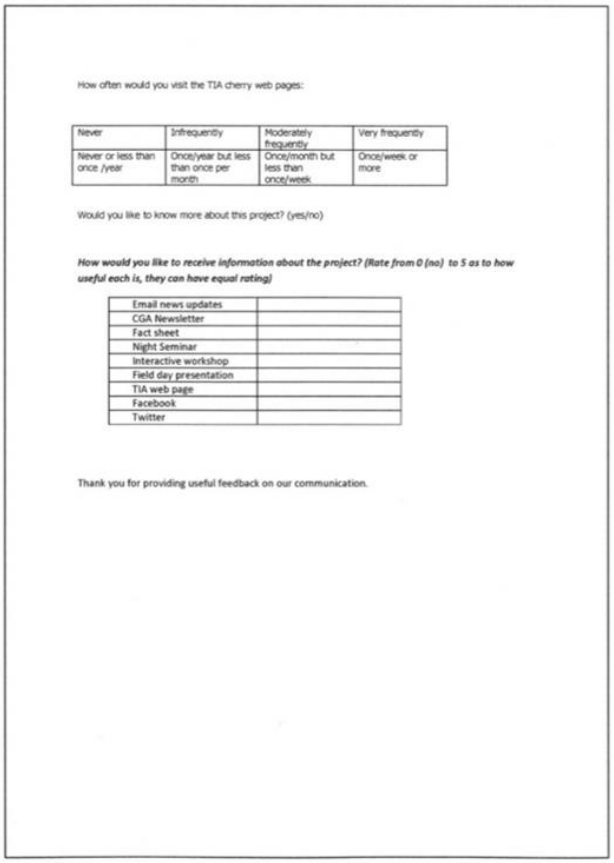
The next questions relate a current TIA research project

How familiar are you with the project known as

'Healthy soils for consistent quality cherry fruit' ***OR*** *'Improving fruit quality and consistency in cherries through maximised nutrient availability'*

Never heard of before		Have heard of the project but not sure what it is about		Know what the project is all about and who is running it
Not familiar		Familiar		Very familiar
1		3		5

If you have heard of the project, do you recall where or how you heard about it?



How often would you visit the TIA cherry web pages:

Never	Infrequently	Moderately frequently	Very frequently
Never or less than once /year	Once/year but less than once per month	Once/month but less than once/week	Once/week or more

Would you like to know more about this project? (yes/no)

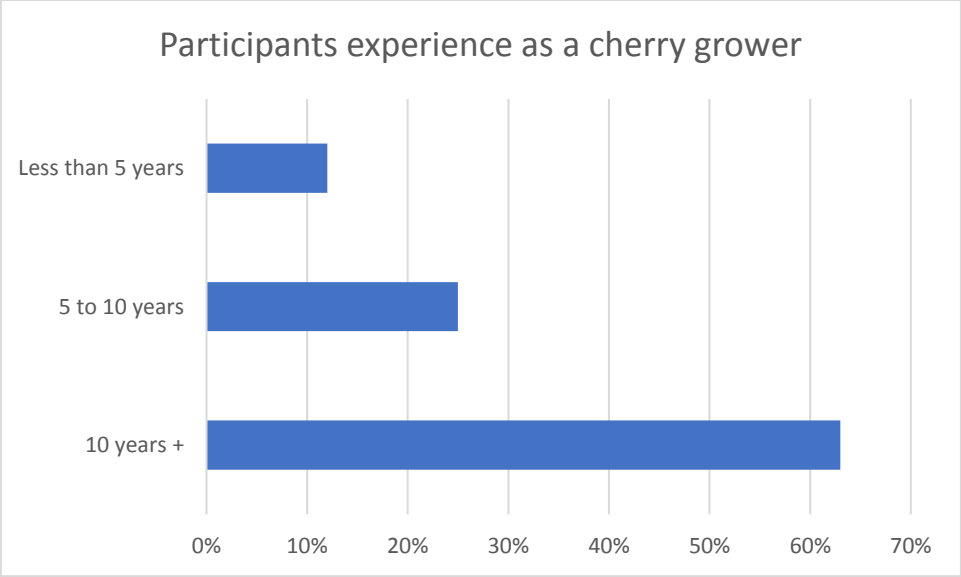
How would you like to receive information about the project? (Rate from 0 (no) to 5 as to how useful each is, they can have equal rating)

Email news updates	
CGA Newsletter	
Fact sheet	
Night Seminar	
Interactive workshop	
Field day presentation	
TIA web page	
Facebook	
Twitter	

Thank you for providing useful feedback on our communication.

Cherry growers were chosen at random from each cherry production region of Tasmania to participate in a short phone interview about their interaction with the project and how they would like to receive information about the project.

Participant demographics and cherry growing experience: There was a wide range of grower participation in cherry growing from relatively new (less than 5 years) to very experienced (greater than 10 years).



Only one grower had previously been involved in cherry research on their property.

Where and how do growers access information? The growers interviewed had a low level of familiarity with the project 'Improving fruit quality and consistency in cherries through maximised nutrient availability'.

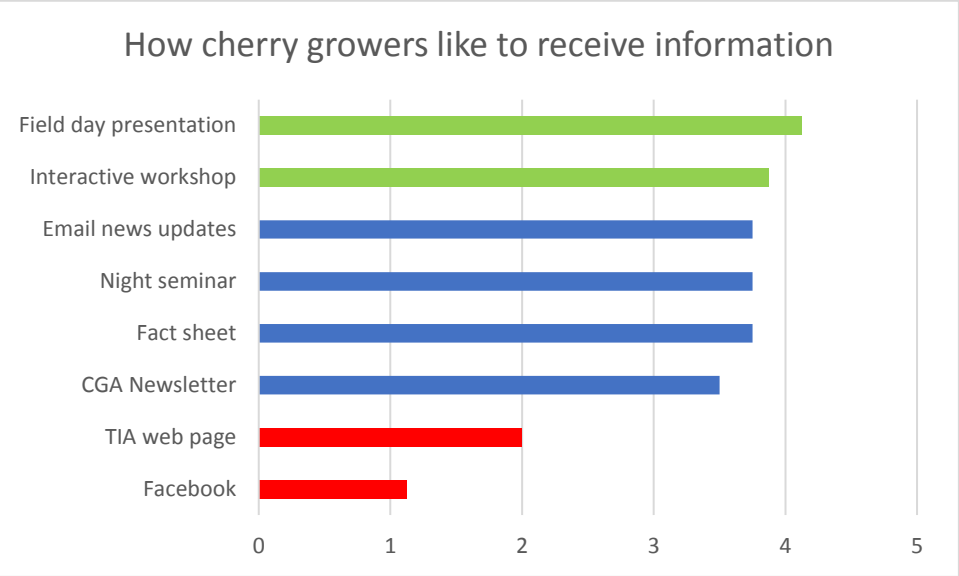
- 75% indicated they had not heard of the project before.
- 25%indicated that they had heard of the project but were not sure what it is about.

Growers who were familiar with the project indicated the following sources:

- Fruit Growers Tasmania Field day, November 2015
- Fruit Growers Tasmania magazine

Growers indicated infrequent to no interaction with either the Cherry Growers Australia web pages or the Tasmanian Institute of Agriculture web pages with only 2 growers indicating they accessed either of these but infrequently.

Growers indicated the following preferences for how they would like to receive information about the project where a rating of 5 was the most preferred and 0 the least preferred method.



Comments made by growers included

- Information overload was an issue –too many emails
- Timing and location are important considerations when holding events – they should be regional.

The responses indicate that growers place greatest value on events with field day presentations and interactive workshops as the most preferred format.

Growers indicated that other methods such as email news updates, night seminars, fact sheets and hardcopy newsletters were also of value.

Facebook and web pages were the lowest rated formats for information on new practices.

(i) Survey – Participating growers

Phone interviews were conducted with the two participating growers' mid-way through the project, 2015. The interviews with participating growers aimed to find out:

- if they are well informed about the project:
    - understand what the project is about, why we are doing it
- What attitude to alternative management practices, Likelihood to change practices
- If the project is running well on the ground

Summary

Both growers whilst currently using a conventional nutrient management program also see benefit from applying humates and, to a lesser extent, beneficial microbes for orchard productivity and fruit quality. They rated soil organic matter as extremely important and monitor this regularly as a measure of soil health.

The growers have both experienced variable fruit quality and aspire to improve pack out of 1st grade fruit. However, rain was considered the primary factor affecting fruit quality, with one grower rating crop nutrition as the second most important factor.

Both growers demonstrated a positive attitude to implementing new management practices based on research results, particularly if those had been achieved on their property.

To date, growers had received some information about the project from technical staff, CGA newsletter and fact sheets and were able to describe the nature of the project in their own words, showing good understanding of what the project was about. Their preference for future communication about the project was via one on one discussion with the researcher or email update.

The growers indicated that the project only minimally impacted or had no impact on their day to day orchard operations and that communication about on ground activities had been timely.

Experience: Both participating growers are experienced (15 years +) cherry growers.

Current nutrient management practices

Both growers use a largely conventional nutrient management program of basal fertiliser (NPK + trace elements) followed by fertigation and foliar fertilizer applications during the season. Decision making about nutrient application is made in conjunction with a private agronomist based on soil and leaf analysis.

One grower applied kelp as a less conventional supplement for both frost protection and plant vigour.

Attitude to alternative management practices / practice change:

Both growers demonstrated a positive attitude to implementing new management practices.

Both growers indicated that they would apply new management practices:

- Recommended by agronomists or specialists
- Based on new research

Grower 2 also indicated they conducted their own research in order to find the best management practices.

"Adoption of a new practice would require either something that is physically obvious in the orchard or measureable as an improvement in pack out. Even a 2 to 3% improvement in pack out would be an advantage if the cost:benefit stacked up."

Current fruit quality and future aspirations for fruit quality

Both growers indicated a degree of variability in fruit quality from season to season ranging from highly variable to somewhat variable, indicating this is a significant impact on productivity and profitability.

	Highly variable from year to year *(boom to bust)*	*Somewhat variable* *(Never a complete write off but sometimes very bad)*	*Mostly consistent quality from year to year* *(fruit always saleable but quality varies)*	*Quality is consistent but better quality is achievable*	*Consistently high quality*
Grower 1					
Grower 2					

Both growers indicated that rain was the primary determinant of fruit quality. Grower 1 indicated nutrition as the next most important factor whilst Grower 2 indicated other environmental factors (wind, heat) then disease (fruit rots).

Grower 1 aspired to a 90% packout of 1st grade fruit whilst Grower 2 believed 80% was achievable.

How well informed are participants about the project? The growers indicated they had received some information to date and were able to describe the project in their own words.

	Not at all	Very little	Some information	Well informed	Very well informed
Grower 1					
Grower 2					

Growers put in their own words how they would describe the project to another grower:

"Well it is a nutrition trial trying to find a satisfactory soil balance without using commercial fertilizer applications, using organic humates, kelps rather than NPK blends. Just trying to see what it does to the trees over a 5 year period, it's a long term project"

"The project is at (growers farm) with 3 different sites. One uses herbicides. It all comes down to soil health. I know they are using additives/ biological additives and then they are assessing fruit quality, tree growth – trying to reduce chemical fertilizer on to the block."

Future communication about the project

Growers described what information they would like from the project and in what format they found most useful.

"We would like results, see what's been done. I can see what it's doing to the orchard. The trees aren't performing. It would be interesting to see what the results are compared to how the trees look"

"If we could find some better way of applying fertilizers or a better fertilizer program we would be interested"

1. One on one discussion with researcher (Grower 1 rated this highest)
2. Email updates (Grower 2 rated this highest)
3. CGA Newsletter
4. Fact sheet
5. Night Seminar
6. Interactive workshop
7. Field day presentation

"The whole idea of having these projects on our place is to have that one on one early information. That's the advantage of having it on our place, we get the one on one information early and we can assess it with our own eyes on our own place. And then we can get the information from seminars and conferences and all of the above. Emails are often lost in translation, but they don't cost anything so it is worth sending them through. The night seminars are good."

Attitude and aspirations regarding alternative management practices?

Both growers indicated a need to see better outcome in terms of fruit quality without compromising yield to consider completely changing practices to alternative nutrient management.

Their views on the impact of soil biology on fruit quality varied with one grower indicating that this was of only a little importance whilst the other grower indicated soil biology was moderately important. Both growers had a relatively ad hoc approach to the application of beneficial microbes.

Both growers indicated that soil organic matter was extremely important (the highest rating) to orchard productivity and fruit quality and one grower uses regular measurements of soil organic matter to gauge soil health. Humates were a regular addition to each orchard.

How growers value and understand soil biology, soil organic matter and the use of humates and their importance for orchard productivity and fruit quality:

Soil Biology

	Not important	Of only a little importance	Somewhat important	Moderately important	Extremely important
Grower 1					
Grower 2					

Soil Organic Matter

	Not important	Of only a little importance	Somewhat important	Moderately important	Extremely important
Grower 1					
Grower 2					

"We are more proactive here with trying to keep the organic matter up. We are always checking this from soil tests. This is our gauge of whether the soil is healthy".

With your current knowledge of humates and beneficial microbes, how likely would you be to include them in your current orchard management?

Humates

	I wouldn't	Unlikely to include	I would include them in a small area of the orchard	I will apply them to my entire orchard
Grower 1				
Grower 2				

"*We currently apply 1 or 2 on every year through the drippers"*

"We apply them to all the orchard – when we add fertilizer we always put humates. Because we are spending so much on fertilizer we want to get the maximum uptake we can. A lot of the products come with humate added to it, it can be difficult to use – blocking filters/drippers through fertigation. We sometimes flood it on through a jet, say after calcium sprays."

Beneficial microbes

	I wouldn't	Unlikely to include	I would include them in a small area of the orchard	I will apply them to my entire orchard
Grower 1				
Grower 2				

"We currently use these sporadically, ad hoc. The trial rows are very yellow from green tip to leaf fall – so we think they need more than just the microbes, useful as a supplement but not a sole nutrition program"

"It's usually a top dress every so often just to boost the numbers. "

Project impact on their operation

Growers indicated they had often or always received timely communication about TIA operations on their property, with minimal impact on the day to day operations. Text messages were a preferred communications method.

Appendix 6 – Site plans

(i) Derwent Valley site

HAL Cherry soil biology - CY12002

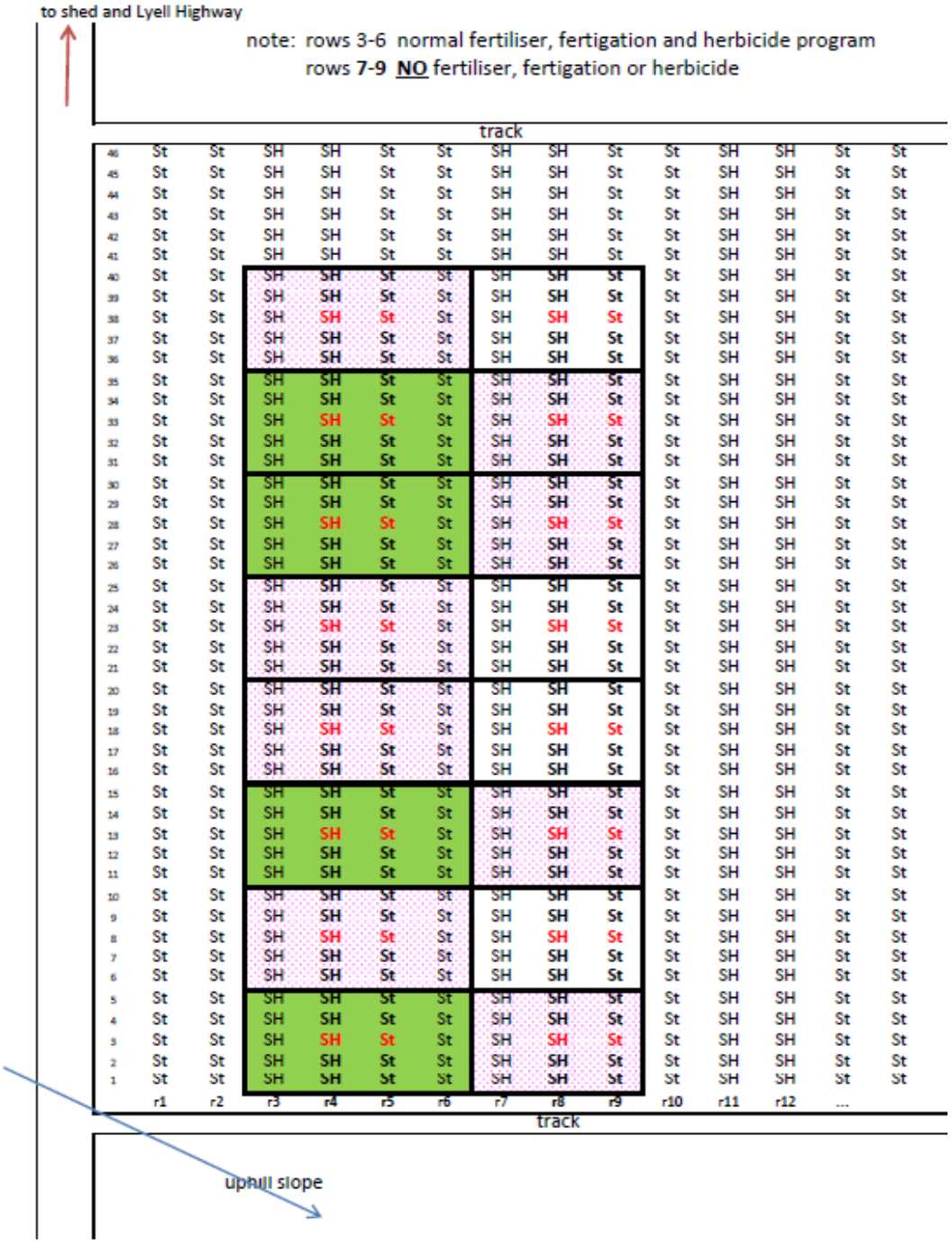
Site: Rosegarland (Hansen Orchards) - Block A16

Cultivars: Sweetheart (SH) / Staccato (St)
Age: planted 2007
Row orientation: east/west
Spacing: 5m x 2m
Soil type: dolerite/clay

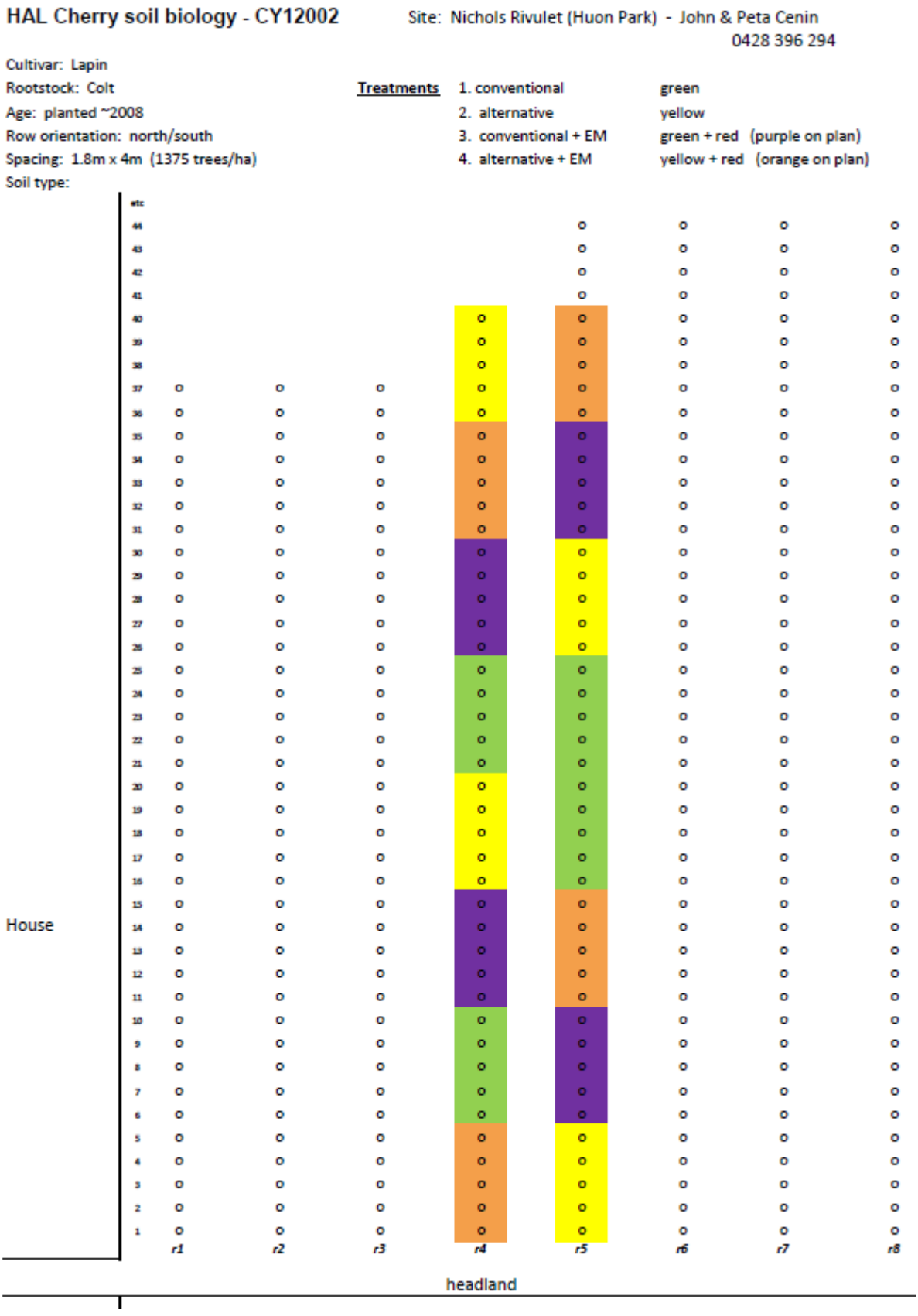
Rootstock: Colt

Treatments

1. control — green
2. restorative — white
3. control + EM — green + red
4. restorative + EM — white + red



(ii) Huon Valley site



Appendix 7 – Soil analyses

(i) Nutrient analysis of organic amendments used in the trial.

	Ferbon®	Compost
N	1.34 %	1.50 %
P	0.199 %	0.75 %
K	0.462 %	0.61 %
S	1.77 %	0.26 %
Ca	1.48 %	1.31 %
Mg	0.279 %	0.98 %
Na	0.246 %	0.18 %
Fe	9100 ppm	1.81 %
Cl	NA	0.37 %
Mn	488 ppm	383.29 ppm
Zn	142 ppm	199.87 ppm
Cu	91 ppm	65.09 ppm
Co	11.8 ppm	6.68 ppm
B	54.7 ppm	30.79 ppm
Mo	9 ppm	4.38 ppm
PH	6.2	6.5
Electrical Conductivity	3255 uS/cm	2000 uS/cm
Organic carbon	37.5 %	n/a
Moisture Content	35.4 %	n/a

(ii) Organic amendments and minerals applied in the alternative treatments.

	Sweetheart (Rosegarland)					Lapin (Nicholls Rivulet			
	2012	2013	2014	2015	2016	2013	2014	2015	2016
Ferbon	300	300	-	-	-	300	-	-	-
Humified compost	-	-	800	800	2000	-	800	800	2000
Soluble humate granules	-	-	20	20	20	-	20	20	20
Dolomite lime (autumn)	-	-	500	500	-	-	-	500	-
Diatomaceous earth	-	-	-	-	-	-	1000	-	-
Calcitic lime	-	-	-	-	-	-	1000	-	-
Gypsum	50	50	-	-	-	-	700	-	-
Elemental sulphur	-	-	-	-	-	50	-	-	-
Ammonium sulphate	30	30	-	-	-	50	-	-	-
Potassium sulphate	20	20	-	-	-	10	-	-	-
Magnesium sulphate	-	-	-	-	-	-	-	-	100
Manganese sulphate	25	25	1.5	25	25	20	25	25	25
Zinc sulphate	2	2	-	-	-	-	-	-	-
Copper sulphate	2	2	-	-	-	-	-	-	-
Iron sulphate	-	-	-	-	2	-	-	-	-
Borax	8	8	-	-	-	10	-	8	
Sodium molybdate	0.5	0.5	1	-		0.5	-	1	

(iii) Baseline soil nutrient levels

Test	*Nutrient*		*Units*	*Grove*	*Derwent Valley*	*Nicholls Rivulet*
Morgan	Calcium	Ca	mg/kg	1391	3140	2233
	Magnesium	Mg	mg/kg	308	294	254
	Potassium	K	mg/kg	137	243	289
	Phosphate	P	mg/kg	16.5	17.7	36.5
	Nitrate Nitrogen	N	mg/kg	1.2	43.9	21.4
	Ammonium Nitrogen	N	mg/kg	9.7	14.2	2.7
Mehlich 3	Phosphorus	P	mg/kg	90	79	254
Bray 2	Phosphorus	P	mg/kg	118	90	364
KCl	Sulphate Sulphur	S	mg/kg	18.1	137.7	83.8
1:5 Water	pH		units	7.20	6.60	6.90
	Conductivity		dS/m	0.094	0.360	0.268
Calculation	Chloride Estimate		equiv ppm	60	230	171
Calculation	Organic Matter		% OM	4.1	5.1	5.8
	Calcium	Ca	mg/kg	1569.03	3461.03	2552
	Magnesium	Mg	mg/kg	349	343	279
	Potassium	K	mg/kg	161	413	353
	Sodium	Na	mg/kg	24	51	68
Calculations	Aluminium	Al	mg/kg	4	9	6
Calculations	Cation Exchange Capacity		ME/100 g	11.22	21.37	16.23
	Total Cation Exchange (inc. H/ Al)		ME/100 g	11.26	22.85	16.55
Base Saturation Calculations	**Calcium**	**Ca^{2+}**	**%**	69.8	76.0	77.3
	Magnesium	**Mg^{2+}**	**%**	25.6	12.4	13.9
	Potassium	**K^{+}**	**%**	3.7	4.6	5.5
	Sodium	**Na^{+}**	**%**	0.9	1.0	1.8
	Hydrogen	**H^{+}**	**%**	0.0	6.0	1.5
	Other Bases	**Al^{3+}**	**%**	0.4	0.5	0.4
Calculation	Calcium/ Magnesium Ratio		ratio	2.73	6.12	5.54
DTPA	Zinc	Zn	mg/kg	12.4	8.5	20.2
	Manganese	Mn	mg/kg	59	61	3
	Iron	Fe	mg/kg	261	212	196
	Copper	Cu	mg/kg	12.9	5.8	10.2
$CaCl_2$	Boron	B	mg/kg	0.93	1.09	1.33
	Silicon	Si	mg/kg	62	70	62
LECO IR Analyser	Total Carbon	C	%	2.33	2.94	3.30
	Total Nitrogen	N	%	0.17	0.27	0.24
Calculations	Carbon/ Nitrogen Ratio		ratio	13.9	10.9	13.8
PCSM	Paramagnetism		µcgs	540	410	<10
Permanganate Oxidisable	Labile Carbon	C	%	0.72	0.74	0.64
Water Extractable	Chloride	Cl	mg/kg	15	22	47
Total Acid Extractable	Calcium	Ca	mg/kg	2,217	4,826	3.594
	Magnesium	Mg	mg/kg	574	1,254	600
	Potassium	K	mg/kg	229	1,034	838
	Sodium	Na	mg/kg	<50	215	114
	Sulfur	S	mg/kg	226	374	433
	Phosphorus	P	mg/kg	349	334	779
	Zinc	Zn	mg/kg	25	38	71
	Manganese	Mn	mg/kg	129	595	104
	Iron	Fe	mg/kg	21,320	21,389	4,000
	Copper	Cu	mg/kg	34.0	29.4	38.3
	Boron	B	mg/kg	2.1	2.9	3.4
	Silicon	Si	mg/kg	641	770	835
	Aluminium	Al	mg/kg	3,345	12,587	6,056
	Molybdenum	Mo	mg/kg	<0.5	<0.5	<0.5
	Cobalt	Co	mg/kg	1.3	34.3	1.2
	Selenium	Se	mg/kg	<0.5	<0.5	<0.5

(iv) Treatments effects on soil nutrient levels after 5 years – Derwent Valley (Rosegarland)

Test	*Nutrient*		*Units*	*Baseline Oct 2012*	*Control April 2017*	*Alternate April 2017*	*Con + EM April 2017*	*Alt + EM April 2017*
Morgan	Calcium	Ca	mg/kg	3140	4133	4642	2990	3633
	Magnesium	Mg	mg/kg	294	438	500	397	436
	Potassium	K	mg/kg	243	154	182	162	273
	Phosphate	P	mg/kg	17.7	18	32	16	36
	Nitrate Nitrogen	N	mg/kg	43.9	3.2	3.7	3.5	6.4
	Ammonium Nitrogen	N	mg/kg	14.2	25	29	23	31
Mehlich 3	Phosphorus	P	mg/kg	79	71	101	56	114
Bray 2	Phosphorus	P	mg/kg	90	66	146	48	190
KCl	Sulphate Sulphur	S	mg/kg	137.7	17	94	26	89
1:5 Water	pH		units	6.60	7.10	7.00	6.90	6.80
	Conductivity		dS/m	0.360	0.297	0.418	0.220	0.406
Calculation	Chloride Estimate		equiv ppm	230	190	268	141	260
Calculation	Organic Matter		% OM	5.1	7.2	10.4	6.6	9.4
	Calcium	Ca	mg/kg	3461.03	4030	4300	3090	3850
	Magnesium	Mg	mg/kg	343	456	520	417	472
	Potassium	K	mg/kg	413	257	295	241	444
	Sodium	Na	mg/kg	51	51	63	52	69
	Aluminium	Al	mg/kg	9	9	10	7	10
Calculations	Cation Exchange Capacity		ME/100g	21.37	24.74	26.77	19.70	24.54
	Total Cation Exchange (inc. H/ Al)		ME/100g	22.85	24.84	26.87	20.08	25.41
Base Saturation Calculations	**Calcium**	**Ca^{2+}**	**%**	76.0	81.3	80.2	77.1	76.0
	Magnesium	**Mg^{2+}**	**%**	12.4	15.2	16.0	17.2	15.4
	Potassium	**K^{+}**	**%**	4.6	2.7	2.8	3.1	4.5
	Sodium	**Na^{+}**	**%**	1.0	0.9	1.0	1.1	1.2
	Hydrogen	**H^{+}**	**%**	6.0	0.0	0.0	1.5	3.0
	Other Bases	**Al^{3+}**	**%**	0.5	0.4	0.4	0.4	0.4
Calculation	Calcium/ Magnesium Ratio		ratio	6.12	5.36	5.02	4.49	4.94
DTPA	Zinc	Zn	mg/kg	8.5	14	20	12	16
	Manganese	Mn	mg/kg	61	63	102	61	153
	Iron	Fe	mg/kg	212	124	119	117	126
	Copper	Cu	mg/kg	5.8	17	18	16	15
$CaCl_2$	Boron	B	mg/kg	1.09	0.71	1.27	0.77	1.94
	Silicon	Si	mg/kg	70	39	41	41	54
LECO IR Analyser	Total Carbon	C	%	2.94	4.09	5.92	3.77	5.39
	Total Nitrogen	N	%	0.27	0.32	0.40	0.30	0.40
Calculations	Carbon/ Nitrogen Ratio		ratio	10.9	12.9	14.7	12.8	13.5
PCSM	Paramagnetism		µcgs	410	320	250	240	340
Permanganate Oxidisable	Labile Carbon	C	%	0.74	0.99	1.48	1.00	1.53
Water Extractable	Chloride	Cl	mg/kg	22	61	59	52	74
Total Acid Extractable	Calcium	Ca	mg/kg	4,826	6,624	12,438	4,413	8,729
	Magnesium	Mg	mg/kg	1,254	1,388	4,099	1,181	2,430
	Potassium	K	mg/kg	1,034	843	834	732	1,049
	Sodium	Na	mg/kg	215	231	246	248	250
	Sulfur	S	mg/kg	374	351	645	350	519
	Phosphorus	P	mg/kg	334	352	441	264	502
	Zinc	Zn	mg/kg	38	61	73	48	58
	Manganese	Mn	mg/kg	595	930	1,105	749	1,221
	Iron	Fe	mg/kg	21,389	19,675	19,931	18,476	20,609
	Copper	Cu	mg/kg	29.4	60.1	63.8	54.4	55.8
	Boron	B	mg/kg	2.9	2.2	3.9	2.8	4.6
	Silicon	Si	mg/kg	770	973	1,056	1,075	1,102
	Aluminium	Al	mg/kg	12,587	10,166	10,084	9,500	9,421
	Molybdenum	Mo	mg/kg	<0.5	0.50	4.14	0.51	5.94
	Cobalt	Co	mg/kg	34.3	32.3	25.8	27.0	26.6
	Selenium	Se	mg/kg	<0.5	<0.5	<0.5	<0.5	<0.5

(v) Treatments effects on soil nutrient levels after 5 years – Huon Valley (Nicholls Rivulet)

Test	*Nutrient*		*Units*	*Baseline Mar 2013*	*Control April 2017*	*Alternate April 2017*	*Con + EM April 2017*	*Alt + EM April 2017*
Morgan	Calcium	Ca	mg/kg	2233	2629	9714	3402	4732
	Magnesium	Mg	mg/kg	254	260	319	252	261
	Potassium	K	mg/kg	289	398	394	316	288
	Phosphate	P	mg/kg	36.5	50	50	46	48
	Nitrate Nitrogen	N	mg/kg	21.4	6.7	9.7	4.7	4.6
	Ammonium Nitrogen	N	mg/kg	2.7	19	45	17	29
Mehlich 3	Phosphorus	P	mg/kg	254	36.1	328	326	275
Bray 2	Phosphorus	P	mg/kg	364	364	325	307	293
KCl	Sulphate Sulphur	S	mg/kg	83.8	20	28	26	20
1:5 Water	pH		units	6.90	7.10	7.40	6.90	7.30
	Conductivity		dS/m	0.268	0.223	0.332	0.230	0.261
Calculation	Chloride Estimate		equiv ppm	171	143	213	147	167
	Organic Matter		% OM	5.8	7.7	10.2	6.7	9.0
	Calcium	Ca	mg/kg	2552	2970	4780	2730	3770
	Magnesium	Mg	mg/kg	279	297	316	265	283
	Potassium	K	mg/kg	353	548	504	373	385
	Sodium	Na	mg/kg	68	40	48	40	41
	Aluminium	Al	mg/kg	6	7	9	6	7
	Cation Exchange Capacity		ME/100g	16.23	18.84	27.95	16.94	22.31
	Total Cation Exchange (inc. H/ Al)		ME/100g	16.55	18.91	28.05	17.27	22.39
Base Saturation Calculations	**Calcium**	**Ca^{2+}**	**%**	77.3	78.7	85.3	79.2	84.3
	Magnesium	**Mg^{2+}**	**%**	13.9	13.0	9.3	12.7	10.5
	Potassium	**K^{+}**	**%**	5.5	7.4	4.6	5.6	4.4
	Sodium	**Na^{+}**	**%**	1.8	0.9	0.7	1.0	0.8
	Hydrogen	**H^{+}**	**%**	1.5	0.0	0.0	1.5	0.0
	Other Bases	**Al^{3+}**	**%**	0.4	0.4	0.4	0.4	0.4
Calculation	Calcium/ Magnesium Ratio		ratio	5.54	6.07	9.18	6.24	8.07
DTPA	Zinc	Zn	mg/kg	20.2	26	24	17	26
	Manganese	Mn	mg/kg	3	11	47	8.2	44
	Iron	Fe	mg/kg	196	194	182	248	207
	Copper	Cu	mg/kg	10.2	28	31	20	35
$CaCl_2$	Boron	B	mg/kg	1.33	1.38	2.57	1.10	2.70
	Silicon	Si	mg/kg	62	43	45	41	49
LECO IR Analyser	Total Carbon	C	%	3.30	4.42	5.86	3.84	5.16
	Total Nitrogen	N	%	0.24	0.29	0.38	0.24	0.36
Calculations	Carbon/ Nitrogen Ratio		ratio	13.8	15.5	15.3	15.9	14.2
PCSM	Paramagnetism		µcgs	<10	60	100	70	70
Permanganate Oxidisable	Labile Carbon	C	%	0.64	1.02	1.26	1.02	1.30
Water Extractable	Chloride	Cl	mg/kg	47	61	61	54	47
Total Acid Extractable	Calcium	Ca	mg/kg	3.594	4.905	19,838	4,293	9,768
	Magnesium	Mg	mg/kg	600	562	1,497	509	1,043
	Potassium	K	mg/kg	838	1,292	1,146	1,043	1,040
	Sodium	Na	mg/kg	114	110	127	97	105
	Sulfur	S	mg/kg	433	398	599	404	561
	Phosphorus	P	mg/kg	779	839	1,039	766	908
	Zinc	Zn	mg/kg	71	92	88	54	82
	Manganese	Mn	mg/kg	104	95	503	80	433
	Iron	Fe	mg/kg	4,000	4,287	4,871	3,575	4,532
	Copper	Cu	mg/kg	38.3	76.8	90.9	58.2	95.0
	Boron	B	mg/kg	3.4	3.8	5.7	2.1	5.1
	Silicon	Si	mg/kg	835	1,453	1,509	1,487	1,487
	Aluminium	Al	mg/kg	6,056	5,462	5,612	4,830	5,176
	Molybdenum	Mo	mg/kg	<0.5	0.54	3.91	0.42	5.26
	Cobalt	Co	mg/kg	1.2	1.3	8.6	1.0	5.5
	Selenium	Se	mg/kg	<0.5	<0.5	<0.5	<0.5	<0.5

(vi) Sample analysis reports

Comprehensive Analysis Report

- adapted from template provided by Quantum Agriculture

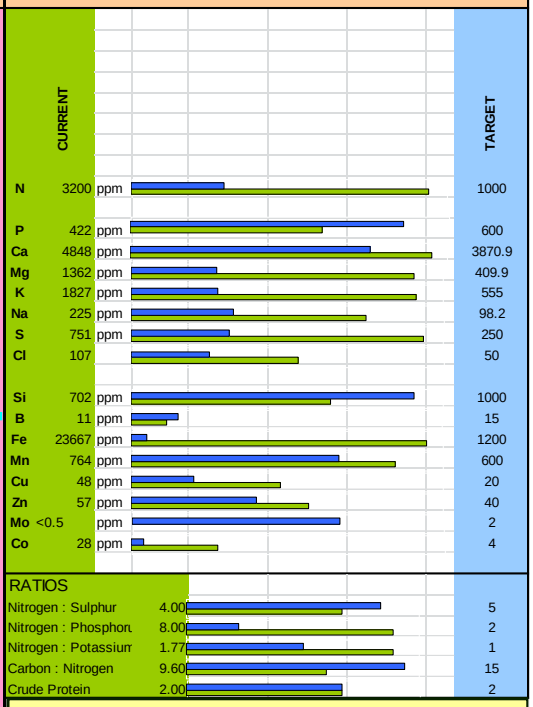
CY12002: Derwent Valley - Sweetheart

DATE:	22 May 2013	**LAND USE:**	Cherry (Sweetheart)
NAME:	S Bound	**BLOCK:**	Derwent Valley - alternative treatm
ADDRESS:		**SAMPLE REC:**	C6219
		CONTACT NO:	

SOIL ANALYSIS

ALBRECHT	CURRENT	TARGET	AVAILABLE NUTRIENT STATUS (LOW / OK / HIGH)
CEC	21.99		
TEC	28.46		
Paramagnetism	600	200 +	
pH-level (1:5 water)	6.00	6.3	
Organic Matter (IR Gas Anal.)	5.40 %	4 - 10 %	
Labile Carbon	0.64 %	0.8 - 1.2 %	
Conductivity (1:2 water)	0.842 mS/cm	0.2 - 0.6 mS/cm	
Ca / Mg Ratio	5.94 :1	5.67 :1	
Nitrate-N (Morgan)	91.6 ppm	10 - 20 ppm	
Ammonium-N (Morgan)	40.9 ppm	10 - 20 ppm	
Phosphorus (Mehlich III)	128.0 ppm	50 - 70 ppm	
Calcium (Mehlich III)	3307.0 ppm	881 ppm	
Magnesium (Mehlich III)	334.0 ppm	93 ppm	
Potassium (Mehlich III)	847.0 ppm	76 - 126 ppm	
Sodium (Mehlich III)	84.0 ppm	7 - 22 ppm	
Sulphur (Morgan)	464.2 ppm	30 - 50 ppm	
Chloride	107.0 ppm	32 - 46 ppm	
Aluminium (Mehlich III)	12.0 ppm	< 3 ppm	
Silicon ($CaCl_2$)	86.0 ppm	40 > 100 ppm	
Boron (Hot $CaCl_2$)	9.5 ppm	1 - 3 ppm	
Iron (DPTA)	86.0 ppm	40 - 200 ppm	
Manganese (DPTA)	94.0 ppm	30 - 100 ppm	
Copper (DPTA)	8.9 ppm	2 - 7 ppm	
Zinc (DPTA)	15.6 ppm	5 - 10 ppm	
Molybdenum (DPTA)	<0.5 ppm	0.5 - 2 ppm	
Cobalt (DPTA)	27.6 ppm	2 - 40 ppm	
Selenium (DPTA)	<0.5 ppm	0.6 - 2 ppm	
Texture:	Loam		
Colour:	Brownish		
BASE SATURATION			
(Levels are not really relevant in soils with a TEC below 5)			
Calcium	58.09 %	68.00 %	
Magnesium	9.78 %	12.00 %	
Potassium	7.63 %	3.00 - 5.00 %	
Sodium	1.28 %	0.50 - 1.50 %	
Aluminium	0.47 %	0.50 %	
Hydrogen	36.00 %	10.00 %	

TOTAL NUTRIENT STATUS



LEAF ANALYSIS

ELEMENT	CURRENT ANALYSIS	TARGET	ELEMENT STATUS (LOW / OK / HIGH)
Nitrogen - N	2.9 %	2.2 - 2.6 %	
Phosphorus - P	0.19 %	0.14 - 0.25 %	
Potassium - K	0.77 %	1.6 - 3.0 %	
Sulfur - S	0.16 %	0.13 - 0.80 %	
Calcium - Ca	2.07 %	0.7 - 3.00 %	
Magnesium - Mg	0.79 %	0.4 - 0.90 %	
Sodium - Na	<0.01 %	0.01 - 0.02 %	
Copper - Cu	7.0 ppm	5 - 16 ppm	
Zinc - Zn	23.0 ppm	20 - 50 ppm	
Manganese - Mn	147.0 ppm	40 - 160 ppm	
Iron - Fe	110.0 ppm	100 - 250 ppm	
Boron - B	64.0 ppm	20 - 60 ppm	
Molybdenum - Mo	<0.1 ppm	1.5 - N/A ppm	
Cobalt - Co	0.1 ppm	N/A ppm	
Silicon - Si	552.0 ppm	500 - 1200 ppm	
Chloride - Cl	0.0	N/A %	
Nitrogen : Sulphur	18.8	15 units	
Nitrogen : Phos	15.8	20 units	
Nitrogen : Potass	3.8	2 units	
Carbon : Nitrogen	16.2	15 units	
Crude Protein	18.4	30 %	
Chloride	0.0	1 %	Extremely Low
Nitrate	0.0	10 - 20 ppm	Extremely Low
Ammonia	0.0	70 - 90 ppm	Extremely Low

NOTES

The **Albrecht**, or **Soluble Test** uses a blend of mild acids and is the common sort of soil test that tells us what may be readily available via water uptake in the top 15 cm of soil. However, it does not tell us what is locked up in the mineral structure of the soil--or what may be available at greater depth.

The **Total Test** is analysed with a mix of very strong acids called ***aqua regia***, and it reveals what is locked up in the soil's mineral structure as though it were an ore sample. Much of this may become available if robust and diverse microbial activity is encouraged.

Since we test and amend soils in order to yield optimum nutrition for plants, the **Tissue Test** is the bottom line that shows how well we used the other two tests. This test also uses *aqua regia*, and it shows what was taken up by the plant--which may or may not be what shows in the Albrecht and/or Total tests.

All too often soluble tests, taken alone, are misleading. Ideally we only want small amounts of nutrients soluble at any one time, as we want most of our nutrients to be insoluble but available. This implies maintaining robust and diverse microbial activity. A complex balance between fungi, actinomycetes, yeasts, bacteria, protozoa, etc. is extremely important, as the essence of control is to use the exact amount of force necessary--no more and no less. Excesses can be as harmful as deficiencies.

For example, magnesium and potassium may both be high in the soluble test, but this can lead to excessive potassium in tissues while magnesium is deficient if the salt levels are high enough to impair the crop's fine feeder root activity, since potassium easily enters plants via water uptake while magnesium is less mobile, depending more on feeder roots to enter the plant. Such situations tend to favour certain weeds, such as tall, lush, potassium loving types. Or, phosphorous may be low in the soluble test, high in the total test and high in the leaf, indicating healthy microbial P release. But high soluble P can lead to low P in tissues, as this condition can shut down further microbial P release because it poisons the fine feeder root environment and impairs its development while at the same time traveling poorly via water uptake roots.

Your Albrecht (CEC) Nutrient Ratios for: DV Rest

ELEMENT OR CATEGORY	YOUR LEVEL	IDEAL LEVEL	NUTRIENT STATUS LOW	MEDIUM	HIGH
CEC RATIOS					
Ca / Mg Ratio	5.94 :1	5.67 :1			
Mg / K Ratio (ppm)	0.39 :1	1.00 :1			
K / Na Ratio	5.95 :1	5.00 :1			
Ca / K Ratio	7.61 :1	15.00 :1			
P / Zn Ratio	8.21 :1	10.00 :1			
Fe / Mn Ratio	0.91 :1	1.10 :1			

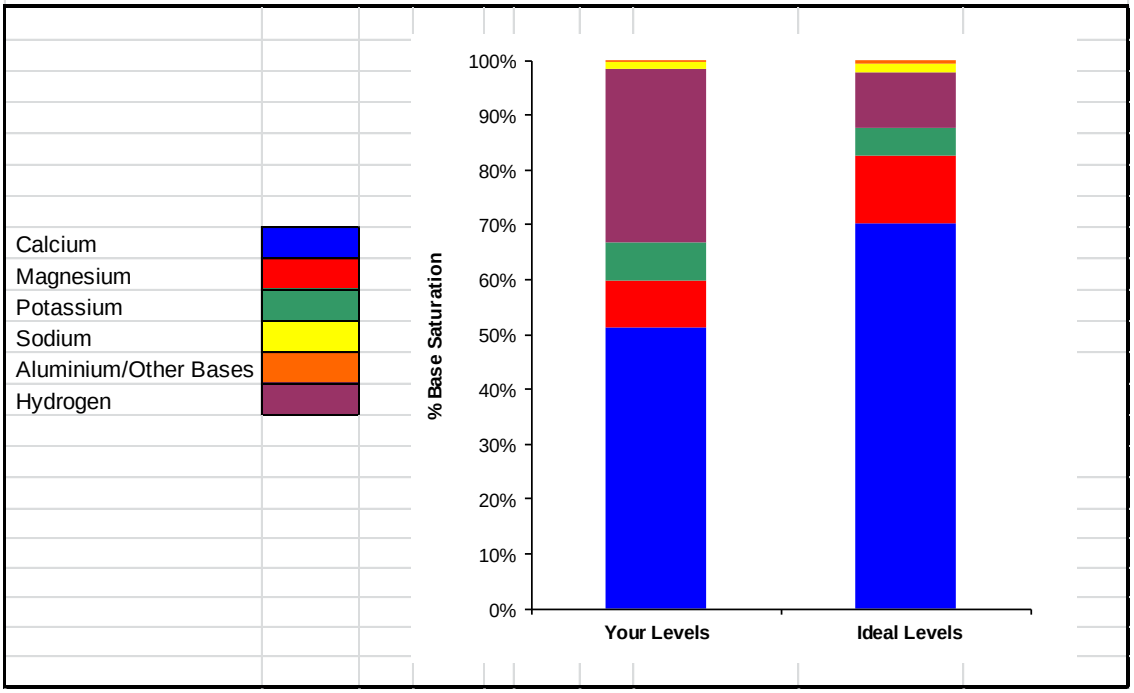
Explanatory Notes: The **Ca/Mg ratio** is the most important factor in high production fertility. When ideal levels are achieved, there will be maximum nutrient availability, optimum soil structure and luxury levels of **oxygen** (the most important element of all in terms of microbe health). The **Mg/K ratio** indicates likely availability of both these important minerals but it also a guideline to phosphate uptake. The **K/Na ratio** is indicative of potassium availability and sodium excesses - when this ratio is inverted, the plant will take up sodium instead of potassium. The **Ca/K ratio** relates to crop quality - when potassium is high in relation to calcium, then the uptake of calcium is retarded and vice versa. The **P/Zn ratio** relates to leaf size and plant sugar production - each of these minerals is capable of retarding availability of the other if the 10:1 ratio is not maintained. The **Fe/Mn ratio** relates to chlorophyll management. If iron is slightly higher than manganese both elements will be at maximum plant availability.

Your La Motte (Reams) Ratios

LA MOTTE RATIOS			
Ca / Mg Ratio	10.37 :1	7.00 :1	
P / K Ratio	0.06 :1	1.00 :1	**Extremely Low**

Explanatory Notes: The **Ca/Mg ratio** is also a key guideline to productivity and profitability in the La Motte test but unlike the CEC equivalent, this ratio does not vary in light vs heavy soils. The **P/K ratio** indicates the biological availability of phosphate - a poor P/K ratio is often linked to compromised soil life and broadleaf weed pressure.

Your Base Saturation Values vs Ideal Values



Comprehensive Analysis Report

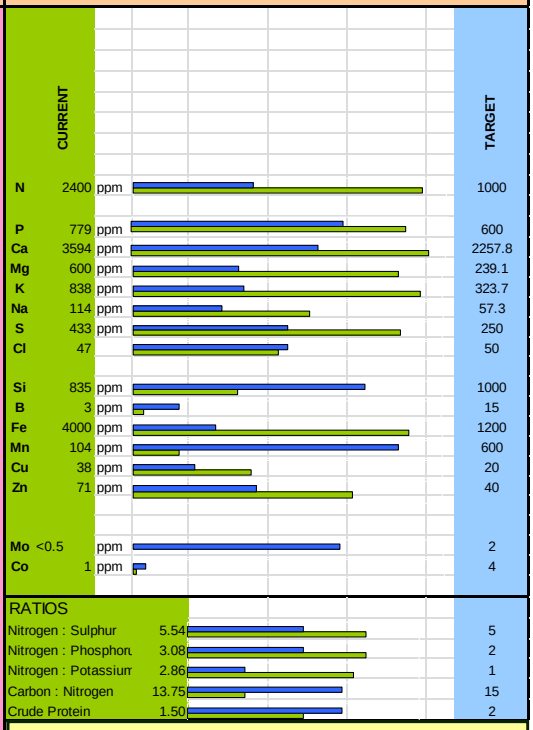
- adapted from template provided by Quantum Agriculture

CY12002: Nicholls Rivulet - Lapin

DATE:	26 April 2013	**LAND USE:**	Cherry (Lapin)
NAME:	S Bound (TIA)	**BLOCK:**	HP #1 (0-10cm)
ADDRESS:		**SAMPLE REC:**	C5477
		CONTACT NO:	

SOIL ANALYSIS

ALBRECHT	CURRENT	TARGET	AVAILABLE NUTRIENT STATUS
			LOW / OK / HIGH
CEC	16.35		
TEC	16.60		
Paramagnetism	<10	200 +	
pH-level (1:5 water)	6.90	6.3	
Organic Matter (IR Gas Anal.)	5.80 %	4 - 10 %	
Labile Carbon	0.64 %	0.8 - 1.2 %	
Conductivity (1:2 water)	0.268 mS/cm	0.2 - 0.6 mS/cm	
Ca / Mg Ratio	5.49 :1	5.67 :1	
Nitrate-N (Morgan)	21.4 ppm	10 - 20 ppm	
Ammonium-N (Morgan)	2.7 ppm	10 - 20 ppm	
Phosphorus (Mehlich III)	254.0 ppm	50 - 70 ppm	
Calcium (Mehlich III)	2552.0 ppm	881 ppm	
Magnesium (Mehlich III)	279.0 ppm	93 ppm	
Potassium (Mehlich III)	353.0 ppm	76 - 126 ppm	
Sodium (Mehlich III)	68.0 ppm	7 - 22 ppm	
Sulphur (Morgan)	83.8 ppm	30 - 50 ppm	
Chloride	47.0 ppm	32 - 46 ppm	
Aluminium (Mehlich III)	6.0 ppm	< 3 ppm	
Silicon ($CaCl_2$)	62.0 ppm	40 > 100 ppm	
Boron (Hot $CaCl_2$)	1.3 ppm	1 - 3 ppm	
Iron (DPTA)	196.0 ppm	40 - 200 ppm	
Manganese (DPTA)	3.0 ppm	30 - 100 ppm	Extremely Low
Copper (DPTA)	10.2 ppm	2 - 7 ppm	
Zinc (DPTA)	20.2 ppm	5 - 10 ppm	
Molybdenum (DPTA)	0 ppm	0.15 - 1.2 ppm	Extremely Low
Cobalt (DPTA)	0 ppm	0.4 - 1.4 ppm	Extremely Low
Molybdenum (DPTA)	<0.5 ppm	0.5 - 2 ppm	
Cobalt (DPTA)	1.20 ppm	2 - 40 ppm	
Selenium (DPTA)	<0.5 ppm	0.6 - 2 ppm	
Texture:	sandy		
Colour:	brownish		
BASE SATURATION			
(Levels are not really relevant in soils with a TEC below 5)			
Calcium	76.86 %	68.00 %	
Magnesium	14.00 %	12.00 %	
Potassium	5.45 %	3.00 - 5.00 %	
Sodium	1.78 %	0.50 - 1.50 %	
Aluminium	0.40 %	0.50 %	
Hydrogen	1.50 %	10.00 %	



LEAF ANALYSIS

ELEMENT	CURRENT ANALYSIS	TARGET	ELEMENT STATUS
			LOW / OK / HIGH
Nitrogen - N	2.8 %	2 - 2.4 %	
Phosphorus - P	0.24 %	0.14 - 0.25 %	
Potassium - K	1.12 %	1.6 - 3.0 %	
Sulfur - S	0.18 %	0.13 - 0.80 %	
Calcium - Ca	1.86 %	0.7 - 3.00 %	
Magnesium - Mg	0.62 %	0.4 - 0.90 %	
Sodium - Na	<0.01 %	0.01 - 0.02 %	
Copper - Cu	7.0 ppm	5 - 16 ppm	
Zinc - Zn	53.0 ppm	20 - 50 ppm	
Manganese - Mn	52.0 ppm	40 - 160 ppm	
Iron - Fe	113.0 ppm	100 - 250 ppm	
Boron - B	62.0 ppm	20 - 60 ppm	
Molybdenum - Mo	0.3 ppm	1.5 - N/A ppm	
Cobalt - Co	0.1 ppm	N/A ppm	
Silicon - Si	297.0 ppm	500 - 1200 ppm	
Chloride - Cl	0.0	N/A %	
Nitrogen : Sulphur	15.8	15 units	
Nitrogen : Phos	11.9	20 units	
Nitrogen : Potass	2.5	2 units	
Carbon : Nitrogen	17.0	15 units	
Crude Protein	17.5	30 %	
Chloride	0.0	1 %	Extremely Low
Nitrate	0.0	10 - 20 ppm	Extremely Low
Ammonia	0.0	70 - 90 ppm	Extremely Low

NOTES

The **Albrecht**, or **Soluble Test** uses a blend of mild acids and is the common sort of soil test that tells us what may be readily available via water uptake in the top 15 cm of soil. However, it does not tell us what is locked up in the mineral structure of the soil--or what may be available at greater depth.

The **Total Test** is analysed with a mix of very strong acids called ***aqua regia***, and it reveals what is locked up in the soil's mineral structure as though it were an ore sample. Much of this may become available if robust and diverse microbial activity is encouraged.

Since we test and amend soils in order to yield optimum nutrition for plants, the **Tissue Test** is the bottom line that shows how well we used the other two tests. This test also uses *aqua regia*, and it shows what was taken up by the plant--which may or may not be what shows in the Albrecht and/or Total tests.

All too often soluble tests, taken alone, are misleading. Ideally we only want small amounts of nutrients soluble at any one time, as we want most of our nutrients to be insoluble but available. This implies maintaining robust and diverse microbial activity. A complex balance between fungi, actinomycetes, yeasts, bacteria, protozoa, etc. is extremely important, as the essence of control is to use the exact amount of force necessary--no more and no less. Excesses can be as harmful as deficiencies.

For example, magnesium and potassium may both be high in the soluble test, but this can lead to excessive potassium in tissues while magnesium is deficient if the salt levels are high enough to impair the crop's fine feeder root activity, since potassium easily enters plants via water uptake while magnesium is less mobile, depending more on feeder roots to enter the plant. Such situations tend to favour certain weeds, such as tall, lush, potassium loving types. Or, phosphorous may be low in the soluble test, high in the total test and high in the leaf, indicating healthy microbial P release. But high soluble P can lead to low P in tissues, as this condition can shut down further microbial P release because it poisons the fine feeder root environment and impairs its development while at the same time traveling poorly via water uptake roots.

Your Albrecht (CEC) Nutrient Ratios for: HP #1 (0-10cm)

ELEMENT OR CATEGORY	YOUR LEVEL	IDEAL LEVEL	NUTRIENT STATUS LOW / MEDIUM / HIGH
CEC RATIOS			
Ca / Mg Ratio	5.49 :1	5.67 :1	
Mg / K Ratio (ppm)	0.79 :1	1.00 :1	
K / Na Ratio	3.06 :1	5.00 :1	
Ca / K Ratio	14.10 :1	15.00 :1	
P / Zn Ratio	12.57 :1	10.00 :1	
Fe / Mn Ratio	65.33 :1	1.10 :1	

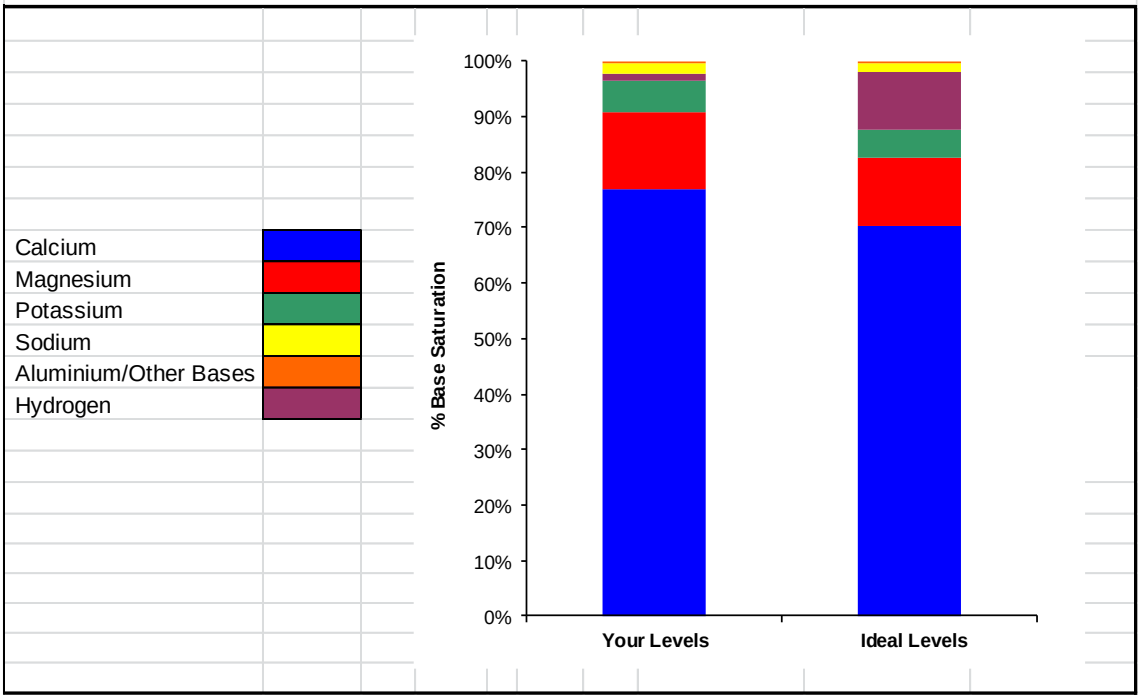
Explanatory Notes: The **Ca/Mg ratio** is the most important factor in high production fertility. When ideal levels are achieved, there will be maximum nutrient availability, optimum soil structure and luxury levels of **oxygen** (the most important element of all in terms of microbe health). The **Mg/K ratio** indicates likely availability of both these important minerals but it also a guideline to phosphate uptake. The **K/Na ratio** is indicative of potassium availability and sodium excesses - when this ratio is inverted, the plant will take up sodium instead of potassium. The **Ca/K ratio** relates to crop quality - when potassium is high in relation to calcium, then the uptake of calcium is retarded and vice versa. The **P/Zn ratio** relates to leaf size and plant sugar production - each of these minerals is capable of retarding availability of the other if the 10:1 ratio is not maintained. The **Fe/Mn ratio** relates to chlorophyll management. If iron is slightly higher than manganese both elements will be at maximum plant availability.

Your La Motte (Reams) Ratios

LA MOTTE RATIOS			
Ca / Mg Ratio	8.79 :1	7.00 :1	
P / K Ratio	0.13 :1	1.00 :1	

Explanatory Notes: The **Ca/Mg ratio** is also a key guideline to productivity and profitability in the La Motte test but unlike the CEC equivalent, this ratio does not vary in light vs heavy soils. The **P/K ratio** indicates the biological availability of phosphate - a poor P/K ratio is often linked to compromised soil life and broadleaf weed pressure.

Your Base Saturation Values vs Ideal Values



Appendix 8 – Data analysis and result interpretations

(i) Analysis of first season data:

1. Harvest and fruit quality assessment for Sweetheart (Derwent Valley site)

Treatment regime (conventional vs alternative) had no effect on crop load, fruit weight or fruit diameter. Addition of effective microbes (EMs) resulted in a significant increase in average fruit weight (10.9g without EMs and 12.0g with EMs). Weight of A grade fruit increased from 12.4 g to 13.5g with the addition of EMs.

Table 1: effect of conventional and alternative treatments on crop load and fruit size of Sweetheart cherry. BCSA = branch cross-sectional area.

	Fruit per cm^2 BCSA	Average fruit weight (g)	A grade average fruit weight	Fruit diameter (mm)
(a) treatment regime				
conventional	36.0	11.5	13.1	30.25
alternative	29.2	11.3	12.8	30.11
LSD (P=0.05)	ns	ns	ns	ns
F Probability	0.249	0.698	0.435	0.366
(b) effective microbes				
No EM	32.5	10.9 a	12.4 a	29.88 a
plus EM	32.7	12.0 b	13.5 b	30.49 b
LSD (P=0.05)	ns	1.0	0.76	0.29
F Probability	0.969	0.05	0.005	<0.001
(c) interaction (regime * effective microbes)				
conventional	33.5	11.5	13.06 b	30.36 b
alternative	31.5	10.4	11.71 a	29.39 a
conventional + EM	38.6	11.6	13.15 b	30.14 b
alternative + EM	26.9	12.3	13.92 b	30.84 c
LSD (P=0.05)	ns	ns	1.08	0.42
F Probability	0.407	0.088	0.009	<0.001

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Fruit firmness, as measured by both the Bioworks FirmTech, and fruit flesh firmness, measured with the Guss Fruit Texture Analyser, were both firmer in fruit from the alternative regime. Skin puncture force was more than 30g higher (10%) in alternative regime fruit, but stem retention force was reduced by 9%. Application of EMs had no effect on fruit firmness, skin puncture force or stem retention force.

Table 2: effect of conventional and alternative treatments on fruit size, firmness, skin strength and stem retention force of Sweetheart cherry.

	Firmness Firmtech (g/mm)	Flesh Firmness (g)	Skin Puncture (g)	Stem retention force (g)
(a) treatment regime				
conventional	342.4 a	103.5 a	297.8 a	797 b
alternative	387.5 b	107.5 b	328.3 b	731 a
LSD (P=0.05)	9.6	3.8	11.8	40
F Probability	<0.001	0.046	<0.001	0.001
(b) effective microbes				
No EM	366.5	103.7	313.0	761
plus EM	363.4	107.3	313.0	768
LSD (P=0.05)	ns	ns	ns	ns
F Probability	0.523	0.068	1.000	0.734
(c) interaction (regime * effective microbes)				
conventional	348.5	103.3	0.302	792
alternative	384.5	104.1	0.324	730
conventional + EM	336.3	103.8	0.293	803
alternative + EM	390.5	110.8	0.332	733
LSD (P=0.05)	ns	ns	ns	ns
F Probability	0.066	0.116	0.155	0.846

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Treatment regime had no effect on fruit sugar content at harvest, but at 42 days post harvest, fruit from the alternative regime had higher sugar levels than conventionally treated fruit. Fruit malic acid content was higher in conventional fruit compared with fruit from the alternative regime. Addition of EMs increased fruit sugar content from 15.19 to 16.22 degrees Brix, but EMs had no effect on malic acid content.

Table 3: effect of conventional and alternative treatments on fruit soluble solid and malic acid content of Sweetheart cherry at harvest and 42 days post harvest. TSS = total soluble solids; dPH = days postharvest

	TSS (Brix)	TSS 42 dPH	Malic acid (g/L)	Malic acid 42 dPH
(a) treatment regime				
conventional	15.61	15.97 a	6.62 b	4.61 b
alternative	15.79	16.94 b	6.13 a	4.03 a
LSD (P=0.05)	ns	0.81	0.30	0.18
F Probability	0.717	0.022	0.002	<0.001
(b) effective microbes				
No EM	15.19 a	16.26	6.30	4.24
plus EM	16.22 b	16.64	6.46	4.41
LSD (P=0.05)	1.01	ns	ns	ns
F Probability	0.047	0.346	0.308	0.071
(c) interaction (regime * effective microbes)				
conventional	15.15	16.30 a	6.73 b	4.75 c
alternative	15.23	16.23 a	5.87 a	3.72 a
conventional + EM	16.08	15.64 a	6.52 b	4.47 b
alternative + EM	16.36	17.65 b	6.39 b	4.34 b
LSD (P=0.05)	ns	1.15	0.42	0.26
F Probability	0.831	0.014	0.019	<0.001

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

As the project was only commenced three months prior to harvest, major differences between treatments in fruit quality were not expected at this early stage of the project. However some positive differences in fruit quality have been observed in the alternative regime and with the application of effective microbes.

2. Soil macrofauna from both Derwent Valley and Nicholls Rivulet sites

The first assessment of soil macrofauna was undertaken in July 2013. A total of 10 soil cores of 2.5mm diameter and 10cm depth were taken from each plot. Cores from each plot were pooled to give one sample per plot and then placed into Tulgren funnels for extraction of fauna. Fauna samples retrieved from the Tulgren funnels were then examined and specimens split into the following groups:

- fungus feeding mites (Acaridae)
- predatory mites (Mesostigmata)
- herbivorous mites (Orabatids)
- beetles (Coleoptera)
- bugs
- centipedes
- millipedes
- flies (Diptera)
- surface collembola (Epigaeic)
- soil collembola (Euedaphic)
- ants (Formicidae)
- nematodes

There were no significant differences between treatments in number of macrofauna in each of the above groups, or in the number of families/genera in each treatment.

Analysis of the worm count data has shown a 245% increase in worm numbers in the alternative treatment compared with the conventional treatment at the Rosegarland (Derwent Valley) site and a 440% increase at the Nicholls Rivulet site.

Table 4: Effect of conventional and alternative treatments on soil worm populations from samples collected in December 2013.

	Number of worms per 0.375 m^2	
	Rosegarland site	Nicholls rivulet site
(a) treatment regime		
conventional	3.3 a	4.1 a
alternative	8.1 b	18.1 b
LSD (P=0.05)	4.0	7.2
F Probability	0.027	0.003
(b) effective microbes		
No EM	6.5	13.9
plus EM	5.0	8.4
LSD (P=0.05)	ns	ns
F Probability	0.427	0.117

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

(ii) Analysis of second season data:

1. Harvest and fruit assessment data

Harvest and laboratory fruit assessment data for 'Lapins' trial at Nicholls Rivulet in the Huon Valley and 'Sweetheart' at Rosegarland in the Derwent Valley.

Treatment regime (conventional vs alternative) had no effect on fruit weight in any of the three cultivars examined. In all cultivars, the percentage of A-grade fruit was higher in the alternative treatments compared with the conventional (57.4 vs 49.5 in 'Lapins'; 40.8 vs 35.4 in 'Sweetheart'). Effective microbe (EM) application had no effect on the percentage of A-grade or reject fruit in any cultivar. There was an interaction between treatment regime and EM application in 'Lapins', with the alternative + EM treatment resulting in the highest percentage A-grade fruit. In the 'Lapins' trial, reject fruit was reduced from 12.9% to 4.2% in the alternative treatments. Addition of EM resulted in a significant reduction in cracked fruit in 'Lapins' (24.4% cracking with EM and 31.9% without EM).

There was no treatment effect on fruit diameter, firmness, skin puncture force, stem retention force, sugar content, juice pH or malic acid content in any cultivar.

Post-harvest fruit assessment of fruit samples kept in cool storage at 0-1°C for 42 days (6 weeks) showed no differences between treatments in cultivar 'Lapin'. In 'Sweetheart', skin puncture force and juice pH were 7% higher in the alternative treatment compared to the conventional (7% and 1.2% resp.).

Table 5: effect of conventional and alternative treatments on fruit weight and percentage A-grade, reject and cracked fruit of 'Lapins' sweet cherry.

	Average fruit weight (g)	Av weight A-grade fruit (g)	% A grade fruit	% Reject fruit	% Cracked fruit
(a) treatment regime					
conventional	12.08	13.50	49.5 a	12.9 b	28.4
alternative	12.63	13.66	57.4 b	4.2 a	27.9
LSD (P=0.05)	*ns*	*ns*	*5.18*	*5.2*	*ns*
F Probability	*0.294*	*0.643*	*0.059*	*0.005*	*0.816*
(b) effective microbes					
No EM	12.56	13.88	51.8	7.26	31.9 b
plus EM	12.15	13.28	55.1	9.89	24.4 a
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*5.0*
F Probability	*0.428*	*0.106*	*0.380*	*0.278*	*0.007*
(c) interaction (regime * effective microbes)					
conventional	12.32	13.79	52.1 ab	11.06	28.3 b
alternative	12.80	13.96	51.5 a	3.46	35.6 c
conventional + EM	11.83	13.20	47.1 a	14.72	28.6 bc
alternative + EM	12.46	13.35	63.2 b	5.06	20.2 a
LSD (P=0.05)	*ns*	*ns*	*11.5*	*ns*	*7.1*
F Probability	*0.882*	*0.981*	*0.047*	*0.663*	*0.005*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 6: effect of conventional and alternative treatments on fruit size, firmness, skin strength and stem retention force of 'Lapins' sweet cherry.

	Fruit diameter (mm)	Firmness FirmTech (g/mm)	Flesh firmness (g)	Skin puncture force (g)	Stem retention force (g)
(a) treatment regime					
conventional	30.37	295	94	362	810
alternative	30.44	297	92	360	772
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.872*	*0.690*	*0.510*	*0.855*	*0.309*
(b) effective microbes					
No EM	30.60	299	95	369	783
plus EM	30.22	293	91	353	799
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.367*	*0.285*	*0.184*	*0.149*	*0.647*
(c) interaction (regime * effective microbes)					
conventional	30.54	296	98	376	799
alternative	30.66	301	92	361	766
conventional + EM	30.21	293	90	348	820
alternative + EM	30.22	293	93	359	778
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.895*	*0.669*	*0.117*	*0.214*	*0.913*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 7: effect of conventional and alternative treatments on fruit soluble solid and malic acid content, juice pH, fruit skin colour and pedicel diameter of 'Lapins' sweet cherry at harvest. TSS = total soluble solids.

	TSS (Brix)	Juice pH	Malic acid content (g/L)	Skin colour	Pedicel diameter (mm)
(a) treatment regime					
conventional	19.3	4.70	4.81	5.3	1.24
alternative	15.6	4.68	4.72	5.5	1.19
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.133*	*0.412*	*0.355*	*0.319*	*0.085*
(b) effective microbes					
No EM	19.1	4.69	4.77	5.5	1.23
plus EM	18.8	4.69	4.75	5.3	1.21
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.528*	*0.894*	*0.798*	*0.267*	*0.472*
(c) interaction (regime * effective microbes)					
conventional	19.7	4.71	4.76	5.4	1.27
alternative	18.6	4.68	4.79	5.6	1.18
conventional + EM	19.0	4.70	4.85	5.3	1.21
alternative + EM	18.6	4.69	4.65	5.4	1.20
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.497*	*0.794*	*0.235*	*0.519*	*0.186*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

*Table 8: effect of conventional and alternative treatments on **postharvest** (35 days after harvest) fruit size, firmness, skin strength and stem retention force of 'Lapins' sweet cherry.*

	Fruit Weight (g)	Fruit diameter (mm)	Flesh firmness (g)	Skin puncture force (g)	Stem retention force (g)
(a) treatment regime					
conventional	13.26	30.4	96	323	529
alternative	13.79	30.7	99	323	496
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.214*	*0.422*	*0.459*	*0.960*	*0.212*
(b) effective microbes					
No EM	13.61	30.7	99	323	499
plus EM	16.44	30.5	96	324	526
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.688*	*0.590*	*0.406*	*0.894*	*0.302*
(c) interaction (regime * effective microbes)					
conventional	13.24	30.4	97	328	521
alternative	13.98	30.9	102	318	477
conventional + EM	13.29	30.4	95	319	538
alternative + EM	13.60	30.5	96	329	515
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.589*	*0.658*	*0.643*	*0.124*	*0.700*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 9: effect of conventional and alternative treatments on postharvest (35 days after harvest) fruit size, firmness, skin strength and stem retention force of 'Lapins' sweet cherry.

	TSS (Brix)	Juice pH	Malic acid content (g/L)	Skin colour	Pedicel diameter (mm)
(a) treatment regime					
conventional	17.6	5.33	3.55	5.9	1.16
alternative	17.9	5.31	3.57	5.9	1.16
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.397*	*0.583*	*0.809*	*0.823*	*0.950*
(b) effective microbes					
No EM	18.1	5.34	3.54	5.97	1.17
plus EM	17.4	5.31	3.58	5.92	1.15
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.072*	*0.180*	*0.545*	*0.068*	*0.255*
(c) interaction (regime * effective microbes)					
conventional	17.9	5.36	3.44	6.0	1.18
alternative	18.2	5.32	3.63	6.0	1.17
conventional + EM	17.3	5.30	3.66	5.9	1.14
alternative + EM	17.5	5.31	3.51	5.9	1.15
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.914*	*0.269*	*0.054*	*0.506*	*0.552*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 10: effect of conventional and alternative treatments on fruit weight and percentage A-grade, reject and cracked fruit of 'Sweetheart' sweet cherry.

	Average fruit weight (g)	Av weight A-grade fruit (g)	% A grade fruit	% Reject fruit	% Cracked fruit
(a) treatment regime					
conventional	10.94	14.47	35.4 a	54.3	56.5
alternative	10.71	14.15	40.8 b	48.8	53.4
LSD (P=0.05)	ns	ns	6.0	ns	ns
F Probability	0.559	0.290	0.070	0.180	0.469
(b) effective microbes					
No EM	10.74	14.16	36.9	53.2	54.9
plus EM	10.91	14.46	39.3	49.9	54.9
LSD (P=0.05)	ns	ns	ns	ns	ns
F Probability	0.659	0.328	0.387	0.411	0.989
(c) interaction (regime * effective microbes)					
conventional	10.73	14.19	35.6	54.4	56.1
alternative	10.74	14.14	38.2	51.9	53.7
conventional + EM	11.15	14.75	35.1	54.1	56.8
alternative + EM	10.68	14.17	43.4	45.7	53.0
LSD (P=0.05)	ns	ns	ns	ns	ns
F Probability	0.549	0.373	0.304	0.454	0.874

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 11: effect of conventional and alternative treatments on fruit size, firmness, skin strength and stem retention force of 'Sweetheart' sweet cherry.

	Fruit diameter (mm)	Compression firmness (g/mm)	Flesh firmness (g)	Skin puncture force (g)	Stem retention force (g)
(a) treatment regime					
conventional	31.75	359	114	360	950
alternative	31.51	360	112	373	896
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.323*	*0.844*	*0.556*	*179*	*0.174*
(b) effective microbes					
No EM	31.60	358	111	360	912
plus EM	31.69	361	116	373	934
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.741*	*0.649*	*0.272*	*0.165*	*0.372*
(c) interaction (regime * effective microbes)					
conventional	31.61	355	112	348	956
alternative	31.59	360	110	371	868
conventional + EM	31.41	362	117	372	944
alternative + EM	31.97	359	114	375	924
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.301*	*0.545*	*0.864*	*0.290*	*0.372*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 12: effect of conventional and alternative treatments on fruit soluble solid and malic acid content, juice pH, fruit skin colour and pedicel diameter of 'Sweetheart' sweet cherry at harvest. TSS = total soluble solids

	TSS (Brix)	Juice pH	Malic acid content (g/L)	Skin colour	Pedicel diameter (mm)
(a) treatment regime					
conventional	18.7	4.57	7.89	5.3	1.37 b
alternative	19.7	4.56	7.65	5.4	1.33 a
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*0.03*
F Probability	*0.100*	*0.517*	*0.398*	*0.192*	*0.016*
(b) effective microbes					
No EM	18.9	4.56	7.58	5.4 b	1.36
plus EM	19.6	4.56	7.95	5.3 a	1.34
LSD (P=0.05)	*ns*	*ns*	*ns*	*0.09*	*ns*
F Probability	*0.265*	*0.903*	*0.200*	*0.032*	*0.299*
(c) interaction (regime * effective microbes)					
conventional	18.0	4.57	7.57	5.4	1.39
alternative	19.8	4.56	7.59	5.5	1.33
conventional + EM	19.5	4.57	8.21	5.3	1.35
alternative + EM	19.7	4.56	7.70	5.3	1.33
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.174*	*0.962*	*0.364*	*0.406*	*0.290*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 13: effect of conventional and alternative treatments on postharvest (35 days after harvest) fruit size, firmness, skin strength and stem retention force of 'Sweetheart' sweet cherry.

	Fruit Weight (g)	Fruit diameter (mm)	Flesh firmness (g)	Skin puncture force (g)	Stem retention force (g)
(a) treatment regime					
conventional	14.36	31.7	138	396 a	367
alternative	14.21	31.5	140	422 b	368
LSD (P=0.05)	*ns*	*ns*	*ns*	*23*	*ns*
F Probability	*0.665*	*0.412*	*0.565*	*0.037*	*0.980*
(b) effective microbes					
No EM	14.18	31.6	137	407	366
plus EM	14.39	31.6	141	411	368
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.553*	*0.965*	*0.247*	*0.737*	*0.974*
(c) interaction (regime * effective microbes)					
conventional	14.15	31.6	138	392	374
alternative	14.22	31.7	136	422	359
conventional + EM	14.57	31.9	138	400	359
alternative + EM	14.20	31.3	144	422	377
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.528*	*0.219*	*0.301*	*0.727*	*0.773*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 14: effect of conventional and alternative treatments on postharvest (35 days after harvest) fruit size, firmness, skin strength and stem retention force of 'Sweetheart' sweet cherry.

	TSS (Brix)	Juice pH	Malic acid content (g/L)	Skin colour	Pedicel diameter (mm)
(a) treatment regime					
conventional	18.7	4.99 a	5.57	5.1	1.05
alternative	19.2	5.05 b	5.22	5.2	0.99
LSD (P=0.05)	*ns*	*0.05*	*ns*	*ns*	*ns*
F Probability	*0.306*	*0.046*	*0.080*	*0.207*	*0.057*
(b) effective microbes					
No EM	18.9	5.02	5.31	5.2	1.02
plus EM	19.0	5.02	5.47	5.1	1.02
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.712*	*0.991*	*0.400*	*0.169*	*0.923*
(c) interaction (regime * effective microbes)					
conventional	18.7	4.97	5.57	5.2	1.06
alternative	19.1	5.07	5.06	5.3	0.98
conventional + EM	18.8	2.01	5.57	5.1	1.03
alternative + EM	19.4	5.03	5.37	5.2	1.00
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.795*	*0.194*	*0.405*	*0.748*	*0.350*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

This project has been running for less than 18 months at the time of harvest, and there have been positive differences emerging in fruit pack-out in all cultivars in the alternative regime across the two seasons that the project has been running. While there was no difference in fruit quality parameters between the two treatment regimes this season, one important point to note is that the alternative regime has not shown any detrimental effects on fruit quality.

2. Soil fauna - samples collected July 2014

To assess soil macro-fauna, a total of 10 soil cores of 2.5mm diameter and 10cm depth were taken from each plot. Cores from each plot were pooled to give one sample per plot and then placed into Tulgren funnels for extraction of fauna. Fauna samples retrieved from the Tulgren funnels were then examined and specimens split into groups. In relation to soil macro-fauna assessments undertaken in July 2013, less than 12 months after the project commencement, there have been no changes in soil invertebrate populations between the different treatments, with the exception of an increase in nematodes at the Nicholls Rivulet site following monthly application of EM, and an increase in number of worms at the Rosegarland site in the alternative regime.

Table 15: effect of conventional and alternative treatments on soil invertebrate fauna at Nicholls Rivulet ('Lapins').

	Acaridae[1]	Coleoptera (beetles)	Epigaeic[2]	Formicidae (ants)	Mesostigmata[3]	Orabatids[4]
(a) treatment regime						
conventional	0.9	1.8	3.1	-	3.6	21.6
alternative	3.0	1.8	0.5	-	3.1	13.4
LSD (P=0.05)	*ns*	*ns*	*ns*	*-*	*ns*	*ns*
F Probability	*0.464*	*1.000*	*0.426*	*-*	*0.755*	*0.424*
(b) effective microbes						
No EM	3.0	1.6	3.5	-	3.4	19.0
plus EM	0.9	1.9	0.1	-	3.4	16.0
LSD (P=0.05)	*ns*	*ns*	*ns*	*-*	*ns*	*ns*
F Probability	*0.464*	*0.708*	*0.312*	*-*	*1.000*	*0.767*
(c) interaction (regime * effective microbes)						
conventional	6.0	1.5	6.2	-	4.0	24.2
alternative	0.0	1.8	0.8	-	2.8	13.8
conventional + EM	0.0	2.0	0.0	-	3.3	19.0
alternative + EM	1.8	1.8	0.2	-	3.5	13.0
LSD (P=0.05)	*ns*	*ns*	*ns*	*-*	*ns*	*ns*
F Probability	*0.197*	*0.708*	*0.385*	*-*	*0.641*	*0.824*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.
[1]fungus feeding mites; [2]surface feeding mites; [3]predatory mites; [4]herbivorous mites

Table 16: effect of conventional and alternative treatments on soil invertebrate fauna at Nicholls Rivulet ('Lapins').

	Bugs	Centipedes	Millipedes	Nematodes	Diptera (flies)	Euedaphic[5]
(a) treatment regime						
conventional	1.3	0.8	0.0	5.0	0.3	2.0
alternative	0.4	0.3	0.1	6.6	0.0	2.4
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.434*	*0.191*	*0.343*	*0.075*	*0.117*	*0.795*
(b) effective microbes						
No EM	1.4	0.5	0.1	4.3 a	0.0	2.8
plus EM	0.3	0.5	0.0	7.4 b	0.3	1.6
LSD (P=0.05)	*ns*	*ns*	*ns*	*1.8*	*ns*	*ns*
F Probability	*0.320*	*1.000*	*0.343*	*0.004*	*0.117*	*0.442*
(c) interaction (regime * effective microbes)						
conventional	2.0	1.0	0.0	4.3	0.0	2.8
alternative	0.8	0.0	0.3	4.3	0.0	2.8
conventional + EM	0.5	0.5	0.0	5.8	0.5	1.3
alternative + EM	0.0	0.5	0.0	9.0	0.0	2.0
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0734*	*0.191*	*0.343*	*0.075*	*0.117*	*0.795*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.
[5]soil collembola

Table 17: effect of conventional and alternative treatments on number of worms, total soil fauna and number of genera at Nicholls Rivulet ('Lapins').

	Worms	Total Fauna no.	Genera	
(a) treatment regime				
conventional	0.0	42.4	5.5	
alternative	0.5	29.9	5.6	
LSD (P=0.05)	*ns*	*ns*	*ns*	
F Probability	*0.063*	*0.338*	*0.798*	
(b) effective microbes				
No EM	0.1	39.6	5.5	
plus EM	0.4	32.6	5.6	
LSD (P=0.05)	*ns*	*ns*	*ns*	
F Probability	*0.316*	*0.585*	*0.798*	
(c) interaction (regime * effective microbes)				
conventional	0.0	52.0	6.0	ab
alternative	0.3	27.2	5.0	a
conventional + EM	0.0	32.8	5.0	a
alternative + EM	0.8	32.5	6.3	b
LSD (P=0.05)	*ns*	*ns*	*1.1*	
F Probability	*0.316*	*0.347*	*0.041*	

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 18: effect of conventional and alternative treatments on soil invertebrate fauna at Rosegarland ('Sweetheart').

	Acaridae[1]	Coleoptera (beetles)	Epigaeic[2] collembola	Formicidae (ants)	Mesostigmata[3]	Orabatids[4]
(a) treatment regime						
conventional	3.6	0.5	0.8	0.8	6.0	1.3
alternative	9.5	0.6	0.9	1.0	6.3	0.8
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.325*	*0.814*	*0.823*	*0.832*	*0.903*	*0.418*
(b) effective microbes						
No EM	7.6	0.8	1.0	1.6	5.5	1.4
plus EM	5.5	0.4	0.6	0.1	6.8	0.6
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.715*	*0.485*	*0.506*	*0.223*	*0.544*	*0.235*
(c) interaction (regime * effective microbes)						
conventional	2.0	0.3	0.8	1.3	4.8	2.0
alternative	13.2	1.3	1.3	2.0	6.3	0.8
conventional + EM	5.2	0.8	0.8	0.3	7.3	0.5
alternative + EM	5.8	0.0	0.5	0.0	6.3	0.8
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.366*	*0.124*	*0.506*	*0.673*	*0.544*	*0.235*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.
[1]fungus feeding mites; [2]surface feeding mites; [3]predatory mites; [4]herbivorous mites

Table 19: effect of conventional and alternative treatments on soil invertebrate fauna at Rosegarland ('Sweetheart').

	Bugs	Centipedes	Millipedes	Nematodes	Diptera (flies)
(a) treatment regime					
conventional	0.8	0.8	0.4	0.3	0.0
alternative	0.4	0.1	0.4	0.4	0.1
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.474*	*0.177*	*1.000*	*0.718*	*0.343*
(b) effective microbes					
No EM	0.3	0.3	0.3	0.3	0.0
plus EM	0.9	0.6	0.5	0.4	0.1
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.244*	*0.403*	*0.427*	*0.718*	*0.343*
(c) interaction (regime * effective microbes)					
conventional	0.00	0.5	0.3	0.0	0.0
alternative	0.5	0.0	0.3	0.5	0.3
conventional + EM	1.5	1.0	0.5	0.5	0.0
alternative + EM	0.4	0.3	0.5	0.3	0.0
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.115*	*0.776*	*1.000*	*0.293*	*0.343*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 20: effect of conventional and alternative treatments on number of worms, total soil fauna and number of genera at Rosegarland ('Sweetheart'). Assessed in July 2013.

	Worms	Total Fauna no.	Genera
(a) treatment regime			
conventional	0.0 a	15.0	4.6
alternative	1.3 b	21.8	5.3
LSD (P=0.05)	*0.9*	*ns*	*ns*
F Probability	*0.018*	*0.375*	*0.580*
(b) effective microbes			
No EM	0.5	19.5	1.9
plus EM	0.8	17.2	5.0
LSD (P=0.05)	*ns*	*ns*	*ns*
F Probability	*0.578*	*0.763*	*0.911*
(c) interaction (regime * effective microbes)			
conventional	0.0	11.8	4.0
alternative	1.0	27.2	5.8
conventional + EM	0.0	18.2	5.3
alternative + EM	1.5	16.2	4.8
LSD (P=0.05)	*ns*	*ns*	*ns*
F Probability	*0.579*	*0.257*	*0.328*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Mycorrhizal assessment*

PhD student, Abdelsalam Abobaker studied the impact of treatments on mycorrhizal colonisation of tree roots. Assessment and analysis and data of samples collected in October 2013 are presented. In summary, at the Rosegarland site which was established 12 months prior to sample collection, treatment regime had no effect on colonisation, but plots receiving monthly application of EM showed a 329% greater number of arbuscules in roots. At the Nicholls Rivulet site which was established 6 months prior to sample collection, there was no difference between treatments in hyphae, vesicles or general colonisation , but the number of arbuscules in the alternative regime were less than half that in the conventional regime, and plots receiving EM also showed reduced arbuscules compared to plots with no EM.

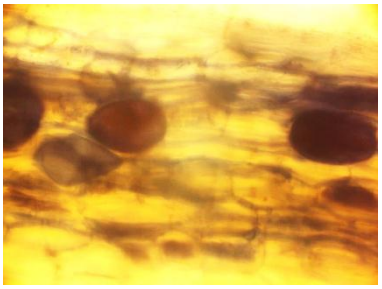
* data provided by PhD student Abdelsalam Abobaker

Table 21: The effect of conventional and alternative fertiliser treatments on mycorrhizal colonization in 'Sweetheart' cherry roots (Rosegarland) 12 months after treatment application

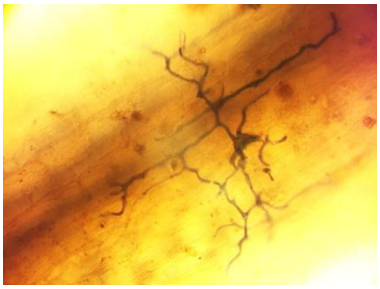
Treatments	**The percentage of AMF colonization**			
Fertilizer	**Hyphae**	**Vesicular**	**Arbuscular**	**General colonisation**
Control	45.4	16.6	3.6	21.8
Alternative	58.3	14.0	6.7	26.5
L.S.D (P = 0.05)	*ns*	*ns*	*ns*	*ns*
F Prob	*0.291*	*0.662*	*0.181*	*0.46*
Effective Microbes (EMs)				
Minus	53.0	19.3	2.4 a	25.0
Plus	50.7	11.3	7.9 b	23.4
L.S.D (P = 0.05)	*ns*	*ns*	*4.87*	*ns*
F Prob	*0.846*	*0.197*	*0.030*	*0.80*
Fertilizer + EMs				
Control-minus EMs	47.7	21.5	0.50	23.3
Alternative-minus EMs	58.3	17.1	4.20	26.7
Control-plus EMs	43.1	11.7	6.70	20.4
Alternative-plus EMs	58.3	10.8	9.20	26.4
L.S.D (P = 0.05)	*ns*	*ns*	*ns*	*ns*
F Prob	*0.846*	*0.765*	*0.778*	*0.83*

Table 22: The effect of conventional and alternative fertiliser treatments on mycorrhizal colonization in 'Lapins' cherry roots (Nicholls Rivulet) 6 months after treatment application.

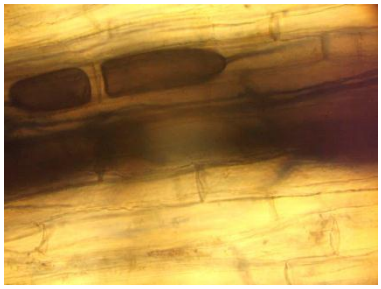
Treatments	The percentage of AMF colonization			
Fertilizer	**Hyphae**	**Vesicular**	**Arbuscular**	**General colonisation**
Control	42.4	17.8	12.4 a	20.1
Alternative	28.5	13.6	5.2 b	13.1
L.S.D (P = 0.05)	*ns*	*ns*	*7.29*	*ns*
F Prob	*0.16*	*0.38*	*0.05*	*0.15*
Effective Microbes (EMs)				
Minus	44.4	19.3	13.6 a	21.5 a
Plus	26.5	12.0	3.9 b	11.7 b
L.S.D (P = 0.05)	*ns*	*ns*	*7.29*	*9.92*
F Prob	*0.08*	*0.13*	*0.01*	*0.05*
Fertilizer + EMs				
Control-minus EMs	58.3	26.2	20.6	29.2
Alternative-minus EMs	30.4	12.5	6.7	13.7
Control-plus EMs	26.5	9.3	4.1	11.0
Alternative-plus EMs	26.6	14.8	3.7	12.5
L.S.D (P = 0.05)	*ns*	*ns*	*ns*	*ns*
F Prob	*0.16*	*0.06*	*0.06*	*0.08*



Mycorrhizal colonization in cherry roots (lens 40x)



Hypha of mycorrhizal fungi and clean cell roots of cherry (lens 20x)



Arbuscules taking the shape of the cell in cherry roots (lens 40x)

Figure 1: Mycorrhizal colonisation in cherry tree roots.

(iii) Analysis of third season data:

1. Harvest and fruit assessment data

Fruit set in 'Lapins' was significantly higher in the alternative treatment compared with the conventional (31.6% vs 26.3%, p=0.038); the same trend was observed in 'Sweetheart', although the differences were not statistically significant. Effective Microbe application had no effect on fruit set.

Treatment regime (conventional vs alternative) had no effect on fruit weight of 'Lapins' or 'Sweetheart'. In all cultivars treatment regime had no significant effect on the percentage of A-grade fruit, although there was a trend towards a greater percentage of A-grade fruit in the alternative treatments compared with the conventional. Effective microbe (EM) application increased the percentage A-grade fruit in 'Lapins' (40.4% vs 32.9%, p=0.035); and although not significant, a similar trend was observed in 'Sweetheart'. EM application reduced the percentage of reject fruit in 'Lapins' (21.5% vs 35.4%, p=0.002) and 'Sweetheart' (14.0% vs 21.6%, p=0.036). There was no effect on fruit cracking of 'Sweetheart' with EM application, but in 'Lapins' cracking was reduced in EM plots compared with conventional (33.1% vs 47.7%, $p < 0.1$).

There was no treatment effect on stem retention force, total soluble content, malic acid content or flesh colour in any cultivar. Skin puncture force of 'Lapins' fruit was higher in under the alternative regime compared with the conventional (97 vs 90, p=0.020 and 341 vs 313, p=0.049 respectively). In the 'Lapins' fruit, skin colour was lighter in the EM treatments compared to the conventional. 'Sweetheart' pedicel diameter was 0.09 mm smaller in the alternative treatments compared with the conventional. EM application had no effect on fruit quality.

Post-harvest assessment of fruit samples kept in cool storage at 0-1°C for 35 days (5 weeks) showed no differences between treatments in cultivar 'Sweetheart' with either treatment regime or EM application. Skin puncture force

was higher in the alternative treatments compared with the conventional in 'Lapins'.

Although treatment responses have been variable across cultivars, the response to the alternative treatment has either had no effect or has been positive in terms of fruit pack-out and quality. When compared with the conventional regime, the alternative regime has not shown any detrimental effects on fruit quality.

Table 23: effect of conventional and alternative treatments on fruit weight and percentage A-grade, reject and cracked fruit of 'Lapins' cherry.

	% fruit Set	% A grade fruit	% Reject fruit	% Cracked fruit	Average fruit weight (g)	A-grade fruit weight (g)
(a) treatment regime						
conventional	26.3 a	35.1	30.3	40.7	10.0	11.7
alternative	31.6 b	38.2	26.6	40.1	10.9	11.8
LSD (P=0.05)	*4.9*	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.038*	*0.330*	*0.292*	*0.937*	*0.379*	*0.802*
(b) effective microbes						
No EM	29.9	32.9 a	35.4 b	47.7	10.6	12.1
plus EM	28.0	40.4 b	21.5 a	33.1	10.3	11.5
LSD (P=0.05)	*ns*	*6.8*	*7.3*	***	*ns*	*ns*
F Probability	*0.400*	*0.035*	*0.002*	*0.094*	*0.685*	*0.303*
(c) interaction (regime * effective microbes)						
conventional	24.1 a	31.8	38.9	48.5	10.1	12.1
alternative	35.8 b	34.0	31.9	46.9	11.2	12.1
conventional + EM	28.5 a	38.4	21.7	32.9	10.0	11.3
alternative + EM	27.5 a	42.3	21.4	33.2	10.6	11.6
LSD (P=0.05)	*6.9*	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.017*	*0.791*	*0.333*	*0.908*	*0.780*	*0.833*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 24: effect of conventional and alternative treatments on fruit size, firmness, skin strength and stem retention force of 'Lapins' cherry.

	Fruit diameter (mm)	Firmness FirmTech (g/mm)	Flesh firmness (g)	Skin puncture force (g)	Stem retention force (g)	Dry matter content (%)
(a) treatment regime						
conventional	29.0	307	90 a	313 a	786	16.45
alternative	29.3	325	97 b	341 b	815	16.80
LSD (P=0.05)	*ns*	*ns*	*5.4*	*28*	*ns*	*ns*
F Probability	*0.610*	*0.107*	*0.020*	*0.049*	*0.612*	*0.397*
(b) effective microbes						
No EM	29.4	319	95	336	818	16.53
plus EM	28.9	313	93	318	783	16.72
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.417*	*0.592*	*0.272*	*0.188*	*0.544*	*0.626*
(c) interaction (regime * effective microbes)						
conventional	29.3	308	92	323	811	16.33
alternative	29.5	330	99	349	824	16.73
conventional + EM	28.8	306	89	303	761	16.58
alternative + EM	29.1	320	96	334	805	16.87
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.887*	*0.712*	*0.812*	*0.815*	*0.780*	*0.896*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 25: effect of conventional and alternative treatments on fruit soluble solid and malic acid content, juice pH, fruit skin colour and pedicel diameter of 'Lapins' cherry at harvest. TSS = total soluble solids.

	TSS (Brix)	Juice pH	Malic acid content (g/L)	Skin colour	Flesh colour	Pedicel diameter (mm)
(a) treatment regime						
conventional	15.2	4.49	3.64	5.7 b	3.8	1.1
alternative	15.7	4.54	3.62	5.5 a	3.8	1.0
LSD (P=0.05)	*ns*	*	*ns*	*0.1*	*ns*	*ns*
F Probability	*0.199*	*0.065*	*0.890*	*0.042*	*0.909*	*0.409*
(b) effective microbes						
No EM	15.5	4.53	3.63	5.5	3.8	1.0
plus EM	15.4	4.50	3.63	5.6	3.7	1.1
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.690*	*0.184*	*0.999*	*0.318*	*0.715*	*0.351*
(c) interaction (regime * effective microbes)						
conventional	15.3	4.52	3.64	5.6	3.9	1.1
alternative	15.7	4.54	3.62	5.5	3.7	1.0
conventional + EM	15.2	4.46	3.65	5.8	3.6	1.1
alternative + EM	15.7	4.53	3.62	5.5	3.8	1.1
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.884*	*0.377*	*0.983*	*0.345*	*0.346*	*0.300*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 26: effect of conventional and alternative treatments on postharvest (35 days after harvest) fruit size, firmness, skin strength and stem retention force of 'Lapins' cherry.

	Fruit diameter (mm)	Flesh firmness (g)	Skin puncture force (g)	Stem retention force (g)
(a) treatment regime				
conventional	30.3	96	332	373 a
alternative	30.4	103	358	438 b
LSD (P=0.05)	*ns*	*ns*	*	*59*
F Probability	*0.863*	*0.152*	*0.093*	*0.037*
(b) effective microbes				
No EM	30.5	101	344	428
plus EM	30.3	98	346	383
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.716*	*0.488*	*0.926*	*0.121*
(c) interaction (regime * effective microbes)				
conventional	30.5	98	328	401
alternative	30.5	104	360	455
conventional + EM	30.2	93	335	345
alternative + EM	30.4	102	356	421
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.721*	*0.699*	*0.714*	*0.678*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 27: effect of conventional and alternative treatments on postharvest (35 days after harvest) fruit size, firmness, skin strength and stem retention force of 'Lapins' cherry.

	TSS (Brix)	Juice pH	Malic acid content (g/L)	Skin colour	Flesh colour
(a) treatment regime					
conventional	15.1	4.61	3.23	5	3.97
alternative	15.4	4.66	3.24	5	4.08
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.500*	*0.101*	*0.967*	*0.989*	*0.674*
(b) effective microbes					
No EM	15.3	4.64	3.25	5	3.87
plus EM	15.1	4.63	3.22	5	4.17
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.657*	*0.787*	*0.859*	*0.989*	*0.267*
(c) interaction (regime * effective microbes)					
conventional	15.2	4.62	3.26	5	3.74
alternative	15.5	4.65	3.25	5	4.01
conventional + EM	15.0	4.60	3.21	5	4.20
alternative + EM	15.3	4.67	3.23	5	4.15
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.905*	*0.447*	*0.921*	*0.989*	*0.543*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 28: effect of conventional and alternative treatments on fruit weight and percentage A-grade, reject and cracked fruit of 'Sweetheart' cherry.

	% fruit Set	% A grade fruit	% Reject fruit	% Cracked fruit	Average fruit weight (g)	Av weight A-grade fruit (g)
(a) treatment regime						
conventional	33.7	41.7	14.7	27.5	12.2	13.0
alternative	38.8	49.5	20.9	24.7	11.4	12.3
LSD (P=0.05)	*ns*	*ns*	*	*ns*	*ns*	*ns*
F Probability	*0.212*	*0.147*	*0.077*	*0.146*	*0.183*	*0.184*
(b) effective microbes						
No EM	34.9	43.5	21.6 b	23.6	11.6	12.7
plus EM	37.6	47.7	14.0 a	25.6	12.0	12.6
LSD (P=0.05)	*ns*	*ns*	*7.0*	*ns*	*ns*	*ns*
F Probability	*0.489*	*0.423*	*0.036*	*0.595*	*0.476*	*0.884*
(c) interaction (regime * effective microbes)						
conventional	31.8	40.0	18.5	25.5	11.5	12.6
alternative	38.0	47.0	24.7	21.6	11.7	12.8
conventional + EM	35.6	43.3	10.9	29.5	12.8	13.5
alternative + EM	39.7	52.1	14.0	21.7	11.2	11.8
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.791*	*0.859*	*0.989*	*0.613*	*0.104*	*0.102*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 29: effect of conventional and alternative treatments on fruit size, firmness, skin strength and stem retention force of 'Sweetheart' cherry.

	Fruit diameter (mm)	Compression firmness (g/mm)	Flesh firmness (g)	Skin puncture force (g)	Stem retention force (g)	Dry matter content (%)
(a) treatment regime						
conventional	29.8	377	112	323	1030	18.2
alternative	28.8	376	116	346	940	18.5
LSD (P=0.05)	*	ns	ns	ns	ns	ns
F Probability	*0.064*	*0.948*	*0.347*	*0.335*	*0.257*	*0.690*
(b) effective microbes						
No EM	29.3	382	115	338	956	18.7
plus EM	29.3	372	113	331	1013	18.0
LSD (P=0.05)	ns	ns	ns	ns	ns	ns
F Probability	0.957	0.236	0.714	0.752	0.468	0.333
(c) interaction (regime * effective microbes)						
conventional	29.5	383	112	333	973	18.5
alternative	29.2	382	118	343	940	18.8
conventional + EM	30.2	372	112	313	1086	17.9
alternative + EM	28.5	372	114	349	940	18.1
LSD (P=0.05)	ns	ns	ns	ns	ns	ns
F Probability	0.173	0.932	0.688	0.592	0.468	0.962

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 30: effect of conventional and alternative treatments on fruit soluble solid and malic acid content, juice pH, fruit skin colour and pedicel diameter of 'Sweetheart' cherry at harvest. TSS = total soluble solids

	TSS (Brix)	Juice pH	Malic acid content (g/L)	Skin colour	Flesh colour	Pedicel diameter (mm)
(a) treatment regime						
conventional	16.9	4.26	5.73	5.49	2.61	1.07 b
alternative	17.2	4.26	5.61	5.36	2.42	0.98 a
LSD (P=0.05)	ns	ns	ns	*	ns	0.06
F Probability	*0.606*	*0.905*	*0.549*	*0.053*	*0.174*	*0.008*
(b) effective microbes						
No EM	17.2	4.25	5.78	5.46	2.44	1.03
plus EM	16.9	4.26	5.55	5.40	2.60	1.02
LSD (P=0.05)	ns	ns	ns	ns	ns	ns
F Probability	0.687	0.743	0.264	0.310	0.233	0.652
(c) interaction (regime * effective microbes)						
conventional	17.1	4.27	5.76	5.58	2.65	1.07
alternative	17.3	4.24	5.80	5.33	2.22	0.99
conventional + EM	16.6	4.25	5.69	5.40	2.57	1.07
alternative + EM	17.2	4.27	5.41	5.39	2.62	0.96
LSD (P=0.05)	ns	ns	ns	*	*	ns
F Probability	0.736	0.207	0.435	0.067	0.094	0.569

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 31: effect of conventional and alternative treatments on postharvest (35 days after harvest) fruit size, firmness, skin strength and stem retention force of 'Sweetheart' cherry.

	Fruit Compression force (g/mm)	Flesh firmness (g)	Skin puncture force (g)	Stem retention force (g)
(a) treatment regime				
conventional	431	127	339	683
alternative	429	128	374	588
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.888*	*0.954*	*0.255*	*0.128*
(b) effective microbes				
No EM	436	128	354	673
plus EM	425	128	359	598
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.389*	*0.987*	*0.869*	*0.660*
(c) interaction (regime * effective microbes)				
conventional	431	127	333	713
alternative	441	129	375	632
conventional + EM	431	129	345	653
alternative + EM	418	127	373	543
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.379*	*0.833*	*0.814*	*0.139*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 32: effect of conventional and alternative treatments on postharvest (35 days after harvest) fruit size, firmness, skin strength and stem retention force of 'Sweetheart' cherry.

	TSS (Brix)	Juice pH	Malic acid content (g/L)	Skin colour	Flesh colour	
(a) treatment regime						
conventional	16.6	4.30	5.38	5.16	2.25	a
alternative	17.0	4.29	5.09	5.11	2.48	b
LSD (P=0.05)	*ns*	*ns*	***	*ns*	*0.15*	
F Probability	*0.635*	*0.825*	*0.098*	*0.497*	*0.007*	
(b) effective microbes						
No EM	17.0	4.30	5.32	5.13	2.28	a
plus EM	16.6	4.29	5.15	5.15	2.44	b
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*0.15*	
F Probability	*0.635*	*0.873*	*0.317*	*0.781*	*0.045*	
(c) interaction (regime * effective microbes)						
conventional	16.9	4.31	5.37	5.18	2.18	
alternative	17.0	4.28	5.27	5.08	2.39	
conventional + EM	16.4	4.28	5.39	5.15	2.31	
alternative + EM	16.9	4.30	4.91	5.15	2.57	
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*	
F Probability	*0.781*	*0.262*	*0.248*	*0.504*	*0.753*	

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

(iv) Analysis of fourth season data (2015/16):

1. Harvest and fruit assessment data

Crop load in Lapins was 30% higher in the alternative treatment compared with the conventional (Table 1), but there was no difference between treatments in Sweetheart (Table 13). Addition of EM improved fruit packout in Lapins, with 84% A-grade fruit in EM treated trees compared with 77% in conventional. Fruit cracking in Lapins was reduced by 80% in the alternative regime, while EM application reduced cracking by 73%.

Yield efficiency in Lapins was higher under the alternative regime and both EM treatments compared with the conventional treatment (Table 2). There was no treatment effect on fruit flesh colour, pedicel diameter or fruit dry matter content in either Lapins (Table 2) or Sweetheart (Table 14).

Lapins fruit diameter (Table 3) and weight (Table 4) were lower in the alternative regime than the conventional, but this is most likely a result of the higher crop load under the alternative regime.

Fruit firmness was not affected by treatment in either Lapins (Table 5, 6) or Sweetheart (Table 17, 18). EM application reduced skin puncture force by 8% in the Lapins (Table 7) but had no effect in Sweetheart (Table 19). There was no treatment effect on stem retention force in Lapins (Table 8), but in Sweetheart the alternative +EM treatment reduced stem retention force (Table 20).

There were no treatment effect in either cultivar on skin colour (Table 9, 21) or TSS (Table 10, 22). Malic acid concentration in Lapins fruit was lower in the alternative regime than the conventional (Table 11), but in Sweetheart the alternative regime produced fruit with higher malic acid concentration (Table 23).

Table 33: effect of conventional and alternative treatments on fruit weight and percentage A-grade, reject and cracked fruit of Lapin cherry.

	No. fruit per cm^2 LCSA	% A grade fruit	% Reject fruit	% Cracked fruit
(a) treatment regime				
conventional	14.0 a	80.9	1.6	12.6 b
alternative	19.4 b	81.1	3.6	2.3 a
LSD (P=0.05)	*5.0*	*ns*	*ns*	*4.0*
F Probability	*0.039*	*0.944*	*0.058*	*<0.001*
(b) effective microbes				
No EM	14.7	77.7 a	2.7	11.8 b
plus EM	18.7	84.3 b	2.5	3.2 a
LSD (P=0.05)	*ns*	*6.3*	*ns*	*4.0*
F Probability	*0.109*	*0.044*	*0.795*	*<0.001*
(c) interaction (regime * effective microbes)				
conventional	9.4 a	73.6 a	1.2	21.1 b
alternative	20.1 b	81.8 ab	4.2	2.5 a
conventional + EM	18.6 b	88.2 b	1.9	4.2 a
alternative + EM	18.8 b	80.4 ab	3.0	2.2 a
LSD (P=0.05)	*7.1*	*9.0*	*ns*	*5.7*
F Probability	*0.044*	*0.019*	*0.365*	*0.001*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 34: effect of conventional and alternative treatments on fruit flesh colour, pedicel diameter, dry matter content and yield efficiency of Lapin cherry at harvest.

	Flesh colour	Pedicel diameter (mm)	Dry matter content (%)	Yield eficiency (kg/cm^2 TCSA)
(a) treatment regime				
conventional	4.7	1.1	19.3	0.186
alternative	4.8	1.0	19.4	0.208
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.722*	*0.099*	*0.880*	*0.448*
(b) effective microbes				
No EM	4.7	1.0	19.2	0.184
plus EM	4.9	1.0	19.5	0.209
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.318*	*0.506*	*0.634*	*0.389*
(c) interaction (regime * effective microbes)				
conventional	4.6	1.1	19.2	0.135 a
alternative	4.8	1.0	19.1	0.233 b
conventional + EM	4.9	1.0	19.3	0.236 b
alternative + EM	4.8	1.0	19.6	0.183 ab
LSD (P=0.05)	*ns*	*ns*	*ns*	*0.089*
F Probability	*0.494*	*0.908*	*0.760*	*0.024*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 35: effect of conventional and alternative treatments on harvest and postharvest fruit diameter of Lapin cherry

	Fruit diameter (mm)				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	31.6 b	30.3 b	30.3 b	30.5 b	30.3 b
alternative	30.4 a	28.9 a	28.6 a	28.7 a	28.6 a
LSD (P=0.05)	*1.1*	*1.16*	*1.22*	*1.03*	*1.20*
F Probability	*0.038*	*0.019*	*0.012*	*0.004*	*0.011*
(b) effective microbes					
No EM	31.4	30.2 b	30.1 b	30.2 b	30.1
plus EM	30.5	29.0 a	28.8 a	29.0 a	28.9
LSD (P=0.05)	*ns*	*1.16*	*1.22*	*1.03*	*ns*
F Probability	*0.098*	*0.039*	*0.040*	*0.032*	*0.055*
(c) interaction (regime * effective microbes)					
conventional	31.0	30.9	30.8	30.9	30.9
alternative	31.8	26.6	29.4	29.4	29.2
conventional + EM	29.7	29.8	29.8	30.0	29.8
alternative + EM	31.4	28.2	27.8	28.0	28.0
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.426*	*0.778*	*0.606*	*0.665*	*0.905*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 36: effect of conventional and alternative treatments on harvest and postharvest fruit weight of Lapin cherry

	Fruit weight (g)				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	13.5 b	13.7 b	13.8 b	13.9 b	13.9 b
alternative	11.8 a	12.1 a	11.9 a	11.9 a	12.0 a
LSD (P=0.05)	*1.5*	*1.19*	*1.20*	*1.00*	*1.15*
F Probability	*0.007*	*0.014*	*0.006*	*0.002*	*0.004*
(b) effective microbes					
No EM		13.5	13.5 b	13.5 b	13.5
plus EM		12.4	12.2 a	12.3 a	12.4
LSD (P=0.05)	*ns*	*ns*	*1.20*	*1.00*	*ns*
F Probability		*0.059*	*0.036*	*0.024*	*0.056*
(c) interaction (regime * effective microbes)					
conventional		14.2	14.2	14.3	14.4
alternative		12.9	12.8	12.7	12.7
conventional + EM		13.3	13.4	13.5	13.5
alternative + EM		11.4	11.0	11.1	11.4
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability		*0.586*	*0.381*	*0.417*	*0.753*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 37: effect of conventional and alternative treatments on harvest and postharvest fruit compression firmness of Lapin cherry, as measured with Bioworks firmtech

	Fruit firmness (compression) (g/mm)				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	285	311	330	297	280
alternative	280	296	324	281	263
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.525*	*0.252*	*0.689*	*0.382*	*0.255*
(b) effective microbes					
No EM	291	308	335	297	283
plus EM	274	298	319	281	263
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.072*	*0.436*	*0.254*	*0.354*	*0.138*
(c) interaction (regime * effective microbes)					
conventional	300	320	343	308	297
alternative	282	296	327	287	268
conventional + EM	270	301	316	286	262
alternative + EM	277	296	321	276	258
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.172*	*0.447*	*0.456*	*0.721*	*0.377*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 38: effect of conventional and alternative treatments on harvest and postharvest fruit flesh firmness of Lapin cherry

	Fruit flesh firmness (g)				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	103	101	116	141	143
alternative	100	102	107	137	141
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.587*	*0.721*	*0.152*	*0.609*	*0.837*
(b) effective microbes					
No EM	107 b	103	116	145	146
plus EM	97 a	100	107	134	138
LSD (P=0.05)	*9.6*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.038*	*0.375*	*0.207*	*0.175*	*0.273*
(c) interaction (regime * effective microbes)					
conventional	111	104	121	147	146
alternative	103	102	110	143	146
conventional + EM	95	97	112	136	140
alternative + EM	98	102	103	132	137
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.256*	*0.431*	*0.874*	*0.985*	*0.789*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 39: effect of conventional and alternative treatments on harvest and postharvest fruit skin puncture force of Lapin cherry

	Fruit skin puncture force (g)				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	359	364	422	446	445
alternative	354	348	395	443	444
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.700*	*0.426*	*0.124*	*0.853*	*0.985*
(b) effective microbes					
No EM	373 b	371	419	455	457
plus EM	340 a	341	398	434	433
LSD (P=0.05)	*31*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.042*	*0.172*	*0.226*	*0.202*	*0.166*
(c) interaction (regime * effective microbes)					
conventional	387	384	434	457	456
alternative	358	357	404	452	458
conventional + EM	331	345	414	434	434
alternative + EM	349	338	385	433	431
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.130*	*0.621*	*0.907*	*0.885*	*0.882*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 40: effect of conventional and alternative treatments on harvest and postharvest stem retention force of Lapin cherry

	Fruit stem retention force (g)				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	622	606	473	371	274
alternative	597	617	502	365	295
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.545*	*0.776*	*0.312*	*0.756*	*0.205*
(b) effective microbes					
No EM	621	618	499	384	286
plus EM	598	606	477	353	283
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.581*	*0.751*	*0.438*	*0.144*	*0.864*
(c) interaction (regime * effective microbes)					
conventional	645	619	506	407	277
alternative	597	617	492	361	295
conventional + EM	599	594	441	336	271
alternative + EM	597	618	513	370	295
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.577*	*0.732*	*0.144*	*0.071*	*0.868*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 41: effect of conventional and alternative treatments on harvest and postharvest fruit skin colour of Lapin cherry

	Fruit skin colour				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	5.6	5.5	5.5	5.6	5.8
alternative	5.6	5.5	5.4	5.6	5.6
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.971*	*0.538*	*0.423*	*0.867*	*0.278*
(b) effective microbes					
No EM	5.6	5.4	5.4	5.6	5.6
plus EM	5.7	5.6	5.5	5.6	5.8
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.228*	*0.119*	*0.423*	*0.734*	*0.096*
(c) interaction (regime * effective microbes)					
conventional	5.5	5.4	5.4	5.5	5.7
alternative	5.6	5.5	5.4	5.6	5.5
conventional + EM	5.8	5.7	5.6	5.7	5.8
alternative + EM	5.7	5.5	5.4	5.6	5.8
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.379*	*0.119*	*0.490*	*0.579*	*0.627*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 42: effect of conventional and alternative treatments on harvest and postharvest fruit TSS content of Lapin cherry

	Fruit total soluble solids content (°Brix)				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	17.4	17.2	16.7	17.3	17.2
alternative	17.1	17.2	16.8	17.2	17.3
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.245*	*0.941*	*0.884*	*0.839*	*0.898*
(b) effective microbes					
No EM	17.4	17.1	17.0	17.4	17.2
plus EM	17.1	17.3	16.4	17.1	17.4
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.313*	*0.302*	*0.361*	*0.671*	*0.678*
(c) interaction (regime * effective microbes)					
conventional	17.7	17.1	17.1	17.6	16.9
alternative	17.1	17.0	16.9	17.2	17.4
conventional + EM	17.2	17.3	16.2	17.0	17.6
alternative + EM	17.0	17.4	16.6	17.2	17.2
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.417*	*0.640*	*0.649*	*0.614*	*0.277*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 43: effect of conventional and alternative treatments on harvest and postharvest fruit malic acid content of Lapin cherry

	Fruit malic acid content (g/L)				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	5.10 b	4.95	4.89 b	3.71	3.32
alternative	4.66 a	4.57	4.52 a	3.58	3.23
LSD (P=0.05)	*0.39*	*ns*	*0.17*	*ns*	*ns*
F Probability	*0.035*	*0.066*	*<0.001*	*0.387*	*0.588*
(b) effective microbes					
No EM	4.97	4.85	4.70	3.65	3.34
plus EM	4.80	4.67	4.71	3.64	3.20
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.366*	*0.350*	*0.849*	*0.907*	*0.389*
(c) interaction (regime * effective microbes)					
conventional	5.23	4.98	4.82	3.76	3.35
alternative	4.71	4.72	4.57	3.55	3.33
conventional + EM	4.98	4.92	4.96	3.66	3.28
alternative + EM	4.32	4.43	4.47	3.61	3.12
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.692*	*0.553*	*0.150*	*0.580*	*0.681*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 44: effect of conventional and alternative treatments on harvest and postharvest fruit pH of Lapin cherry

	Fruit juice pH				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	4.28	4.34 a	4.32 a	4.57	4.67
alternative	4.36	4.42 b	4.37 b	4.60	4.72
LSD (P=0.05)	*ns*	*0.07*	*0.04*	*ns*	*ns*
F Probability	*0.077*	*0.040*	*0.034*	*0.388*	*0.193*
(b) effective microbes					
No EM	4.33	4.39	4.36	4.60	4.69
plus EM	4.32	4.38	4.33	4.56	4.70
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.735*	*0.765*	*0.141*	*0.316*	*0.689*
(c) interaction (regime * effective microbes)					
conventional	4.28	4.35	4.33	4.59	4.68
alternative	4.38	4.43	4.39	4.61	4.71
conventional + EM	4.30	4.34	4.31	4.55	4.67
alternative + EM	4.34	4.42	4.35	4.58	4.74
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.355*	*0.905*	*0.765*	*0.782*	*0.616*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 45: effect of conventional and alternative treatments on fruit weight and percentage A-grade, reject and cracked fruit of Sweetheart cherry.

	No. fruit per cm^2 LCSA	% A grade fruit	% Reject fruit	% Cracked fruit
(a) treatment regime				
conventional	22.8	71.7	5.5	1.9
alternative	21.5	77.9	4.3	0.8
LSD (P=0.05)	*ns*	*ns*	*ns*	***
F Probability	*0.723*	*0.143*	*0.394*	*0.079*
(b) effective microbes9.8				
No EM	22.1	74.7	4.6	1.4
plus EM	22.3	74.9	5.2	1.3
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.965*	*0.968*	*0.635*	*0.836*
(c) interaction (regime * effective microbes)				
conventional	21.7	73.9	5.2	1.9
alternative	22.5	75.6	4.0	0.9
conventional + EM	23.9	69.5	5.8	1.9
alternative + EM	20.6	80.3	4.7	0.7
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.583*	*0.270*	*0.978*	*0.884*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 46: effect of conventional and alternative treatments on fruit soluble solid and malic acid content, juice pH, fruit skin colour and pedicel diameter of Sweetheart cherry at harvest. TSS = total soluble solids

	Flesh colour	Pedicel diameter (mm)	Dry matter content (%)	Yield eficiency (kg/cm^2 TCSA)
(a) treatment regime				
conventional	4.5	1.04	21.0	0.175
alternative	4.9	1.03	22.4	0.167
LSD (P=0.05)	*	*ns*	*	*ns*
F Probability	*0.065*	*0.599*	*0.068*	*0.763*
(b) effective microbes				
No EM	4.7	1.04	21.6	0.166
plus EM	4.7	1.04	21.8	0.174
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.858*	*0.824*	*0.768*	*0.695*
(c) interaction (regime * effective microbes)				
conventional	4.5	1.04	20.5	0.165
alternative	4.9	1.03	22.7	0.167
conventional + EM	4.5	1.04	21.6	0.181
alternative + EM	4.9	1.04	22.0	0.165
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.895*	*0.904*	*0.178*	*0.686*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 47: effect of conventional and alternative treatments on harvest and postharvest fruit diameter of Sweetheart cherry

	Fruit diameter (mm)				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	28.1 b	28.5 b	28.3 b	28.5	28.1
alternative	27.0 a	27.2 a	27.1 a	27.4	27.2
LSD (P=0.05)	*1.0*	*1.1*	*1.0*	*ns*	*ns*
F Probability	*0.025*	*0.031*	*0.020*	*0.115*	*0.219*
(b) effective microbes					
No EM	27.7	27.7	27.5	27.8	27.5
plus EM	27.5	27.9	27.8	28.1	27.8
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.653*	*0.671*	*0.577*	*0.562*	*0.642*
(c) interaction (regime * effective microbes)					
conventional	28.4	28.5	28.3	28.3	28.0
alternative	26.9	27.0	26.8	27.3	27.0
conventional + EM	27.9	28.4	28.3	28.7	28.3
alternative + EM	27.0	27.5	27.3	27.6	27.4
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.488*	*0.586*	*0.576*	*0.931*	*0.984*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 48: effect of conventional and alternative treatments on harvest and postharvest fruit weight of Sweetheart cherry

	Fruit weight (g)				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	11.4	11.4	11.4	11.4	11.1
alternative	10.5	10.4	10.5	10.6	10.6
LSD (P=0.05)	*ns*	*0.8*	*0.8*	*ns*	*ns*
F Probability	*0.060*	*0.040*	*0.038*	*0.152*	*0.401*
(b) effective microbes					
No EM	10.9	10.7	10.8	10.8	10.6
plus EM	11.4	11.1	11.2	11.2	11.0
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.812*	*0.259*	*0.323*	*0.387*	*0.481*
(c) interaction (regime * effective microbes)					
conventional	11.5	11.2	11.3	11.2	10.9
alternative	10.3	10.1	10.2	10.3	10.3
conventional + EM	11.3	11.5	11.6	11.6	11.3
alternative + EM	10.8	10.8	10.8	10.9	10.8
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.449*	*0.592*	*0.767*	*0.821*	*0.973*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

*Table 49: effect of conventional and alternative treatments on **postharvest** (35 days after harvest) fruit compression firmness of Sweetheart cherry.*

	Fruit firmness (compression) (g/mm				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	325	343	350	360 b	350
alternative	296	303	318	319 a	316
LSD (P=0.05)	*ns*	***	*ns*	*36*	***
F Probability	*0.129*	*0.085*	*0.148*	*0.030*	*0.081*
(b) effective microbes*					
No EM	312	321	328	327	329
plus EM	309	325	339	353	337
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.865*	*0.839*	*0.599*	*0.142*	*0.625*
(c) interaction (regime * effective microbes)					
conventional	326	340	347	343	349
alternative	298	302	309	311	308
conventional + EM	324	347	352	378	351
alternative + EM	294	304	326	328	324
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.960*	*0.904*	*0.756*	*0.591*	*0.714*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

*Table 50: effect of conventional and alternative treatments on harvest and **postharvest** fruit firmness of Sweetheart cherry*

	Fruit flesh firmness (g)				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	106	*	130	135	148
alternative	111	*	125	131	154
LSD (P=0.05)	*ns*	*	*ns*	*ns*	*ns*
F Probability	*0.593*	*	*0.464*	*0.673*	*0.562*
(b) effective microbes					
No EM	109	*	125	135	150
plus EM	108	*	130	131	152
LSD (P=0.05)	*ns*	*	*ns*	*ns*	*ns*
F Probability	*0.833*	*	*0.539*	*0.666*	*0.862*
(c) interaction (regime * effective microbes)					
conventional	109	*	130	137	150
alternative	111	*	121	132	151
conventional + EM	104	*	130	132	147
alternative + EM	112	*	129	130	157
LSD (P=0.05)	*ns*	*	*ns*	*ns*	*ns*
F Probability	*0.762*	*	*0.579*	*0.827*	*0.630*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 51: effect of conventional and alternative treatments on harvest & postharvest skin puncture force of Sweetheart cherry

	Fruit skin puncture force (g)				
Harvest		14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	310	*	394	397	413
alternative	335	*	389	403	433
LSD (P=0.05)	*ns*	*	*ns*	*ns*	*ns*
F Probability	*0.406*	*	*0.823*	*0.755*	*0.334*
(b) effective microbes					
No EM	318	*	388	399	422
plus EM	327	*	389	400	425
LSD (P=0.05)	*ns*	*	*ns*	*ns*	*ns*
F Probability	*0.765*	*	*0.777*	*0.976*	*0.892*
(c) interaction (regime * effective microbes)					
conventional	313	*	402	408	423
alternative	323	*	375	391	420
conventional + EM	307	*	386	385	402
alternative + EM	347	*	403	415	447
LSD (P=0.05)	*ns*	*	*ns*	*ns*	*ns*
F Probability	*0.623*	*	*0.350*	*0.251*	*0.261*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 52: effect of conventional and alternative treatments on harvest & postharvest stem retention force of Sweetheart cherry

	Fruit stem retention force (g/mm				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	652 b	680 b	528	462	355
alternative	551 a	556 a	494	466	347
LSD (P=0.05)	*58*	*66*	*ns*	*ns*	*ns*
F Probability	*0.003*	*0.002*	*0.423*	*0.870*	*0.860*
(b) effective microbes					
No EM	628	619	513	453	341
plus EM	575	617	494	475	361
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.068*	*0.942*	*0.941*	*0.401*	*0.656*
(c) interaction (regime * effective microbes)					
conventional	647 b	662	521	467	333
alternative	609 b	576	504	438	349
conventional + EM	658 b	698	535	457	377
alternative + EM	492 a	535	485	494	346
LSD (P=0.05)	*82*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.034*	*0.220*	*0.691*	*0.232*	*0.604*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 53: effect of conventional and alternative treatments on harvest and postharvest fruit skin colour of Sweetheart cherry

	Skin colour				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	5.4	5.4	5.6	5.8	*
alternative	5.5	5.5	5.7	5.8	*
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*
F Probability	*0.403*	*0.174*	*0.173*	*0.978*	*
(b) effective microbes					
No EM	5.4	5.4	5.7	5.8	*
plus EM	5.5	5.5	5.7	5.8	*
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*
F Probability	*0.748*	*0.271*	*0.800*	*0.668*	*
(c) interaction (regime * effective microbes)					
conventional	5.4	5.4	5.7	5.8	*
alternative	5.5	5.5	5.7	5.8	*
conventional + EM	5.4	5.4	5.6	5.8	*
alternative + EM	5.6	5.6	5.8	5.9	*
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*
F Probability	*0.461*	*0.960*	*0.100*	*0.199*	*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 54: effect of conventional and alternative treatments on harvest and postharvest fruit total soluble solids content of Sweetheart cherry

	Fruit total soluble solids) (Brix)				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	18.2	18.3	18.5	19.4	17.6
alternative	19.5	19.1	19.7	19.1	18.7
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.114*	*0.308*	*0.092*	*0.726*	*0.219*
(b) effective microbes					
No EM	18.6	18.6	18.8	18.8	18.0
plus EM	19.1	18.7	19.4	19.7	18.3
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.492*	*0.879*	*0.351*	*0.265*	*0.772*
(c) interaction (regime * effective microbes)					
conventional	18.2	18.6	18.6	19.3	17.7
alternative	18.9	18.7	19.0	18.3	18.3
conventional + EM	18.2	18.1	18.4	19.5	17.5
alternative + EM	20.0	19.4	20.4	19.9	19.0
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.443*	*0.403*	*0.238*	*0.358*	*0.565*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 55: effect of conventional and alternative treatments on harvest and postharvest fruit malic acid concentration of Sweetheart cherry

	Fruit malic acid content (g/L)				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	6.54 a	6.46 a	6.19 a	5.27	3.47 a
alternative	7.21 b	7.12 b	6.93 b	5.68	4.45 b
LSD (P=0.05)	*0.42*	*0.48*	*0.34*	*ns*	*0.55*
F Probability	*0.006*	*0.014*	*0.001*	*0.249*	*0.003*
(b) effective microbes					
No EM	6.84	6.76	6.46	5.28	3.97
plus EM	6.91	6.81	6.66	5.67	3.92
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.722*	*0.830*	*0.240*	*0.289*	*0.840*
(c) interaction (regime * effective microbes)					
conventional	6.55	6.44	6.15	5.10	3.44
alternative	7.13	7.08	6.78	5.47	4.50
conventional + EM	6.53	6.48	6.24	5.43	3.45
alternative + EM	7.29	7.15	7.08	5.90	4.39
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.632*	*0.947*	*0.500*	*0.874*	*0.816*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 56: effect of conventional and alternative treatments on harvest and postharvest fruit juice pH of Sweetheart cherry

	Fruit juice pH				
	Harvest	14 dPH	28 dPH	42 dPH	56 dPH
(a) treatment regime					
conventional	4.17 b	4.21 b	4.31 b	4.39 b	4.60 b
alternative	4.10 a	4.10 a	4.21 a	4.28 a	4.37 a
LSD (P=0.05)	*0.06*	*0.04*	*0.06*	*0.09*	*0.09*
F Probability	*0.013*	*<0.001*	*0.006*	*0.036*	*<0.001*
(b) effective microbes					
No EM	4.10	4.15	4.24	4.33	4.46
plus EM	4.15	4.16	4.27	4.34	4.51
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.079*	*0.453*	*0.250*	*0.684*	*0.230*
(c) interaction (regime * effective microbes)					
conventional	4.15	4.23	4.31	4.39	4.59
alternative	4.05	4.07	4.18	4.26	4.32
conventional + EM	4.18	4.20	4.31	4.38	4.60
alternative + EM	4.12	4.12	4.24	4.30	4.42
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.592*	*0.075*	*0.233*	*0.581*	*0.329*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

(v) Analysis of fifth season data (2016/17):

1. Harvest and fruit assessment data

There were no treatment effects on fruit set in any of the cultivars examined (Tables 1, 2), but differences were observed between cultivars with respect to treatment effect on the proportion of A grade, cracked and reject fruit. In Lapins (Table 1) the alternative regime produced a greater proportion of A grade fruit and less cracked and reject fruit than the conventional regime.

Addition of effective microbes (EM) to the conventional regime increased the proportion of A grade fruit compared to the conventional alone. The percentage of reject fruit was reduced in the conventional treatment by the addition of EM, while adding EM to the alternative treatment had no additional effect. In Sweetheart (Table 2), the Conventional + EM and alternative treatments had significantly less cracked fruit than the conventional;

There were no significant differences in fruit weight or diameter in either cultivar. In Lapins (Table 4), fruit compression firmness was 4% lower in the alternative regime compared with the conventional regime; addition of EM also reduced fruit compression firmness by 4%. There were no treatment effects in Sweetheart (Table 5).

Flesh firmness and skin puncture force of Lapins fruit were reduced in the alternative regime compared with the conventional regime (10% and 5% respectively), but in Staccato (Table 6) the alternative regime increased flesh firmness by 9% and skin puncture force by 15%. There were no differences observed in these fruit quality parameters in the Sweetheart.

Dry matter content of Lapins fruit was reduced by 7% in the alternative regime compared with the conventional. There was no effect on dry matter content (DMC) in the sweetheart.

Addition of EM had no effect on stem retention force in Lapins or Sweetheart.

Compared with the conventional regime, the alternative regime reduced TSS in Lapins. Malic acid content was higher in the alternative regime compared with the conventional in Sweetheart, but there were no differences between nutrient regimes in Lapins.

In both Lapins and Sweetheart, skin colour was lighter in the alternative regime than in the conventional, suggesting fruit were not as ripe.

The lower TSS and juice pH and higher malic acid content observed overall in the Sweetheat compared with Lapins suggests that this cultivar was harvested at less than optimal maturity.

Post-harvest assessments showed similar trends to harvest assessments.

Table 57: effect of nutrient regime and effective microbes (EM) on fruit set, fruit weight and percentage A-grade, reject and cracked fruit of 'Lapin' cherry.

	% fruit set	% A grade fruit	% Reject fruit	% Cracked fruit	Average fruit weight (g)	A-grade fruit weight (g)
(a) treatment regime						
conventional	25.1	31.5 a	41.3 b	56.8 b	12.6	13.9
alternative	31.8	37.2 b	28.0 a	35.8 a	10.7	12.7
LSD (P=0.05)	*ns*	*5.5*	*11.5*	*12.3*	*ns*	*ns*
F Probability	*0.089*	*0.043*	*0.027*	*0.003*	*0.140*	*0.051*
(b) effective microbes						
No EM	28.0	30.8 a	41.1 b	57.4 b	11.8	13.2
plus EM	28.9	37.9 b	28.2 a	35.3 a	11.5	13.3
LSD (P=0.05)	*ns*	*5.5*	*11.5*	*12.3*	*ns*	*ns*
F Probability	*0.824*	*0.016*	*0.031*	*0.002*	*0.843*	*0.930*
(c) interaction (regime * effective microbes)						
conventional	23.2	22.8 a	56.4 b	71.3	12.1	13.6
alternative	32.8	38.9 b	25.8 a	43.4	11.5	12.9
conventional + EM	27.0	40.2 b	26.2 a	42.4	13.2	14.2
alternative + EM	30.8	35.6 b	30.2 a	28.3	10.0	12.4
LSD (P=0.05)	*ns*	*7.8*	*16.3*	*ns*	*ns*	*ns*
F Probability	*0.449*	*0.001*	*0.006*	*0.253*	*0.305*	*0.359*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 58: effect of nutrient regime and effective microbes (EM) on fruit set, fruit weight and percentage A-grade, reject and cracked fruit of 'Sweetheart' cherry.

	% fruit Set	% A grade fruit	% Reject fruit	% Cracked fruit	Average fruit weight (g)	A-grade fruit weight (g)
(a) treatment regime						
conventional	18.5	63.8	6.2	27.2	13.6	13.6
alternative	21.7	62.9	5.6	25.1	13.3	13.6
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.311*	*0.869*	*0.763*	*0.714*	*0.328*	*0.905*
(b) effective microbes						
No EM	21.3	62.4	7.6	27.7	13.4	13.5
plus EM	18.9	64.3	4.2	24.6	13.5	13.6
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.449*	*0.729*	*0.109*	*0.586*	*0.969*	*0.759*
(c) interaction (regime * effective microbes)						
conventional	17.9	59.7	9.7	34.5 b	13.6	13.5
alternative	24.7	62.2	5.8	20.9 a	13.3	13.5
conventional + EM	19.1	67.9	2.8	19.8 a	13.6	13.6
alternative + EM	18.8	60.7	5.7	29.4 ab	13.3	13.6
LSD (P=0.05)	*ns*	*ns*	*ns*	*11.2*	*ns*	*ns*
F Probability	*0.268*	*0.256*	*0.097*	*0.047*	*0.978*	*0.897*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 59: effect of nutrient regime and effective microbes (EM) on fruit size, firmness, skin strength, stem retention force and dry matter content of 'Lapin' cherry.

	Fruit diameter (mm)	Fruit compression force (g/mm)	Flesh firmness (g)	Skin puncture force (g)	Stem retention force (g)	Dry matter content (%)
(a) treatment regime						
conventional	31.1	418 b	152 b	556 b	884	22.1 b
alternative	30.2	401 a	131 a	528 a	956	20.5 a
LSD (P=0.05)	*ns*	*15*	*12*	*17*	*ns*	*0.8*
F Probability	*0.065*	*0.033*	*0.008*	*0.010*	*0.198*	*0.005*
(b) effective microbes						
No EM	30.7	418 b	140	546	974	20.9
plus EM	30.6	401 a	144	538	865	21.7
LSD (P=0.05)	*ns*	*15*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.761*	*0.036*	*0.397*	*0.257*	*0.073*	*0.067*
(c) interaction (regime * effective microbes)						
conventional	31.2	427	152	565	950	22.0
alternative	30.2	409	128	528	998	19.7
conventional + EM	31.0	409	153	546	817	22.1
alternative + EM	30.2	393	136	529	913	21.2
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.783*	*0.945*	*0.505*	*0.197*	*0.647*	*0.078*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 60: effect of nutrient regime and effective microbes (EM) on fruit size, firmness, skin strength, stem retention force and dry matter content of 'Sweetheart' cherry.

	Fruit diameter (mm)	Fruit compression force (g/mm)	Flesh firmness (g)	Skin puncture force (g)	Stem retention force (g)	Dry matter content (%)
(a) treatment regime						
conventional	30.9	376	115	335	860	17.9
alternative	31.0	350	118	344	926	18.7
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.660*	*0.070*	*0.361*	*0.446*	*0.302*	*0.077*
(b) effective microbes						
No EM	30.9	357	113 a	328	886	18.2
plus EM	31.0	369	121 b	351	901	18.4
LSD (P=0.05)	*ns*	*ns*	*7*	*ns*	*ns*	*ns*
F Probability	*0.582*	*0.371*	*0.026*	*0.062*	*0.807*	*0.564*
(c) interaction (regime * effective microbes)						
conventional	30.8	370	113	323	849	18.2
alternative	30.9	344	113	333	922	18.2
conventional + EM	30.9	382	118	347	872	17.6
alternative + EM	31.2	356	125	355	930	19.2
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.850*	*0.985*	*0.292*	*0.955*	*0.900*	*0.077*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 61: effect of nutrient regime and effective microbes (EM) on fruit soluble solid and malic acid content, juice pH, and fruit skin colour of 'Lapin' cherry at harvest. TSS = total soluble solids.

	TSS (Brix)	Juice pH	Malic acid content (g/L)	Skin colour	Flesh colour
(a) treatment regime					
conventional	20.8 b	4.5	5.0	5.76 b	5.37 b
alternative	18.7 a	4.5	5.1	5.43 a	5.12 a
LSD (P=0.05)	*1.8*		*ns*	*0.16*	*0.14*
F Probability	*0.036*		*0.316*	*0.004*	*0.006*
(b) effective microbes					
No EM	19.2	4.5	5.1	5.51 a	5.08 a
plus EM	20.3	4.5	5.0	5.69 b	5.41 b
LSD (P=0.05)	*ns*	*ns*	*ns*	*0.16*	*0.14*
F Probability	*0.194*	*0.085*	*0.372*	*0.035*	*0.002*
(c) interaction (regime * effective microbes)					
conventional	20.6	4.5	5.1	5.72	5.31 b
alternative	17.8	4.4	5.2	5.29	4.86 a
conventional + EM	21.0	4.5	4.9	5.81	5.43 b
alternative + EM	19.6	4.5	5.1	5.57	5.39 b
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*0.20*
F Probability	*0.355*	*0.431*	*0.697*	*0.197*	*0.014*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 62: effect of nutrient regime and effective microbes (EM) on fruit soluble solid and malic acid content, juice pH, and fruit skin colour of 'Sweetheart' cherry at harvest. TSS = total soluble solids

	TSS (Brix)	Juice pH	Malic acid content (g/L)	Skin colour	Flesh colour
(a) treatment regime					
conventional	16.6	3.98	8.72 a	5.12 b	3.37
alternative	17.1	3.95	9.47 b	4.80 a	3.37
LSD (P=0.05)	*ns*	*ns*	*0.44*	*0.21*	*ns*
F Probability	*0.229*	*0.083*	*0.004*	*0.008*	*0.979*
(b) effective microbes					
No EM	16.8	3.97	9.15	5.00	3.47
plus EM	16.9	3.96	9.04	4.93	3.27
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.867*	*0.612*	*0.584*	*0.472*	*0.233*
(c) interaction (regime * effective microbes)					
conventional	16.7	3.98	8.84	5.15	3.43
alternative	17.0	3.96	9.47	4.86	3.51
conventional + EM	16.5	3.98	8.61	5.12	3.31
alternative + EM	17.3	3.94	9.48	4.76	3.24
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*	*ns*
F Probability	*0.562*	*0.644*	*0.556*	*0.764*	*0.617*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 63: effect of nutrient regime and effective microbes (EM) on postharvest (42 days after harvest) fruit firmness, skin strength and stem retention force of 'Lapin' cherry.

	Fruit compression force (g/mm)	Flesh firmness (g)	Skin puncture force (g)	Stem retention force (g)
(a) treatment regime				
conventional	463 b	167 b	555 b	700
alternative	433 a	145 a	507 a	686
LSD (P=0.05)	*24*	*15*	*37*	*ns*
F Probability	*0.023*	*0.017*	*0.023*	*0.633*
(b) effective microbes				
No EM	449	155	534	712
plus EM	447	156	527	675
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.876*	*0.877*	*0.659*	*0.245*
(c) interaction (regime * effective microbes)				
conventional	464	171	570	730
alternative	434	140	498	694
conventional + EM	463	162	539	671
alternative + EM	432	151	515	679
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.933*	*0.171*	*0.154*	*0.477*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 64: effect of nutrient regime and effective microbes (EM) on postharvest (42 days after harvest) fruit firmness, skin strength and stem retention force of 'Sweetheart' cherry.

	Fruit Compression force (g/mm)	Flesh firmness (g)	Skin puncture force (g)	Stem retention force (g)
(a) treatment regime				
conventional	413	121	343	497
alternative	406	130	358	540
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.558*	*0.523*	*0.206*	*0.258*
(b) effective microbes				
No EM	404	124	342	528
plus EM	415	133	359	508
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.368*	*0.128*	*0.156*	*0.578*
(c) interaction (regime * effective microbes)				
conventional	408	122	336	510
alternative	400	127	349	547
conventional + EM	417	132	351	484
alternative + EM	412	133	367	532
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.890*	*0.711*	*0.84*	*0.882*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 65: effect of nutrient regime and effective microbes (EM) on postharvest (42 days after harvest) fruit total soluble solids (TSS) content, juice pH, malic acid content and skin colour of 'Lapin' cherry.

	TSS (Brix)	Juice pH	Malic acid content (g/L)	Skin colour
(a) treatment regime				
conventional	21.0 b	4.7 b	4.4	5.5 b
alternative	19.3 a	4.6 a	4.5	5.2 a
LSD (P=0.05)	*1.0*	*0.03*	*ns*	*0.2*
F Probability	*0.009*	*0.005*	*0.382*	*0.009*
(b) effective microbes				
No EM	20.2	4.6	4.6	5.3
plus EM	20.1	4.7	4.3	5.4
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.902*	*0.400*	*0.103*	*0.375*
(c) interaction (regime * effective microbes)				
conventional	21.2	4.7 b	4.4	5.5
alternative	19.1	4.6 a	4.8	5.1
conventional + EM	20.7	4.7 b	4.4	5.5
alternative + EM	19.6	4.7 b	4.3	5.3
LSD (P=0.05)	*ns*	*0.04*	*ns*	*ns*
F Probability	*0.267*	*0.011*	*0.190*	*0.585*

Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

Table 66: effect of nutrient regime and effective microbes (EM) on postharvest (42 days after harvest) fruit total soluble solids (TSS) content, juice pH, malic acid content and skin colour of 'Sweetheart' cherry.

	TSS (Brix)	Juice pH	Malic acid content (g/L)	Skin colour
(a) treatment regime				
conventional	16.3	4.16 b	6.56 a	5.5 b
alternative	16.8	4.12 a	7.13 b	5.0 a
LSD (P=0.05)	*ns*	*0.02*	*0.34*	*0.1*
F Probability	*0.355*	*0.006*	*0.005*	*0.012*
(b) effective microbes				
No EM 16.4	4.14	6.79	5.1	
plus EM	16.7	4.15	6.90	5.0
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.579*	*0.546*	*0.514*	*0.384*
(c) interaction (regime * effective microbes)				
conventional	16.3	4.15	6.56	5.2
alternative	16.4	4.12	7.03	5.0
conventional + EM	16.2	4.17	6.56	5.2
alternative + EM	17.2	4.12	7.23	4.9
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
F Probability	*0.438*	*0.325*	*0.535*	*0.384*

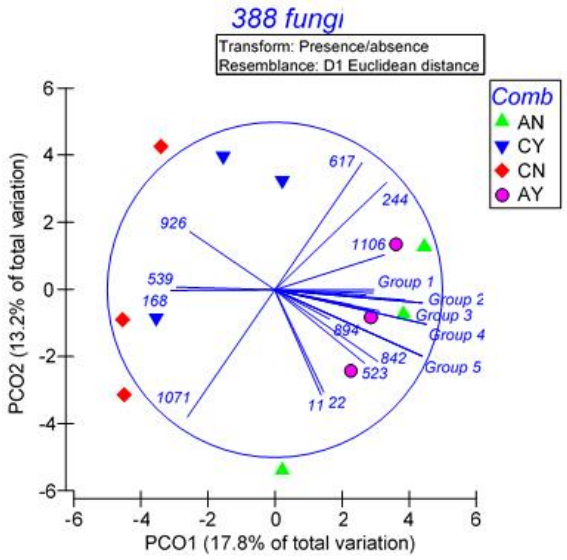
Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test.

(vi) Soil culture DNA analysis

After trimming for quality, a total of 405,934 fungal and 193,808 bacterial sequence reads were obtained from the 12 soil and 5 microbial cultures. There was very little overlap between micro-organisms detected in soil and those prevalent in the microbial cultures so these datasets were analysed separately.

Of the 1730 bacterial MOTUs 1718 were detected in soil, 18 in microbial cultures with six represented in both. In addition to the full dataset, reduced datasets containing 1182 MOTUs (>0.01%), 835 MOTUs (>0.02%), 405 MOTUs (>0.05%) and 224 MOTUs (>0.1%) were analysed but no significant treatment effects were observed.

Of the 1142 fungal MOTUs, 1120 were detected in soil, 25 in the microbial cultures and only three in both. A reduced dataset consisting of 388 MOTUs with overall abundance >0.01% was also tested and produced results very similar to those from the entire dataset. Fertiliser treatments had a significant (P=0.0023) effect on the presence/absence of fungal taxa, though not on the relative abundance of fungal taxa (Figure2).



AN – Alternative fertiliser, no EM
CY – Conventional fertiliser, EM
CN – Conventional fertiliser, no EM
AY – Alternative fertiliser, EM

Figure 2: Principal co-ordinate analysis of the 388 most abundant fungal species showing vectors with a high correlation (>0.9) to one of the first two axes or correlation to fertiliser treatment. AN

Table 67: Key to OTUs in Figure 2 clockwise from top.

OTU#	Fungal identification
617	Ascomycota ; Sordariomycetes ; Hypocreales ; Nectriaceae ; Fusarium sp
244	Ascomycota ; Dothideomycetes ; Pleosporales ; Pleosporaceae ; Drechslera sp
1106	Unidentified
358 (Group 1)	Basidiomycota ; Agaricomycetes ; Agaricales ; Entolomataceae ; Clitopilus cf scyphoides
288 (Group 1)	Ascomycota; Unclassified, highest similarity to parasites of amoeba
1020 (Group 1)	Mucoromycota; Mortierellomycotina; Mortierellales; Mortierellaceae; Mortierella cf. exigua
200 (Group 2)	Ascomycota ; Sordariomycetes ; Unclassified ; Unclassified ; Myrmecridium ; Myrmecridium schulzeri
129 (Group 2)	Ascomycota ; Dothideomycetes ; Pleosporales ; Unclassified
459 (Group 2)	Basidiomycota ; Agaricomycetes ; Agaricales ; Bolbitiaceae ; Conocybe velutipes
161 (Group 3)	Basidiomycota ; Unclassified ;
63 (Group 3)	Basidiomycota ; Unclassified ;
923 (Group 3)	Ascomycota ; Leotiomycetes ; Unclassified ;
287 (Group 4)	Glomeromycota; Glomeromycetes; Paraglomerales; Paraglomeraceae; Paraglomus cf. laccatum
221 (Group 4)	Glomeromycota ; Glomeromycetes ; Paraglomerales ; Unclassified ;
951 (Group 5)	Glomeromycota ; Glomeromycetes ; Glomerales ; Glomeraceae ; Unclassified
277 (Group 5)	Glomeromycota ; Glomeromycetes ; Glomerales ; Glomeraceae ; Funneliformis sp. 1
1042 (Group 5)	Glomeromycota ; Glomeromycetes ; Glomerales ; Glomeraceae ; Funneliformis sp. 2
894	Basidiomycota ; Agaricomycetes ; Agaricales ; Cortinariaceae ; Unclassified
842	Glomeromycota ; Glomeromycetes ; Paraglomerales ; Unclassified
523	Ascomycota ; Sordariomycetes ; Hypocreales ; Unclassified ; Acremonium sp.
11	Basidiomycota ; Agaricomycetes ; Auriculariales ; Auriculariaceae ; Unclassified
1071	Basidiomycota ; Agaricomycetes ; Agaricales ; Lyophyllaceae ; Fibulochlamys ; Fibulochlamys chilensis
168	Unidentified
539	Ascomycota ; Sordariomycetes ; Glomerellales ; Plectosphaerellaceae ; Acrostalagmus luteoalbus
926	Basidiomycota ; Agaricomycetes ; Sebacinales ; Sebacinaceae ; Unclassified

Analysis of soil microbial communities showed that bacterial communities were highly similar across all treatments with no significant effect of EM application or fertiliser treatments. The majority of the bacterial and fungal species in the EM inoculum were not found in the soil and those that were detected were at extremely low levels. Analysis of fungal species based on presence/absence was significantly affected by fertiliser treatment but not by EM application (P=0.0015). Analysis based on relative abundance resulted in no significance of either treatment, indicating that the differences are based on species with lower relative abundance.

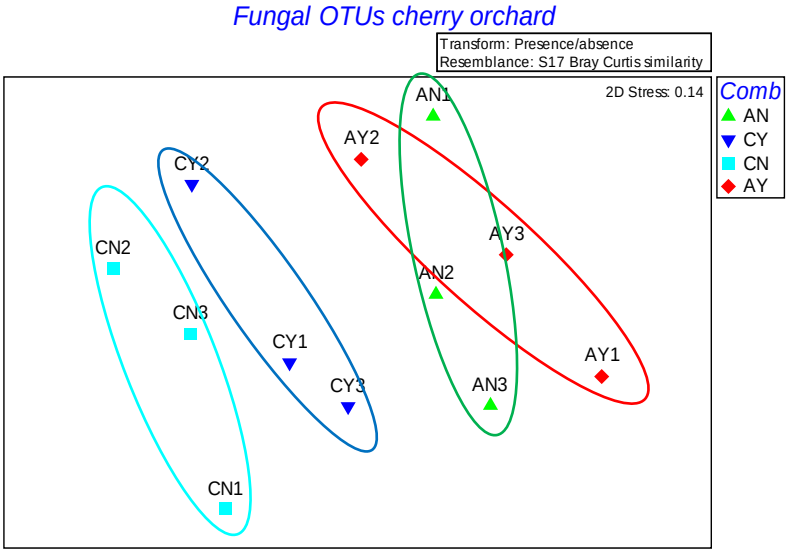


Figure 5: Fungal composition of soils in the various soil treatments:
AN – Alternative fertiliser, no EM; CY – Conventional fertiliser, EM;
CN – Conventional fertiliser, no EM; Y – Alternative fertiliser, EM

(vii) EM inoculum analysis

Only seven bacterial species were present at >1% of reads from the inoculum and six of these were species of *Lactobacillus,* the seventh being *Acetobacter okinawensis. Lactobacillus* sp. 1 was detected at very low levels (2 reads) in one soil sample (no EM treatment). *Acetobacter okinawensis* was detected at low levels (1-6 reads) in 8 of the 12 soils samples (3 with and 5 without EM treatment).

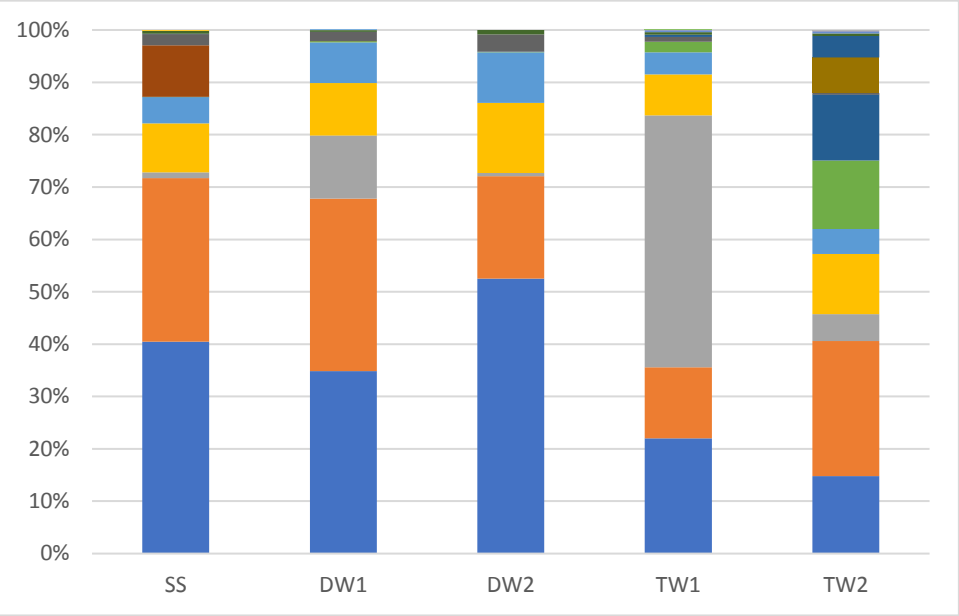


Figure 3: Bacterial composition of 'Effective Microbes' inoculum and four different brews. SS is the commercial product, used as inoculum to brew the product that is applied. DW1 and DW2 were cultured in distilled water, TW1 and TW2 were cultured in tap water.

Key to Bacterial OTUs in cultures (in order of overall abundance)

OTU#	Species identification
1673	Firmicutes ; Bacilli ; Lactobacillales ; Lactobacillaceae ; *Lactobacillus buchneri*
682	Firmicutes; Bacilli; Lactobacillales; Lactobacillaceae; *Lactobacillus sp. 1*
251	Proteobacteria ; Alphaproteobacteria ; Rhodospirillales ; Acetobacteraceae ; *Acetobacter okinawensis*
1162	Firmicutes ; Bacilli ; Lactobacillales ; Lactobacillaceae ; *Lactobacillus kisonensis*
209	Firmicutes ; Bacilli ; Lactobacillales ; Lactobacillaceae ; *Lactobacillus camelliae*
1594	Firmicutes ; Clostridia ; Clostridiales ; Clostridiaceae ; *Clostridium tyrobutyricum*
813	Bacteroidetes ; Bacteroidia ; Bacteroidales ; Prevotellaceae ; *Prevotella* sp. 1
798	Firmicutes ; Bacilli ; Lactobacillales ; Lactobacillaceae ; *Lactobacillus* sp. 2
632	Firmicutes ; Bacilli ; Lactobacillales ; Lactobacillaceae ; *Lactobacillus* sp. 3
201	Bacteroidetes ; Bacteroidia ; Bacteroidales ; Prevotellaceae ; *Prevotella* sp. 2
380	Firmicutes ; Bacilli ; Lactobacillales ; Lactobacillaceae ; *Lactobacillus casei*
1168	Firmicutes ; Bacilli ; Lactobacillales ; Lactobacillaceae ; *Lactobacillus vini*
757	Firmicutes ; Clostridia ; Clostridiales ; Clostridiaceae ; *Clostridium puniceum*
1453	Firmicutes ; Bacilli ; Lactobacillales ; Lactobacillaceae ; *Pediococcus damnosus*
595	Actinobacteria ; Actinobacteria ; Bifidobacteriales ; Bifidobacteriaceae ; *Bifidobacterium* sp.
876	Firmicutes ; Bacilli ; Lactobacillales ; Lactobacillaceae ; *Lactobacillus* sp. 4
1647	Proteobacteria ; Betaproteobacteria ; Hydrogenophilales ; Hydrogenophilaceae ; *Hydrogenophilus* sp.
1445	Tenericutes ; Mollicutes ; Acholeplasmatales ; Acholeplasmataceae ; Candidatus Phytoplasma ; Sugarcane phytoplasma

Only three fungal species were present in the inoculum as >1% of reads, these were *Candida* aff. *ethanolica, Brettanomyces* sp. cf. *custersianis* and *Pichia* sp. cf. *manshurica.* These are all yeasts in the Saccharomycetales. The remaining species comprised only 18 of the 25,382 reads from the inoculum and can be presumed to be contaminants. Apart from *Candida* aff. *ethanolica* none of the fungal species found in the EM inoculum were found in the soil samples. *Candida* aff. *ethanolica* comprised only 3 of the 28,809 reads from one of the soil samples, but this plot had not had EM treatment.

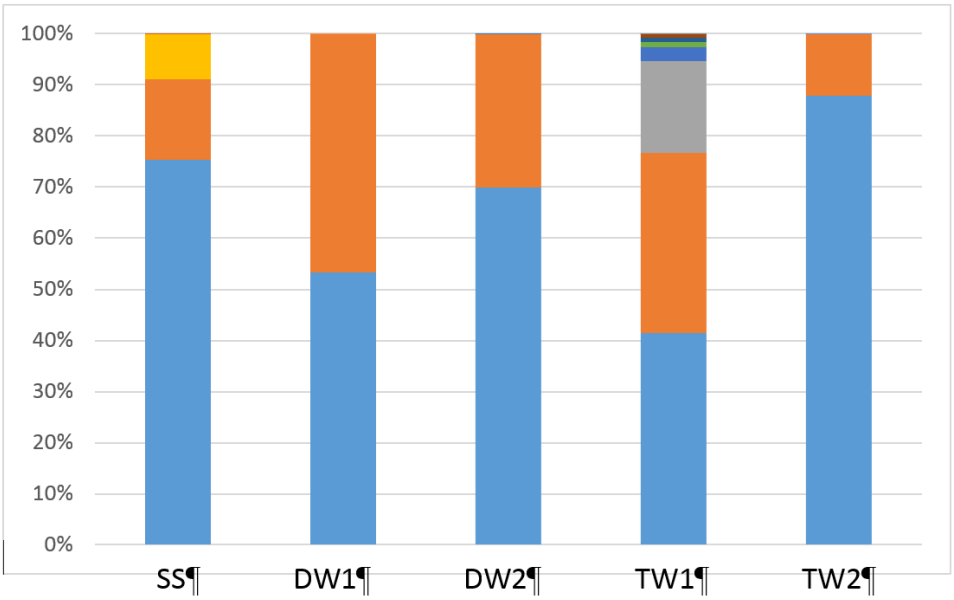


Figure 4: Fungal composition of 'Effective Microbes' inoculum and four different brews. SS is the commercial product, used as inoculum to brew the product that is applied. DW1 and DW2 were cultured in distilled water, TW1 and TW2 were cultured in tap water.

Key to Fungal OTUs in cultures

	Species identification
936*	Ascomycota; Saccharomycotina; Saccharomycetes; Saccharomycetales; Pichiaceae; *Candida* aff. *ethanolica*
1000*	Ascomycota; Saccharomycotina; Saccharomycetes; Saccharomycetales; Pichiaceae; *Brettanomyces* sp. cf. *custersianis*
99	Basidiomycota; Pucciniomycotina; Microbotryomycetes; Microbotryomycetes incertae sedis; *Curvibasidium* cf. *Rhodotorula nothofagi*
1109*	Ascomycota; Saccharomycotina; Saccharomycetes; Saccharomycetales; Pichiaceae; *Pichia manshurica*
774	Basidiomycota; Agaricomycotina; Tremellomycetes; Cystofilobasidiales; Cystofilobasidiaceae; *Cystofilobasidium capitatum*
127	Basidiomycota; Agaricomycotina; Tremellomycetes; Filobasidiales; Piskurozymaceae; *Piskurozyma* sp.
268	Fungi ; Ascomycota ; Sordariomycetes ; Coniochaetales ; Coniochaetaceae ; *Lecythophora* sp.
1099	Fungi ; Ascomycota ; Eurotiomycetes ; Eurotiales ; Aspergillaceae ; *Penicillium* sp
574	Fungi ; Unclassified ;
34	Fungi ; Unclassified ;
1034	Fungi ; Unclassified ;
352	Fungi ; Ascomycota ; Eurotiomycetes ; Eurotiales ; Aspergillaceae ; *Penicillium* sp
682	Fungi ; Unclassified ;
1049	Fungi ; Unclassified ;
561	Fungi ; Unclassified ;
806	Fungi ; Ascomycota ; Eurotiomycetes ; Eurotiales ; Aspergillaceae ; *Penicillium glabrum*
1069	Fungi ; Unclassified ;
148	Fungi ; Unclassified ;

Appendix 9 – Literature review

CY12002 – Literature Review: Soil organic matter and soil health

Introduction 2
The soil environment 2
Soil health 3
Soil physical properties 4
Soil texture 4
Soil structure 4
Soil porosity 5
Water-holding capacity 5
Bulk density 5
Soil organic matter 5
Function of humus 6
The process of decomposition 6
Carbon cycling 7
Non-humic substances 7
Nitrogen mineralisation 7
Phosphorous mineralisation and solubilisation 8
Soil biota 8
Soil fauna 9
Soil microbial biomass 9
Soil biology and mineralisation 10
N-fixing bacteria 10
P-solubilising microorganisms 11
Mycorrhizal fungi 11
Soil fertility 12
Plant nutrients and uptake 12
Essential nutrients 13
Plant nutrient uptake 14
Organic nitrogen 14
Role of Boron and Silicon 14
The rhizosphere 15
Impacts of conventional farming practices in orchards 16
Environmental impact of artificial inputs in orchards 16
Soil degradation problems 16
Nutrient Depletion and Soil Fertility 17
Soil Erosion 17
Leaching 18
Returning to sustainable production 18
Increasing soil organic matter content 19
Compost 19
Surface Mulching 21
Cover crops / Living mulches 22
Impact of soil organic matter on crop growth and yield 23
Impact on tree growth 23
Crop yield and quality 24
Using bio-fertilisers to improve sustainability in orchard crops 25
Easy methods to assess soil health 26
Conclusions 27
References 28

Introduction

Current fruit production systems, although highly productive, contain practices that are unsustainable in the long term and orchardists are becoming increasingly aware that an ecologically balanced soil system is essential for maintaining healthy crops and optimising fruit quality. The goal of a sustainable agricultural system is to adopt methods that depend primarily on renewable inputs for maintaining current levels of crop productivity (Sainju and Singh 1997).

Soil degradation occurs as part of natural cycles in the ecosystem but human abuse of this valuable resource contributes greatly to its rate of decline. On a global scale, approximately 12,000,000 hectares of arable land is destroyed and abandoned annually due to non-sustainable farming practices (Pimental *et al.* 1995). The importance of soil in relation to human populations is illustrated very strongly in history, as soil degradation has been instrumental in the fall of some ancient civilisations. According to Hillel (1991), the degradation of these fertile soils is largely due to the past actions of primary producers. Contemporary farmers are experiencing the same problems that plagued our predecessors, but we are now farming more intensively and on a larger scale. We have also added to these issues by the use of chemical fertilisers and pesticides and the production of more waste and air pollution (Hillel, 1991). In simple economic terms the result of soil degradation is reduced soil productivity. This means increased cost of production which, in turn can affect the state of the agricultural industries and may go on to affect the state of economics (LMTF, 1995).

The advent of inorganic fertilisers in the nineteenth century enabled the nutrient enhancement of soil such that crop production and yield could be increased with suitable application of supplemental nutrients. Despite many texts focussing on holistic agriculture and the complex interactions within farming systems, coupled with evidence from Asia of fields being worked for 4,000 years without depleting soil fertility, by the 1950s the shift in mainstream agriculture resulting from technological advances created a system relying on agrichemicals (chemical fertilisers, pesticides and herbicides), new crop varieties and labour-saving energy-intensive machinery (Reganold *et al.* 1990). This system is today known as conventional farming. While this system initially contributed to the preservation of the natural resource base and biodiversity through replacement of nutrients removed in harvested crops and erosion, increased biomass production, adoption of high yield varieties and use of otherwise non-productive land (Byrnes and Bumb 1998), it has now led to a decline in the yield potential of agricultural soils as the biological processes that maintained their health and quality became overtaxed (Welbaum *et al.* 2004). These authors note that during *the 1970s, 1980s, and 1990s the scientific literature became filled with reports of 'soil fatigue', 'soil degradation' and 'soil loss'*.

As a result of growing concern worldwide, many farmers are seeking alternative practices that would make agriculture more sustainable. There are numerous names given to variants of non-conventional agriculture which come under the guise of sustainable agriculture, including organic, alternative, regenerative, ecological or low-input, however Reganold *et al.* (1990) points out that just because a farm is organic or alternative does not mean that it is sustainable. To be truly sustainable farmers need to understand the complex interactions within agricultural ecologies and develop a systems approach. In moving away from conventional agriculture with its heavy reliance on pesticides and fertilisers, farmers often experience decreased yields, severe weed problems, increased pest pressure and reduced soil fertility. However, by careful management and a slow change in practices, the long term benefits are likely to be substantial. Reganold *et al.* (1991) reports that reduced yields during a transition period are often counterbalanced by a reduction in input costs.

One important misconception that needs to be addressed is that sustainable agriculture does not represent a return to old farming methods, but combines traditional methods focussing on soil conservation with modern technology. There is a continuum between conventional farming, relying predominantly on manufactured chemicals, and systems with a total reliance on natural additives. There are advantages and disadvantages to any system, and the key will be to achieve a balance to enable the production of high quality crops without degrading the environment.

The soil environment

Soil is defined as the top layer of the earth's crust. It is an extremely complex medium formed by mineral particles, organic matter, water, air and living organisms. While an obvious function of soil is its

physical role in supporting plants, it plays a major role in underpinning all the processes that support human societies and economies (Cork *et al.* 2012). Because the disintegration of parent rock to form a functional soil (pedogenisis) can take hundreds to thousands of years, soil is regarded as a non-renewable resource.

For the production of agricultural crops, soil serves as a reservoir of plant nutrients and, providing factors such as temperature, light and moisture are not limiting, normally supplies a substantial amount of the nutrient requirements (Ludwick *et al.* 1995a). Soil also functions as a habitat and genetic reserve for numerous organisms (Liebig 2001). It has also been described as an environmental filter that cleans air and water, acting as a major sink for unwanted or waste gas and materials, a detoxifying agent for the decomposition of organic waste and a means for recycling of the nutrients needed at all levels of life (Wallace and Terry, 1998). In addition, soil buffers the influx of rain to control the flow of water to rivers and streams, also affecting the likelihood of flood events and drought (Hillel, 1991).

The overall condition of soils is influenced by the interaction of soil physics and chemistry with soil biodiversity. Soil properties vary depending on where and how the soil has been formed, and changes in soil properties can be brought about through agricultural activity (Cotching 2009). When discussing soil quality, there are two components that need to be considered, the inherent component, relating to the natural characteristics of the soil (such as texture) which are the result of soil-forming factors, and the dynamic soil quality component which is readily affected by management practices and includes characteristics such as compaction, biological functioning and root proliferation.

The terms quality and health are often used interchangeably in relation to soils. Cotching (2009) reminds us that poor soils can be in good health, just as good soils can be in a degraded state.

More recently the term resilience has been introduced into soil science to address sustainability of the soil resource and to combat soil degradation. According to Seybold et al. (1999), soil resilience is related to soil quality in terms of the recovery of soil functions, while soil resistance relates to the degree of change in soil functions following a disturbance. Thus, during a disturbance, soil quality becomes a function of soil resistance, and after a disturbance soil quality becomes a function of soil resilience.

Cork et al. (2012) describe the multiple factors that influence soil resistance and resilience, including soil properties such as organic matter, aggregation, the quantity and quality of carbon inputs, clay content and soil pH. They also list terrain characteristics, landscape position, parent material, climate, water balance, vegetation and soil biodiversity as important. The 2011 State of the Environment Report (Australian State of the Environment Committee 2011) included the following features of good-quality and resilient land:

- leakage of nutrients is low
- biological production is high relative to the potential limits set by climate
- levels of biodiversity are relatively high
- rainfall is efficiently captured and held within the root zone
- rates of soil erosion and deposition are low, with only small quantities transferred out of the system
- contaminants are not introduced into the landscape, and existing contaminants are not concentrated to levels that cause harm
- systems for producing food and fibre for human consumption do not rely on large net inputs of energy.

Soil health

Cotching (2009) defined soil health as the capacity of a soil to sustain biological productivity, maintain environmental health, and promote plant, animal and human health, or put more simply, the capacity of the soil for self renewal. The concept of soil health is not new, according to Liebig (2001) Greek and Roman philosophers were aware of the importance of soil health to agricultural prosperity over 2000 years ago. However our awareness of the soil ecosystem has increased dramatically over the last few decades and we now understand that the soil ecosystem is an interdependent life-support system. A healthy soil contains adequate levels of all nutrients, small and large pore spaces for air and water, good levels of organic matter and a thriving population of micro-organisms. Ultimately, the health of a soil can only be identified by how the soil performs all of its functions (Cotching 2009). Liebig (2001) has suggested that management strategies that optimise multiple soil functions have a greater potential for improving soil health over strategies focussing on a single function.

Measurement of soil health is based on a range of soil properties, and no single soil property can be used to define the health of a soil. Some of the key indicators used to determine soil health include soil carbon, pH and structure of the topsoil. Liebig (2001) emphasises that, as well as being a reflection of producer success and natural resource conservation, indicators should be easy to measure and simple to interpret. Examples of indicators meeting his criteria include: crop yield, profit, risk of crop failure, soil organic matter content, soil depth, percent soil cover, leachable salts and energy use.

Soil physical properties

Soil physical properties include soil texture, structure and porosity, bulk density, and water holding capacity. Physical properties influence air-water relations in the soil (Fageria 2012), and can be improved by the addition of organic matter.

Soil texture

Soil texture refers to the inorganic solid material of the soil mass, and defines the relative amounts of fine and coarse material present. There are three separate components that make soil texture: sand (0.02-2mm diameter), silt (0.002-0.02mm), and clay (≤0.002mm). Soil organic matter (SOM) content is related to its clay content, tending to increase as the clay content increases; in predominantly inorganic soils, a major part of the organic matter is found in the clay and silt fractions. Fageria (2012) reports that texture has an effect on aggregation, and is one of the relevant attributes in resistance to compaction. Zhang *et al.* (1997) report that as SOM increases, the susceptibility to compaction decreases.

Soil structure

The aggregation of soil particles is one of the most important physical properties of soils as it is essential in maintaining good soil structure for plant growth (Ibrahim and Shindo 1999). Good soil structure allows greater levels of air exchange and water infiltration, which encourages root growth. Increased water infiltration also results in less run-off during irrigation or rain, while larger particle sizes make soils more resistant to wind erosion. Soil structure also determines the workability of the soil. A poorly aggregated soil is less functional at different levels of wetting, as it can be massive when dry and a slurry when wet. Poorly bound aggregates are more likely to disintegrate into smaller crumbs or individual particles when exposed to a mechanical force such as soil tilling, freeze/thawing and the force of falling raindrops.

Soil aggregation is part of an organised hierarchy with different factors responsible for binding the sub-units of soil aggregates at each level (Brady and Weil, 1999). Aggregates are naturally formed assemblages of sand, silt, clay, organic matter, root hairs, microorganisms and their mucilaginous secretions, extracellular polysaccharides, and fungal hyphae as well as the resulting pores (Fortuna 2012), and can be broadly classified into micro (<0.25mm) and macro-aggregates (>0.25mm). Tisdall and Oades (1982) put forward the theory that a strong correlation existed between overall stability and organic matter content, with organic matter increasing proportionally with a rise in aggregate stability, and, conversely, soil organic matter decreasing with a corresponding deterioration in soil structure and aggregate stability. The improvement in soil aggregate size and reduction in bulk density following addition of organic matter to the soil observed by Bound and Wilks (2003) supports this theory.

Brady and Weil (1999) described two factors or processes as contributing to the formation of soil aggregates; biological and physical-chemical (abiotic) processes. The physical-chemical processes of aggregation formation tended to be the most important at the smaller end of the scale, being mainly associated with clays and consequently finer texture soils. In this case divalent and polyvalent ions are important in binding small clay particles together with electrostatic forces. Where monovalent ions are in excess in soil there is a distinct lack of this type of soil binding. For example, soils with excessive amounts of monovalent sodium ions (Na^+), described as sodic soils, have a tendency to be dispersive. In extreme cases sodic soils can be highly erosive in the presence of water. Tunnel erosion is a severe symptom of sodic soils. Biological processes of aggregate formation tend to be most important at the larger scale, being mainly associated with sandy soils with little clay content (Brady and Weil, 1999).

Haynes and Swift (1990) describe the biological formation of stable soil aggregates as occurring in two phases. The first phase being the aggregation phase involving production of exocellular microbial polysaccharide mucigels by microorganisms. The second phase involves stabilising of the aggregates due to the buildup of soil humic material over time. It was further suggested that a pool of carbohydrate from organic matter is involved in the formation of stable aggregates. This expanded on comments by

Oades (1984) that the degree of macro-aggregation was provided by hyphae through the physical enmeshment of soil particles.

In summary, soil aggregation is dependent on divalent ions, fungal hyphae, mucigels produced by soil biota and most importantly organic matter to physically bind a hierarchy of particles together.

Soil porosity

Soil porosity refers to the space between soil particles, which consists of various amounts of water and air. Porosity depends on both soil texture and structure. For example, a fine soil has smaller but more numerous pores than a coarse soil. A coarse soil has bigger particles than a fine soil, but it has less porosity, or overall pore space. Water can be held tighter in small pores than in large ones, so fine soils can hold more water than coarse soils.

Water-holding capacity

Water holding capacity of soil is the ability of a particular type of soil to hold water against the force of gravity. Available water is the difference between field capacity, which is the maximum amount of water the soil can hold, and wilting point where the plant can no longer extract water from the soil. Soil texture and structure greatly influence water infiltration, permeability, and water-holding capacity. Soils with smaller particles (silt and clay) have a larger surface area than those with larger sand particles, and a large surface area allows a soil to hold more water. In other words, a soil with a high percentage of silt and clay particles, which describes fine soil, has a higher water-holding capacity. Organic matter percentage also influences water-holding capacity.

Bulk density

Soil bulk density is defined as the mass of dry soil per unit bulk volume and is often used as a simple index for assessing compaction and productivity. It is significantly influenced by SOM, with higher organic matter levels resulting in lower bulk density. According to Fageria (2012), soil bulk density significantly influences nutrient uptake through its effect on physical, chemical and biological properties of soil-plant systems.

Soil organic matter

Soil organic matter is a major source of nutrients such as phosphorus, sulphur and nitrogen, and the main food that supplies carbon and energy to soil organisms. It has been described by Brady and Weil (1999) as consisting of a wide range of organic substances (carbon containing molecules). Organic substances have been categorised as polysaccharides (cellulose, hemicellulose, sugars, starches, and pectin substances), lignins and proteins (Ludwick *et al.* 1995b). The breakdown of plant, animal and microorganism residues provide material for the synthesis of new compounds by different microorganisms.

Organic matter is a vital component of a healthy soil, and the amount of organic matter in a soil is determined by the balance between accumulation and loss. Without adequate plant materials being returned to the soil or without replacement with soil amendments, SOM continuously degrades in the soil (Sainju and Singh 1997). Organic matter has a major influence on physical, chemical and biological properties of soil (Table 1) and is also essential for a healthy, diverse soil fauna, playing a pivotal role in many soil processes crucial to productive and sustainable agriculture (Masciandaro *et al* 1997; Aslam *et al* 1999; Cotching 2009).

Contributions to the soil-plant system from the addition of composted organic matter include improved soil structure (through aggregation of clay particles), increased microbial activity (enhanced nutrient cycling and weathering of soil materials), improved soil stability and water infiltration and provision to plants of a larger pool of nutrients from which to draw (Stratton and Rechcigl 1998). According to Bot and Benites (2005), while the rate of decomposition and accumulation of SOM is determined by soil properties such as texture, pH, temperature, moisture, aeration, clay mineralogy and soil biological activities, SOM in turn can modify many of these same soil properties. In soils with low clay content, as is the case with many orchard topsoils, organic matter plays the major role in stabilisation of structure and nutrient and water retention.

Table 1. Functions of soil organic matter (adapted from Cotching (2009))

Physical functions	Chemical functions	Biological functions
- bind soil particles together in stable aggregates - influence water holding and aeration - greater porosity - reduced bulk density - improved water infiltration	- major source of cation exchange capacity (CEC) - source of pH buffering - binding site for heavy metals and pesticides	- food source for microbes, meso-and macrofauna - major reservoir of plant nutrients

Soil organic matter is not homogeneous in its composition but exists as a mixture of plant and animal litter in various stages of decomposition, microbial biomass and its detritus, and charcoal (Skjemstad *et al.* 1998). In his description of SOM, Cotching (2009) divides non-living organic matter into four distinct pools:

(i) organic matter dissolved in soil water,

(ii) particulate organic matter that is partially decomposed but has identifiable cell structure,

(iii) humus comprising organic molecules of identifiable structure such as proteins and cellulose, and molecules with no identifiable structure but with reactive regions that allow the molecule to bond with other mineral and organic soil components (humic and fulvic acids and humin), and

(iv) inert organic matter or charcoal derived from the burning of plants.

Humus is normally the largest pool and can comprise over 50% of the total SOM, while particulate organic matter can constitute up to 25%. Inert organic matter can be up to 10% of the total SOM. The turnover of non-living SOM is influenced by:

- environmental factors such as rainfall, temperature and biomass input;
- edaphic factors such as associations with the mineral fraction, soil pH and redox potential; and
- management practices through the impacts of tillage, weed and trash management, rotation and fertilisers.

Function of humus

Humus is a black or brown decay resistant complex organic compound derived from decaying organic matter that accumulates in soil. It is formed by humic substances, including humic acids, fulvic acids, hymatomelanic acids and humins (Bot and Benites 2005). Along with colloidal clay particles, humus plays a significant role in the nutrient holding capacity of the soil. Humic substances are able to interact with metal ions, oxides, hydroxides, mineral and organic compounds, including toxic pollutants, to form water-soluble and water-insoluble complexes. The surface of humus has negatively charged sites which are able to loosely bind and temporarily store cations (positively charged ions) (Brady and Weil 1999). This ability to bind exchangeable cations is known as the Cation Exchange Capacity (CEC). CEC is important in plant nutrition and soil fertility as it is considered an indicator of the nutrient holding capacity of the soil (Ludwick *et al.* 1995b).

Humus is an important buffer, reducing fluctuations in soil acidity and nutrient availability. Compared with simple organic molecules, humic substances are very complex and large, with high molecular weights. Because of the complex structure of humic substances, humus cannot be used by many micro-organisms as an energy source and remains in the soil for a relatively long time. Fulvic acids are produced in the earlier stages of humus formation and have smaller molecules than humic acids. The relative amounts of humic and fulvic acids in soils vary with soil type and management practices. The humus of forest soils is characterized by a high content of fulvic acids, while the humus of agricultural and grassland areas contains more humic acids (Bot and Benites 2005).

The process of decomposition

Decomposition of organic matter is a natural biological process. It involves the physical breakdown and biochemical transformation of complex organic molecules into simpler organic and inorganic molecules. The speed of decomposition is determined by three major factors: soil organisms, the physical

environment and the quality of the organic matter (Brussaard, 1994, cited in Bot and Benites 2005). In the decomposition process, different products are released: carbon dioxide (CO_2), energy, water, plant nutrients and resynthesized organic carbon compounds. The simpler organic molecules such as sugars, amino acids, and cellulose are readily consumed by many organisms, hence do not remain in the soil for long, chemicals such as resins and waxes are more difficult for soil organisms to break down.

Carbon cycling

Organic matter has also been considered to play a critical role in the global carbon balance. Tate (1987) has suggested that under favourable conditions, the atmospheric carbon dioxide that has been sequestered by plants into abundant tissues would eventually be incorporated back into the soil organic matter and subsequently released back into the atmosphere through microbial respiration (Brady and Weil 1999). Carbon cycling (Figure 1) is the continuous transformation of organic and inorganic carbon compounds by plants and soil biota between the soil, plants and the atmosphere (Bot and Benites 2005). The continual addition of decaying plant residues to the soil surface, the breakdown of soil organic matter, and root growth and decay contribute to the biological activity and the carbon cycling process.

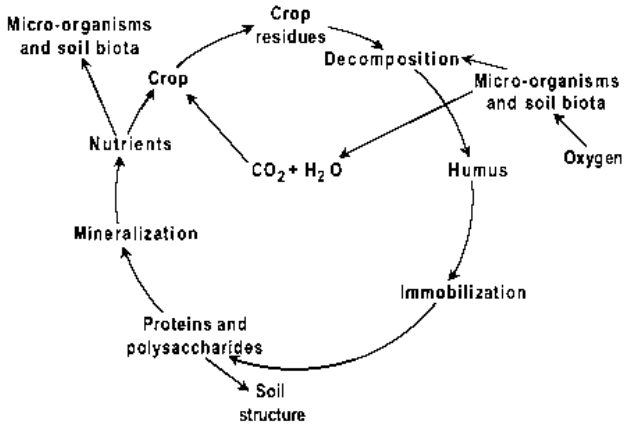


Figure 1: The carbon cycling process in soils (source Bot and Benites 2005).

Non-humic substances

Non-humic organic molecules, such as proteins, amino acids, sugars, and starches, are released directly from cells of fresh residues (Bot and Benites 2005). This is the active (easily decomposed) fraction of SOM and is the main food supply for various organisms in the soil. It is influenced strongly by weather conditions, moisture status of the soil, growth stage of the vegetation, addition of organic residues, and cultural practices, such as tillage.

Carbohydrates occur in the soil in three main forms: free sugars in the soil solution, cellulose and hemicellulose; complex polysaccharides; and polymeric molecules of various sizes and shapes that are attached strongly to clay colloids and humic substances (Stevenson 1994, cited in Bot and Benites 2005). The simple sugars, cellulose and hemicellulose are easily broken down by micro-organisms, and may constitute 5-25 % of the organic matter in most soils. Polysaccharides (long-chain sugar molecules) promote better soil structure through their ability to bind inorganic soil particles into stable aggregates. Other soil properties affected by polysaccharides include CEC, anion retention and biological activity (Bot and Benites 2005).

Nitrogen mineralisation

The biological oxidation of relatively immobile ammonium (NH_4^+) or ammonia (NH_3) to highly mobile nitrate (NO_3^-) is known as nitrification. This is a two step process in soils in which ammonium or ammonia is first converted to nitrite (NO_2^-) and then to nitrate (NO_3^-). Two groups of obligate autotrophic bacteria are involved – *nitrosomonas* are responsible for the first conversion to nitrite, and *nitrobacter* convert nitrite to nitrate (Sahrawat 2008). Denitrification is the reduction of N oxides (nitrate and nitrite), and is one of the major mechanisms for N loss from the soil (Fageria 2012). Soil organic matter, soil pH, temperature, nitrate concentration, aeration and water status control denitrification rates in soils. Both nitrification and denitrification produce nitrous oxide (N_2O).

By-products of the metabolic oxidation or reduction of C and N compounds include greenhouse gases

(GHG) such as carbon dioxide (CO_2), methane (CH_4) and N_2O (Fortuna 2012).

Phosphorous mineralisation and solubilisation

The efficiency of P use by plants from both soil and fertiliser sources is often poor, even in soils with relatively high amounts of total P. Phosphorous is a relatively immobile elements in both soil and plants compared to other macronutrients; plants acquire phosphorous from soil solution as phosphate anion (HPO_4^{2-} and $H_2PO_4^-$). Soil P dynamics is characterised by physicochemical (sorption-desorption) and biological (immobilisation-mineralisation) processes (Khan *et al.* 2009). Large amounts of P applied as fertiliser enters into the immobile pools through a precipitation reaction with highly reactive Al^{3+} and Fe^{3+} ions in acidic, and Ca^{2+} ions in calcareous or normal soils (Gyaneshwar *et al.* 2002). Soil microorganisms play a key role in soil P dynamics and subsequent availability of phosphate to plants (Richardson 2001).

Soil biota

There is a diverse array of organisms inhabiting the soil, ranging in size from microscopic to larger organisms such as earthworms. Soil biota can be divided into flora (plants) and fauna (animals). Plant roots and macro-algae comprise the macroflora, while soil microflora consist of bacteria, actinomycetes, fungi and algae. Bacteria take part in some of the most important transformations in soils including weathering of rocks and minerals, breakdown of organic matter, and many aspects of nutrient cycling. Fungi are important in the decomposition of organic matter and also play an important part in stabilising soil aggregates. Mycorrhizal fungi play a major part in securing nutrients for plant production and many plants are dependent on such relationships.

Soil fauna is classified according to size, although there is some variation between authors as to the upper and lower limits of each size category, macrofauna is generally defined as being larger than 2mm in size; mesofauna are 0.1 to 2mm in size, and microfauna less than 100µm (0.1 mm) in size.

Soil biota play a key role in cycling of organic nutrients for plant growth and some beneficial soil microbes can compete with disease causing agents, thus reducing the incidence of disease in plants. Table 2 lists soil dwelling organisms that may be considered to be beneficial to plant production.

Table 2. Soil biota (adapted from Peterson and Luxton (1982))

Taxonomic group	Common name	Food source
Microflora (< 5µm in size)	Bacteria Fungi Actinomycetes Algae	
Microfauna (0.1 – 2.0mm in size***)***		
Protozoa		Bacteria, fungi, algae, detritus, microfauna
Nematoda	Nematodes	Plant juices, fungal mycelia, bacteria, algae, micro- and mesofauna
Mesofauna (0.1 – 2.0mm in size***)***		
Oligochaeta - Enchytraidae	Potworms	Dead plant material, fungal mycelia
Collembola	Springtails	Dead plant material, bacteria, fungi
Acari	Mites	Dead plant material, microflora, miro- & mesofauna
Protura	Coneheads	Detritus, microflora, mycorrhiza
Diplura	Two-tailed bristletails	Detritus, microflora, mesofauna
Pauropoda	Multipedes	Detritus, microflora
Symphyla	Garden centipedes	Detritus, microflora, plant roots
Macrofauna (> 2mm in size)		
Oligochaeta - Lumbricidae - Megascolecidae - Acanthodrilidae	Earthworms	Dead plant material, microflora
Crustacea - Isopoda - Amphipoda	Slaters Landhoppers	Dead plant material, microflora
Diplopoda)	Millipedes	Dead plant material, microflora
Diptera (larvae	Flies	Dead plant material, microflora, plant roots, meso- & macrofauna
Isoptera	Termites	Living plant tissue, dead leaves, dead wood, fungi
Trichoptera (larvae)	Caddis fly	Dead plant material, plant roots
Lepidoptera (larvae)	Moths / butterflies	Dead plant material, plant roots
Coleoptera	Beetles / weevils	Dead organic material, microflora, roots, macro- & mesofauna
Chilopoda	Centipedes	Macro- & mesofauna

Arachnomorpha - Pseudoscorpiones	False scorpions	
- Opiliones	Harvestmen	Macro- & mesofauna
- Aranae	Spiders	
Formicoidea	Ants	Living plants, fungi, macro- & mesofauna
Gastropoda	Snails / slugs	Living plants, dead plant material, fungi

Soil fauna

Earthworms are an important component of the soil biota. Their activities have been noted to greatly enhance soil fertility and productivity by altering both the physical and chemical conditions in the soil and increasing the availability of mineral nutrients to plants (Brady and Weil, 1999). Hartley and Rahman (1994) suggest that a good earthworm population is between 100-400 earthworms per m^2 for cultivated land and between 400-1000 /m^2 for permanent pasture. Earthworms are able to transport and mix organic, mineral and microbial soil components to deeper soil horizons. Pettersson and Wistinghausen (1979) have suggested that the prevalence of earthworms within compost-amended soils appeared to be representative of an improvement in the living conditions for soil organisms, which acted to open up the soil. Based upon this assertion, it has been further stated that organic fertilisers, via earthworms, indirectly increased the area penetrable by roots, subsequently improving the conditions for a humus increase in the subsoils. In contrast, however, inorganic soil amendments appeared to restrict activity due to subsoils being more compacted (Pettersson and Wistinghausen, 1979).

Brady and Weil (1999) have suggested that earthworm activity enhances soil fertility and productivity by altering the physical and chemical conditions in the soil and increasing the availability of mineral nutrients to plants. Bound and Wilks (2003) found that the addition of any organic material in vegetable cropping soils increased the population of earthworms. Pérès *et al.* (1998) also found that organic matter quantitatively increased the abundance and biomass of the earthworm community in French vineyards.

Mesofauna play a role in nutrient cycling by shredding materials into smaller pieces with higher surface area, thus providing greater access for microorganisms that recycle the majority of carbon (Fortuna 2012). Soil invertebrate biomass and diversity, particularly of mites, is often positively correlated with soil health (Coleman *et al*. 2004; Axelsen and Kristensen 2000) and crop performance (Baker and Crisp 2009) and can therefore be used as indicators of soil health.

Soil microbial biomass

Soil microbial biomass is the living component of soil organic matter, excluding soil animals and plant roots (Dalal 1998). It comprises less than 5% of organic matter in soil but according to Dalal performs at least three critical functions: acting as a labile source; an immediate sink of carbon, nitrogen, phosphorous and sulphur; and an agent of nutrient transformation and pesticide degradation. Dalal also states that microorganisms form symbiotic associations with roots, act as biological agents against plant pathogens, contribute towards soil aggregation, and participate in soil formation. Soil microorganisms rely on inputs of fresh, labile substrate such as plant and animal residues and root exudates for growth and reproduction. However these substrates are not always abundant, hence the soil microbial life-cycle is characterised by intermittent periods of growth and dormancy depending on the availability of readily degradable fresh substrates (Mondini *et al.* 2006). Following a study aimed at clarifying the mechanisms involved in the transition from dormancy to activity, Mondini *et al.* reported that trace amounts (micro-grams) of different simple and complex substrates (glutamic acid, amino acids mix, glucose, protein hydrolysates, carbohydrates, compost extracts) caused an immediate and significant increase in soil microbial activity, indicating that soil microorganisms have evolved specific metabolic and physiological strategies to equip them for survival and growth in the soil.

Microbial biomass is central to organic matter cycling, and hence, carbon sequestration by soil. The higher the level of microbial activity the higher the rate of mineralisation of organic matter (Pettersson and Wistinghausen 1979). Sparrow (pers. communication) described soil microbial biomass as the "eye of the needle" through which all decomposing organic matter must pass before being transformed into plant available nutrients and soil humus. Thus it can be considered a measure of the organic matter processing capacity or turnover rate of a soil, the flux of which has been reported as being affected by the higher levels of organic C in the larger pools of microbial biomass (Cooper and Warman 1997). Furthermore, microbial activities within the residues have been suggested to mimic slow release type fertiliser with minimal leaching of the plant available nutrients into the groundwater (Muchovej and

Pacovsky 1997).

The importance of soil microbes in a healthy system is outlined by Kausadikar (2010) who summarises the following roles of soil microbes:

- conversion of complex organic nutrients into simpler inorganic forms (mineralisation) which are readily absorbed by the plant for growth;
- production of a variety of substances like indole acetic acid (IAA), gibberellins, antibiotics etc. which directly or indirectly promote plant growth;
- synthesis of polysaccharides, lignins and gums which have an important role in cementing / binding of soil particles to produce stable aggregates;
- degradation of organic matter / substances - including cellulose, lignins and proteins (in plant cell walls), glycogen (animal tissues), proteins and fats (plants, animals). Cellulose is degraded by bacteria and fungi. Lignins and proteins are partially digested by fungi, protozoa and nematodes. Proteins are degraded to individual amino acids mainly by fungi;
- humus formation;
- biological nitrogen fixation - conversion of atmospheric nitrogen into ammonia and nitrate.

Comparative 'benchmark' references of microbial biomass as critical or threshold and optimum levels do not currently exist. All currently used soil microbial biomass methods have some limitations, and it is difficult to compare soil microbial biomass values which have often been obtained by different methods in different laboratories. In a study by Cooper and Warman (1997), conducted to assess microbial activity within both composted and fertilised plots, dehydrogenase enzyme activity (DHA) was implicated as being one of the better indicators of microbial activity, due to its occurrence only within living cells.

Soil biology and mineralisation

Mineralisation is the conversion by soil micro-organisms of organically bound elements such as nitrogen, phosphorous, sulphur into inorganic mineral forms (in the case of N into ammonium (NH_4^+) and nitrate (NO_3^-)). Studies have shown that only 1.5 - 3% of organic N mineralises annually (Roy *et al.* 2006). Immobilisation is the opposite of mineralisation (mobilisation) where (using N as an example) inorganic N is used by the micro-organisms in decomposing organic residues in the soil. As the microbes die the organic N may be released as either ammonium or nitrate or be incorporated in the humus complex. Both reactions occur simultaneously, the net balance of available mineral nitrogen depending on the carbon/nitrogen ratio of the decomposing organic residues (Brady and Weil 1999). Hence by breaking down carbon structures and rebuilding new ones or storing the C into their own biomass, soil biota plays a major role in the ability of a soil to provide the crop with sufficient nutrients through nutrient cycling processes (Bot and Benites 2005).

Nutrient mobilisation increases with temperature. According to Roy *et al.* (2006), a temperature increase of 10ºC doubles the rate of chemical reactions involved in nutrient mineralisation. Hence the rate of mineralisation in tropical climates is 4-6 times higher than in temperate climates.

Working with living mulches, Masciandaro *et al.* (1997) reported that living mulches stimulated soil metabolism through the bioactivity of micro-organisms, worms and plant roots. Carbon and nitrogen metabolism was accelerated by living mulch treatments, and occurred through enzymatic processes. Pettersson and Wistinghausen (1979) have also stated that, although organic matter levels can be equal to or higher in inorganic amended soils than in organic (compost) amended soils, the turnover rate or mineralisation is often been much lower in inorganic soil. Subsequently, the higher rate of mineralisation of organic matter in compost-amended soils has been attributed to the level of microbial activity in organic amended soils.

N-fixing bacteria

The major conversion of atmospheric nitrogen (N_2) into ammonia, and subsequently into proteins, is achieved by prokaryotes (bacteria) in the process called nitrogen fixation (or dinitrogen fixation). Two groups of nitrogen fixers are recognised:

1. free-living bacteria, including the cyanobacteria (blue-green algae), *Azotobacter*, *Nitrosomas*, and *Nitrobacter*; and
2. mutualistic (symbiotic) bacteria such as *Rhizobium*, associated with legumes, and *Spirillum lipoferum*, associated with cereal grasses (Leu 2012; Wagner 2012).

The symbiotic nitrogen-fixing bacteria attach and colonise host roots at epidermal cell junctions, root hairs, cap cells and sites of emerging lateral roots (McNear 2013), where they multiply and stimulate formation of root nodules - enlargements of plant cells and bacteria in intimate association. Within the nodules the bacteria convert free nitrogen to nitrates, which the host plant utilizes for its development.

P-solubilising microorganisms

Up to 40% of the culturable population of soil bacteria and fungi is able to solubilize various forms of precipitated P, including *Bacillus*, *Pseudomonas*, *Penicullium* and *Aspergillus* spp. (Richardson 2001). The mechanisms involved in microbial solubilisation of inorganic phosphate include acidification and chelation by organic acids produced by the microorganisms, releasing P (He *et al.* 2002).

Richardson and Simpson (2011) summarise the mechanisms by which microorganisms enhance the capacity of plants to acquire P from soil as follows:

1. increased root growth through either an extension of existing root systems (ie. mycorrhizal associations) or by hormonal stimulation of root growth, branching or root hair development (phytostimulation through production of hormones and enzymes)
2. alteration of sorption equilibria that increases the net transfer of phosphate ions into soil solution or facilitate the mobility of organic P through microbial turnover
3. through induction of metabolic processes that are effective in directly solubilising and mineralising P.

Mycorrhizal fungi

Mycorrhizal fungi form a symbiotic relationship that aids the plant through an increase in effective root area, thus providing access to an increased supply of nutrients in the soil. There are two distinct types of mycorrhizal fungi:

1. ectomycorrhiza (EM) where the fungus forms a dense covering of hyphae over the root tip from which hyphae grow into the intercellular spaces forming a net (Hartig net) of hyphae around the root cortex cells, but do not penetrate the cell walls; and
2. endomycorrhiza in which the fungal hyphae grow into the root cortex, entering the cells to form a fan-like highly branched structure known as an arbuscule. This gives rise to the name arbuscular mycorrhiza (AM). The endomycorrhiza are obligate symbionts, hence cannot be grown independent of their plant hosts

Both endo- and ectomycorriza can demand up to 20-40% of the photosynthically fixed carbon produced by the plant (McNear 2013). The AM fungi are the most abundant of all mycorrhizal associations, forming associations with about 90% of terrestrial plant species (Smith and Smith 2012). AM fungi play a significant role in plant P uptake, regardless of whether the plant responds positively to colonisation in terms of growth or P content; and also provide other benefits including avoidance of toxins, and increased plant tolerance to drought and to some diseases (Smith and Smith 2012).

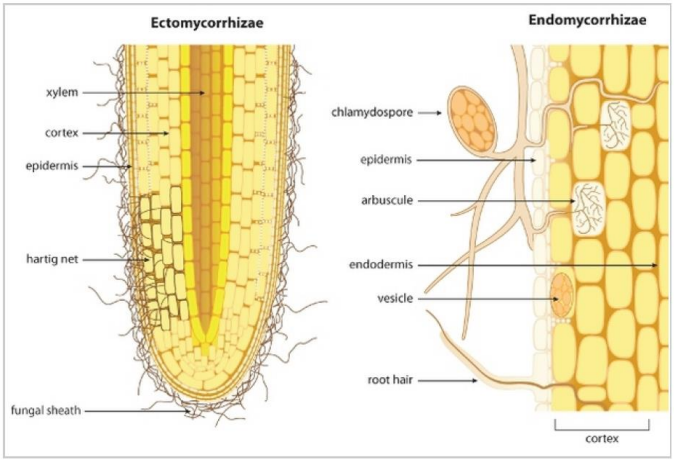


Figure 2: Schematic showing the difference between ectomycorrhizae and endomycorrhizae colonization of plant roots. Source: McNear 2013

Soil fertility

According to Voorhees (1916) soil fertility involves many conditions, all of which exert varying degrees of influence. His primary condition was that a soil should contain those elements found in the plant; however even with these elements being present in the soil, without adequate water and suitable soil/air temperatures and physical soil characteristics, crops cannot be grown successfully. Voorhees suggests that the benefits of addition of organic matter in the form of farmyard manures and green-manures are the result of indirect action resulting in an increase in soil water-holding capacity, and improved tilth or physical character. His implication that nutrients are not readily available for plant uptake in manures compared with artificial fertilisers, and an absence of discussion on the role of soil microbiology indicates a lack of understanding of the role of soil microbes in nutrient cycling.

The assertion by Francis (2005) that fertile soils normally hold all the nutrition required for healthy crop growth, but rely on the right combination and volume of microbial populations to digest and transform these minerals to compounds readily available for plant uptake is in agreement with the statement by Krasil'nikov in 1958 (cited in Anderson 1992) that the degree of soil fertility is determined by the intensity of the life processes of the microbial population. In light of the discussion in previous sections of this review, this definition is a logical one, and goes a long way towards explaining why soils depleted of organic matter and microorganisms require increasing inputs of chemical fertilisers to enable continued crop production.

Plant nutrients and uptake

Chemical elements (nutrients) required for healthy plant growth are divided into non-mineral and mineral. The non-mineral nutrients are carbon (C), hydrogen (H) and oxygen (O) and these are obtained from the atmosphere and water. The mineral nutrients are obtained from the soil and are divided into macro- and micronutrients; micronutrients are just as important for plant growth as macronutrients, but are required in smaller quantities. Optimising plant growth and fruit quality involves balancing all the macro and micro nutrients (Grobe 1997). When one element is deficient, its absence affects uptake and utilisation of other elements. Liebig's Law of the Minimum - *that growth is controlled not by the total amount of resources available, but by the scarcest resource (limiting factor)* - was postulated in terms of nutrient availability; however it applies equally to all resources required for plant growth. Albrecht (cited in Leu 2012) strongly supported the concept of the soil as a living body and was the first soil scientist to show the importance of having all the soil minerals in a balanced ratio along with adequate levels of organic matter.

The ultimate source of all soil minerals, with the exception of nitrogen, is the parent rock from which the soil is derived. Soils derived from mineral-poor rocks will have lower nutrient (mineral) reserves as will soils where considerable leaching has occurred, such as older soils or soils in higher rainfall climates. Whatever the nutrient content of a soil, the bulk of it is not immediately accessible to plants as large quantities of nutrients are locked up by complex chemical and physical interactions with minute soil particles (colloids). Nutrients are present in the soil in three states: unavailable, exchangeable and water soluble. Plant nutrient uptake is from the soil solution, but only a small portion of the available nutrients move freely in the soil solution; most are loosely bound by negatively charged clay colloids, layer silicates and organic matter in exchangeable form. Metal hydroxides present in soil and some humic substances are positively charged and bind anions such as phosphate (Roy *et al.* 2006). This mechanism acts as a storehouse for nutrient cations (positive charge) and anions (negative charge). Cations such as Ca^{2+}, Mg^{2+} and K^{+} are adsorbed to the negatively charged surfaces and hence are protected against leaching. Nitrogen can be taken up as either nitrate (NO_3^-) or ammonium (NH_4^+), but NO_3^- moves freely through the soil whereas NH_4^+ is held by cation exchange sites and hence is less mobile. Ions not bound can be easily leached and hence lost from the rooting zone.

The availability of nutrients in the soil is also strongly affected by soil pH (acidity/alkalinity). Soil pH is the negative logarithm of the hydrogen ion activity of a soil. Low pH (excessive acidity) reduces the availability of certain beneficial nutrients such as calcium, magnesium and phosphorous. At the same time undesirable and potentially toxic elements such as Aluminium become plant available. Similarly soils with a high pH have reduced availability for many nutrients.

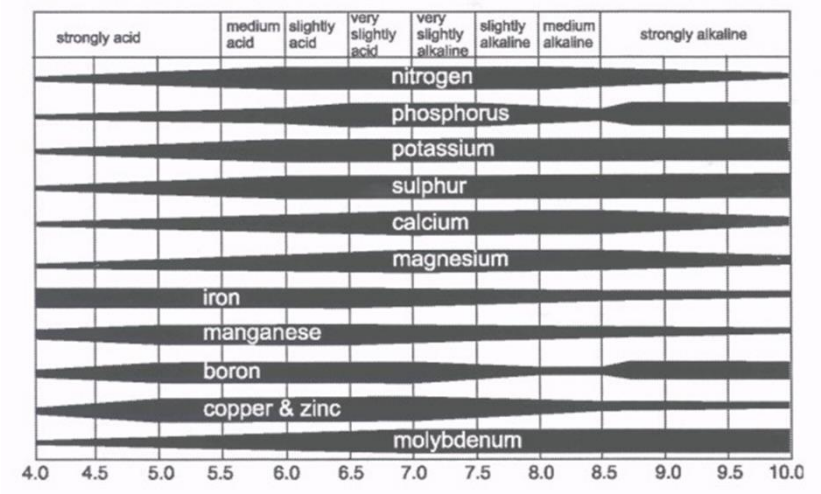


Figure 3: Effect of soil pH on nutrient availability. Source: SSD 2015

As discussed previously, the amount of organic matter and clay colloids and the type of clay determine cation exchange capacity of a soil. The higher the amount of colloidal material in the soil the greater the ability of the soil to absorb and exchange nutrients. Soils low in organic matter, and thus humus content, also have a weak anion exchange capacity, hence the reason why anions such as nitrate, sulphur and boron are readily leached (Leu 2012). By determining the available nutrient status of a soil, measures can be taken to ensure optimal plant nutrition and minimise depletion of soil fertility.

Essential nutrients

There are 16 elements considered essential for plant growth and development. Essentiality is based on criteria formulated by Arnon and Stout (1939):

1. An element is essential if, being deficient, the plant is unable to complete the vegetative or reproductive stage of its life cycle;
2. The deficiency can be prevented or corrected only by supplying the specific element causing the deficiency; and
3. That element is directly involved in the nutrition of the plant.

A fourth criterion has been added over time: that the essentiality of any element is proved in all plants tested. The essentiality of most micronutrients was established between 1922 and 1954, with nickel being added as a 17th element in 1987 (Roy *et al*. 2006). There are other elements that perform beneficial functions in plants and Subbarao *et al*. (2003) suggested the term 'functional nutrient', which they defined as *a nutrient being required for maximal biomass yield and/or is functional in a metabolic role to the extent that the critical level of an essential nutrient is reduced*. Nutrients that fit this definition include sodium, silicon, cobolt, and vanadium. It is probable that more nutrients may be added in future.

Table 3: Essential and functional nutrients for plant growth (source: Glendinning 1999; Jones and Jacobsen 2001).

Element	Role in plant	Form used by plant	Source
Carbon (C)	Constituent of carbohydrates; Necessary for photosynthesis	CO2	air
Hydrogen (H)	Maintains osmotic balance; Important in numerous biochemical reactions; Constituent of carbohydrates	H_2O (liquid) H^+	water
Oxygen (O)	Constituent of carbohydrates; Necessary for respiration	H_2O (liquid) O_2 (gas)	air/water
Nitrogen (N)	Necessary for chlorophyll synthesis; Constituent of proteins, nucleic acids	NO_3^- (nitrate) NH_4^+ (ammonium)	air/soil
Phosphorous (P)	Role in photosynthesis, respiration, energy storage and transfer, cell division, cell enlargement; Constituent of many proteins, coenzymes, nucleic acids, and metabolic substrates	$H_2PO_4^-$ HPO_2^{2-} (phosphate)	soil

Potassium (K)	Involved with photosynthesis, carbohydrate translocation, protein synthesis	K^+	soil
Calcium (Ca)	Component of cell walls; Activates several plant enzyme systems; plays a role in structure and permeability of membranes	Ca^{2+}	soil
Magnesium (Mg)	Component of chlorophyll Enzyme activator	Mg^{2+}	soil
Sulphur (S)	Necessary for chlorophyll formation; Constituent of enzymes and volatile organic compounds	SO_4^{2-} (sulphate)	soil
Boron (B)	Important in sugar translocation and carbohydrate metabolism	H_3BO_3 (boric acid) $H_2BO_3^-$ (borate)	soil
Chlorine (Cl)	Involved in energy reactions; activates enzyme systems; involved in transport of K, Ca, Mg within the plant	Cl^- (chloride)	soil
Copper (Cu)	Catalyst for respiration; component of various enzymes	Cu^{2+}	soil
Iron (Fe)	Involved with chlorophyll synthesis and in enzymes for electron transfer; acts as an oxygen carrier	Fe^{2+} (ferrous) Fe^{3+} (ferric)	soil
Manganese (Mn)	Controls several oxidation-reduction systems and photosynthesis	Mn^{2+}	soil
Molybdenum (Mo)	Involved with nitrogen fixation and transforming nitrate to ammonium	MoO_4^{2-} (molybdate)	soil
Nickel (Ni)	Necessary for proper functioning of the enzyme urease, and found to be necessary in seed germination	Ni^{2+}	soil
Zinc (Zn)	Involved with enzyme systems that regulate various metabolic activities; necessary for production of chlorophyll and carbohydrates	Zn^{2+}	soil
Silicon (Si)	Improves cell wall rigidity; Stimulates nutrient uptake and photosynthesis	$Si(OH)_2$	soil
Cobolt (Co)	Component of several enzymes and co-enzymes Used by nodulating bacteria for fixing atmospheric N in legumes	Co^{2+}	soil
Sodium (Na)	Key in maintaining turgor within the plant stem Partly able to replace K	Na^+	soil
Vanadium (V)	Enhances chlorophyll formation and iron metabolism		soil

Plant nutrient uptake

Nutrient uptake is dependent on both the availability of the nutrient in the soil and the plant's ability to absorb that nutrient (Jones and Jacobsen 2001). Nutrients are taken up in an ionic, or charged, form, hence in order to become available to plants, nutrients must be solubilised or released from mineral sources and mineralised from organic sources (Roy *et al.* 2006). Nutrients vary in their mobility, both in the plant and in the soil, and this mobility can be influenced by pH, temperature, moisture, and proportion of organic matter, layer silicates and metal hydroxides.

Organic nitrogen

According to Bot and Benites (2005), more than 90% of soil N occurs in organic forms as amino acids, nucleic acids and amino sugars. Small amounts exist in the form of amines, vitamins, pesticides and their degradation products. The rest is present as ammonium (NH_4^+) and is held by the clay minerals. Plants synthesise the amino acids they require by combining nitrates with carbohydrates produced through photosynthesis. It has been assumed that amino acid molecules were too large to be absorbed by roots, and hence the belief has been that nitrogen present in the soil as amino acids was not available to plants unless it was transformed into nitrate. But according to Leu (2012), scientists are now challenging the traditional view on organic nitrogen. He reports that researchers are finding an increasing number of crops that readily take up large amounts of amino acids from the soil organic matter.

Role of Boron and Silicon

There is anecdotal evidence to suggest that boron, silicon and calcium are important in the hierarchy of plant chemistry, and without these nutrients in readily available form, the plant is unable to optimise use of nitrogen, magnesium, phosphorous, carbon, potassium and trace elements in the metabolic pathways involved in growth, flower initiation and fruit development. Yamaguchi *et al.* (1986) discuss the cooperative role of boron and calcium in the building of the plant cell wall. Dick (2009) states that boron is required to activate silicon.

Lewin and Reimann (1969) suggest that silicon can be considered to be an essential element. Silicon has also been implicated in the water economy of plants, with a higher transpiration rate seen in silicon deficient plants. According to Marschner (2002), silicon not only contributes to cell wall rigidity and

strengthening but might also increase cell wall elasticity during extension growth. In his review, Epstein (1994) reports ample evidence that when readily available to plants, silicon plays a large role in growth, mineral nutrition, mechanical strength, and resistance to fungal diseases, herbivory, and adverse chemical conditions of the growing medium. Husby (1998) reported that silicon has been shown to ameliorate abiotic stresses, and also concluded that it has the potential to significantly decrease the susceptibility of plants to disease. Julien (2000) states silicon affects the absorption and translocation of several macro- and micronutrients. Fruit firmness in both strawberry and plum has been shown to increase following foliar application of silicon (Grajkowski *et al.* 2006; Ochmian *et al.* 2006).

Lovel (2009) proposed a hierarchy for how elements work in living organisms, and named this the biochemical sequence. He theorises that there are eight elements (boron, silicon, calcium, nitrogen, magnesium, phosphorous, carbon and potassium) required in the soil for natural, robust plant health. The sequence of the elements is significant. The presence of boron in soil allows adequate silicon to be released from clay and primed for plant uptake (Dick 2009). Silicon plays an important role in improving sap circulation, thus facilitating the distribution of relatively immobile nutritive elements throughout the plant (Toresano-Sanchez *et al.* 2010). The postulated biochemical sequence not only applies to plant health, but also impacts on the diversity of the soil's microbial activity. Deficiency or toxicity in any one of the elements disrupts the balance and 'thins out' the interdependent web of microbial species that provide plants with nutrients in their naturally occurring states.

Lovel suggests that growers who simply use NPK fertilisers are short-circuiting the biological process where strong sap pressure (boron) leads to good nutrient transport (silicon), followed by optimal cell division and photosynthesis (calcium, nitrogen, magnesium and phosphorous). High plant energy (carbon and potassium) then enables plants to shed enough of their sap as root exudates to feed abundant microbial mineral release, nitrogen fixation and protozoal digestion around crop roots. – when soils are truly fertile, plant health is maximised and reflected in fruit quality and shelf life. While there is logic in the way that the sequence has been put together, there is no scientific proof to support its validity.

The rhizosphere

The rhizosphere is the soil zone immediately surrounding the roots, ie the plant-root interface. It is the most dynamic environment in the soil and is directly influenced by root secretions, exudates and associated soil microorganisms. Root secretions are composed of sloughed-off cells from the growing root tip and mucilage secreted by root cap and epidermal cells, as well as a range of chemical substances released by intact cortical cells and root hairs (Forbes and Watson 1992). Mucilage is a viscous, high molecular weight insoluble polysaccharide-rich material that provides protection from desiccation, and binds soil particles to form aggregates (McNear 2013). McNear describes root exudates as including the secretions that are actively released from the root (such as mucilage) and diffusates passively released due to osmotic differences between the cell and soil solution, or lysates from autolysis of epidermal and cortical cells. The organic compounds released through these processes include amino acids, proteins, organic acids, carbohydrates, sugars, vitamins, mucilage, phenolics and other secondary metabolites. Exudates vary according to the stages of plant growth (Lines-Kelly 2005) and act as messengers that stimulate biological and physical interactions between roots and soil organisms, thus modifying the biochemical and physical properties of the rhizosphere. Through the exudation of a wide variety of compounds, roots are able to regulate the soil microbial community, cope with herbivores, encourage beneficial symbioses, acquire nutrients, change the chemical and physical properties of the soil, and inhibit the growth of competing plant species (allelopathy) (Walker et al. 2003; McNear 2013). Rhizosphere microbial communities may also play a role in protecting plants from chemical injury. Anderson et al. (1995) present evidence of toxic chemical effects being abated or reversed by the presence of microorganisms in the soil.

Root exudates provide the food source for microorganisms, particularly those that form symbiotic relationships such as AMF and N-fixing bacteria. Curl (1986, cited in Anderson et al. 1995) states that micro-organisms can also stimulate exudation Protozoa and nematodes that graze on bacteria are also more abundant in the rhizosphere. Much of the nutrient cycling and disease suppression needed by plants occurs within the rhizosphere. Rhizosphere microbes also produce polysaccharides that bind soil particles, increasing the stability of soil aggregates.

Impacts of conventional farming practices in orchards

Environmental impact of artificial inputs in orchards

Chemical use in orchards has been fairly extensive since World War II. In the Huon Valley catchment in Tasmania, the intensive usage of pesticides due to orcharding has been historically documented. According to Wotherspoon *et al.* (1994), annual pesticide usage (insecticides, miticides, fungicides and herbicides) in the region has been estimated at 50 kilograms of solid and 40 litres of liquid per hectare. This has led to environmental contamination, the effects of which are only recently becoming understood.

The maintenance of a bare earth strip along the tree row using herbicides is the standard method of weed control in orchards. Herbicides are the pesticide group most utilised in any crop production system in the US (Ozores-Hampton 1998). The use of herbicide to remove vegetation from the tree line leads to a slow reduction in organic matter (OM) in the soil, and has become associated with a number of problems, including decreased populations of beneficial invertebrates, poor water infiltration and retention resulting in runoff of applied water, wastage of applied fertilisers, poor root growth resulting in sub-optimum tree growth and performance, loss in orchard productivity and an increase in herbicide resistance. Prior to the development of herbicides, composted and non-composted organic mulches were an important method of weed control (Altieri and Liebmans – cited in Ozores-Hampton 1998).

Conventional agriculture depends on large applications of artificial chemical fertilisers to sustain high yields, however it is well recognised that soil fertility can be improved by regular additions of organic matter (Handreck 1988; Hillel 1991). While chemical fertilisers played a significant role in the Green Revolution, excessive use has led to reduction in soil fertility and to environmental degradation (Gyaneshwar et al. 2002). Wotherspoon *et al.* (1994) found that each year local Huon Valley orchards used fertiliser at a rate of 500-1,000 kg/ha compared with 250 kg/ha applied to pasture or 235 kg/ha in forestry. According to Bünemann *et al.* (2006) Australian farmers used around 5.25 million t of fertiliser products in 1999, with a value of approximately AU$2 billion. Grobe (1997) reports that growers relying on NPK fertiliser in order to meet market demand for economically priced fruits and vegetables were finding that their soils were becoming depleted. Excessive fertilisation and poor soil and crop management practices have increased nitrate pollution in the ground-water (Linville and Smith 1971; Follet, cited in Sainju and Singh 1997). According to the *Huon catchment Healthy Rivers Project - Water quality assessment report* (1996) a number of tributaries are showing what the report regarded as high phosphate (up to 0.24 mg/L) and nitrate (up to 0.33 mg/L) levels.

Soil degradation problems

Many issues are associated with soil degradation, however soil fertility and soil erosion are paramount. Soil erosion (both wind and water erosion) is similarly affected by soil organic matter which is essential in maintaining soil structure and water infiltration rates. Other large scale issues that can arise from soil degradation include soil acidification, sodicity, salinity, nutrient leaching and contamination of waterways, and vegetation degradation.

Soil structure is the result of physical, chemical and biological influences operating in the soil (Masciandaro et al. 1997). Many orchards are exhibiting signs of soil degradation, usually first seen as reduced water infiltration and declining tree health and productivity. Boucher (1998) describes the problems of soil compaction in orchards in Tasmania caused by a loss of soil organic matter. Compaction decreases water and nutrient infiltration, reduces root growth, decreases water and nutrient uptake, and can also decrease soil oxygen levels (Unger and Kaspar 1994). Similar problems are occurring in other agricultural regions, for example contamination of waterways by chemicals and silt from agricultural runoff has been reported in Gippsland (Miller 1999).

Organic matter has a major influence on physical, chemical and biological properties of soil and creates a favourable medium for biological reactions in soil environments (Aslam et al. 1999). Soil organic matter (SOM) levels in agricultural soils have decreased with years of cultivation, compared with native soil conditions (Wallace and Terry 1998; Hoogmoed et al. 2000). Sainju and Singh (1997) also describe the continuous degradation of soil organic matter following cultivation without adequate plant material being returned to the soil or without replacement using soil amendments.

It has become evident that increasing organic matter levels in soil can improve soil fertility, nutrient

retention and soil structure. Hence the logical step for improving degraded soils would be to improve the organic matter content of the soil. There are also other benefits to society of using composts and mulches produced from organic wastes, including the reduction in landfill. The conversion of these materials for use as a soil improver, an aid to halt further degradation, or to improve agricultural soils (Handreck 1988) is one of the primary benefits.

Nutrient Depletion and Soil Fertility

The chemical and mineralogical properties of soils are important in determining soil fertility. These soil properties include organic matter, clay, iron and aluminium oxides, salts (N, P, K, S), pH and the percentage of base saturation (Brady and Weil 1999).

Gyanesgwar *et al.* (2002) state that chemical fertilisers often have low use efficiency, meaning that only a portion of the applied nutrients are taken up by plants. Ahmed (1995, cited in Gyanesgwar *et al.* 2002) suggests that the use of chemical fertilisers is reaching the theoretical maximum use beyond which there will be no further increase in yields. Hence the logical step for improving degraded soils would be to improve the organic matter content of the soil. Muchovej and Pacovsky (1997) described the organic matter richness of most compost products as being normally more beneficial at improving the characteristics of a soil than inorganic fertilisers which provided the same chemical nutrients, but in a strictly mineral form. They also stated that carbon content was usually a great deal higher in organic fertilisers and the N, P, S, present in organic residues was often covalently bound to C. To maintain soil organic matter Wallace and Terry (1998) suggested levels of soil organic matter addition should be around 10 tonne/ha/year for tilled soil.

Soil acidity/alkalinity determines the numbers and kinds of organisms that change plant residues into valuable soil organic matter. The pH value also reacts with elements in the soil and directly affects the availability of those nutrients to plants. The major plant nutrients are available to plants in the greatest quantities (and toxic elements are limited) when soil pH is between 6.5-7.0. In a review by Stratton and Rechcigl (1998), it was suggested that the application of composts might improve pH to more neutral levels. However the acidity of the organic materials in the compost must be identified to ensure that pH was not altered to the detriment of plant growth. For example, if the compost was low in base-forming cations, pH can be reduced and alternatively if farm manures or alkaline composts were used, pH can be increased (Brady and Weil 1999).

The application of chemical fertilisers has been linked to developing low pH values in soil. Brady and Weil (1999) reported that chemical fertilisers have had a dramatic effect on pH values over the last fifty years at some sites. The basis of their statement was that microbes in the soil have oxidised the widely used ammonium based fertilisers to produce inorganic acids, providing H^+ ions that have resulted in lower pH values.

The cation exchange capacity (CEC) of soil and organic matter is linked with pH. This linkage or general relationship between pH and CEC can be demonstrated by the fact that CEC increases with pH, as less hydrogen ions (H^+) are adsorbed to the negatively charged sites at the particle surface.

Soil fertility can be reduced in a number of ways: changes in pH, erosion, oxidation and depletion of organic matter and losses to the atmosphere. To improve soil CEC, organic matter can be added to a soil more simply than increasing the clay content or changing soil pH. Stratton and Rechcigl (1998) suggested that the addition of compost could increase the number of cations adsorbed by the soil (increased CEC) with improved cation retention in the root zone.

According to Californian soil scientist Ralph Jurgen (quoted in Grobe 1997), over fertilisation with nitrogen is a common problem. He states that this *results in higher magnesium availability, but lowers uptake of potassium, calcium and other nutrients. The end result is rapid cell wall expansion, which results in weak cell walls. This disrupts the transport mechanism of the plant, and results in crops that are more susceptible to insect and disease attack*.

Soil Erosion

The top layer or A horizon is the most important layer of the soil with regard to plant production. It is typically rich in nutrients, organic matter and biological activity (Hillel 1991; Pimental *et al.* 1995). In a typical ecosystem, loss of soil material occurs due to the action of wind and water, but when the rate of soil loss is greater than soil forming processes (pedogenesis) the thickness of the fertile A horizon is reduced. The mechanisms of soil erosion and particle deposition by both wind and water can be

described in terms of the two equations, Universal Soil Loss Equation (Wischmeier and Smith 1978) and wind erosion equation (Chepil and Woodruff 1963). Soil erosion is initiated when wind speed or surface run off flow rate exceeds the saltation threshold velocity for a given field condition. More simply, wind and water erosion is reduced when soil particle sizes are made larger or the rate of flow of air or water at the soil surface is slowed

Soil erosion rates range from 0.004-0.05 tonne/ha/year in undisturbed forests; in the US and Europe rates of 17 tonne/ha/year have been measured while in Asia, Africa and South America erosion rates can be as high as 30-40 tonne/ha/year (Pimental *et al.* 1995). Pedogenisis takes place at an average sustainable rate of 1 tonne/ha/year in a temperate climate, depending on soil parent material, land use and climate. Hence it can be seen that the rates of soil erosion on farmed land greatly exceed the rate of soil formation. Considering that erosion processes remove topsoil, the most fertile portion of the soil, this eroded soil is 1.3 to 5 times richer in organic matter than soil left behind. An average tonne of fertile topsoil contains 1-6 kg nitrogen, 1-3 kg phosphorus and 2-30 kg potassium. Moderately eroded soils absorb 7-44% less rainfall than the original soil (Pimental *et al.* 1995).

Leaching

Leaching is relevant to both on-farm soil degradation issues as well as off-site problems. Once the nutrients have been leached from the soil they travel through the water table to streams and waterways.

A study into the effect of time of application and continuity of rainfall on leaching of surface applied nutrients found that solute remaining on the soil surface was more readily leached than solute that had diffused into intra-aggregate pore spaces (McLay *et al.* 1991). As the principle source of nutrient leaching losses was considered to be fertilisers, the slow release action of compost soil amendments could reduce leaching potential. Withers *et al.* (2001) also found that surface runoff of phosphorus significantly increased after the application of inorganic and organic fertilisers. This increase was considered to be due to dissolved phosphorous and not to particulate phosphorous. A comparison between surface applied and incorporated amendments found that more phosphorous was released in the surface applied amendments regardless of whether the amendment was inorganic or organic. A study by Eghball and Power (1999) into the application of feedlot manure to soil surfaces by both tillage and non-tillage systems found that it was the form of the nutrient within the amendment that was the key to leaching or non-leaching of plant available nutrients. They found that surface application of feedlot manure did not result in significant nitrogen losses as it contained mainly organic forms of nitrogen and only small concentrations of ammonia, due to the maturity of the amendment, and suggested that more studies were needed to determine the amount of manure and compost nitrogen that becomes plant available under different environmental and soil conditions over time without adverse effects such as leaching.

Returning to sustainable production

Interest in alternative production systems has increased with concern growing over the environment and the long term productivity of the soil (Hanninen 1998). Rovira (cited in Masciandaro *et al*. 1997) states the principal aims of sustainable soil and land uses are to maintain productivity, replenish nutrients removed by crops, enhance desirable soil physical condition and biological activity, minimise use of non-renewable resources, and develop environmental quality.

In orchard systems, there is scope for an integrated approach involving the use of alternative orchard floor management practices to reduce pesticide, herbicide and synthetic fertiliser use, and at the same time improve soil structure and productivity. By building the soil and letting the soil feed the plant, rather than feeding the plant and bypassing the soil system with the use of NPK fertilisers, growers in California found they no longer had to rely on synthetic fertilisers and pesticides to produce marketable crops (Grobe 1997). According to Seybold *et al.* (1999), most soil recovery mechanisms are biologically mediated, including formation and stabilisation of soil structure, cycling of nutrients, detoxification of pollutants and suppression of pathogenic organisms. These authors stress that the inability of microorganisms such as mycorrhizal fungi to recover can lead to long term soil degradation.

Incorporation/addition of organic matter is a proven method of building the soil, and this can be done in numerous ways: application of humates, composts and/or compost teas, use of organic or living mulches, growing cover crops.

The use of soil microorganisms to increase the availability and uptake of mineral nutrients for plants is becoming increasingly popular. Inoculation of soils with microbial mixes such as mycorrhizal fungi, N-fixing bacteria or 'effective' microbes is termed bio-fertilisation or bio-inoculation.

Esitken et al. (2003) lists a number of plant growth promoting rhizobacteria (PGPR) to include strains in the genera *Pseudomonas*, *Azospirillim*, *Burkholdria*, *Bacillus*, *Enterobacter*, *Rhizobium*, *Erwinia*, *Serrotia*, *Alcaligenes*, *Athrobacter*, *Acinetobacter* and *Flavobacterium*, many of which have nitrogen-fixing properties. Khaliq et al. (2006) state that inoculation of soil with effective micro-organisms (EM), a mixed culture of active anaerobic and aerobic microbes, along with organic or inorganic materials is an effective technique for stimulating supply and release of nutrients. The potential of EM to increase plant productivity has been reported by Abobaker et al. (2016). Cavalcante et al. (2012) discusses the emergence of bio-fertilisers as an important component in integrated nutrient supply.

The use of bio-stimulants is also increasing. Bio-stimulants are natural substances applied to soil and plants to improve and regulate physiological processes. When applied in small quantities, bio-stimulants enhance plant growth and development such that the response cannot be attributed to application of traditional plant nutrients. Acid based bio-stimulants include humic acid, fulvic acid and amino acids; extract based bio-stimulants contain seaweeds and fish products.

There is considerable evidence that a transition from traditional to biological agricultural practices can lead to a significant decrease in crop yields (Oberson et al., 1993; Reganold et al., 2001). However, several studies have demonstrated that organic systems are able to achieve high fertility and high yields in the longer term (Granstedt and Kjellenberg, 1997; Glover et al., 2000; Reganold et al., 2001). As traditional and organic systems both have benefits, the challenge is to integrate these systems in such a way as to maximise the beneficial aspects of each system, while limiting their respective detrimental effects.

Increasing soil organic matter content

As noted previously, compared with native soil conditions, soil organic matter levels in agricultural soils have decreased considerably with years of cultivation and reliance on synthetic fertilisers, resulting in chemical and physical degradation of the soil. Adequate amounts of soil organic matter maintain soil quality, preserve sustainability of cropping systems and reduce environmental pollution (Fageria 2012).

Sources of organic matter used in agricultural applications include animal manure, fresh green-waste, processing waste, sewage sludge and compost. Some of these sources are not appropriate in the production processes of all crops so it is important to consider this when choosing an appropriate material. For example, many buying groups insist that fresh uncomposted manures are not appropriate to use in the production of salad vegetables, due to the health concerns posed. There are however, fewer restrictions in perennial tree cropping systems when materials are applied to the orchard floor.

Compost

Prior to the introduction of inorganic fertilisers, compost was applied to the soil as a conditioner or amendment, and various Asian countries have been preparing and using compost as a soil amendment for at least 4,000 years without depleting the fertility of their soil (Howard 1950; Reganold *et al.* 1990). More recently, the application of compost has had renewed interest as part of both organic and conventional food production systems. Compost has been defined as a humus like product of an engineering process derived from organic matter, imparting to the soil all the benefits received from traditional organic matter additions in such forms as leaf litter and crop residues (Stratton and Rechcigl, 1998).

In Australia all commercially produced composts and mulches must adhere to Australian Standard for Composts, soil conditioners and mulches, AS4454-2012.

High quality compost typically has the following characteristics before and during composting:

- Total C:N ratio of 25-30:1, by weight. Microorganisms require a C:N ratio of approximately 30 to make essential proteins. If the ratio varies so that less nitrogen is available, microbial growth (and nutrient conversion) is limited. If nitrogen is low when organic material is being acted upon by microorganisms, it can be to the detriment of the plant (Handreck 1988). As microorganisms are much better at scavenging nitrogen in comparison to plants, the nitrogen immediately available to the plant may be limited (until microbial biomass reduces and releases the nitrogen tied up in the cycle) (Dr M. Line, pers. communication). If nitrogen is supplied in

greater volumes than the microbial population can process it may mean that the excess nitrogen will be lost as ammonium gas (Handreck 1988).
- C:P ratio of 75-150:1.
- Moisture content of 50-55% is optimal in the finished product (Handreck 1988).
- The microbial population in composts and soils are essential to maintain the nutrient cycle, to decompose organic materials and convert nutrients so they are available to plants.

In a review on the effects of compost amendments on soil physical properties, Stratton and Rechcigl (1998) outlined properties such as bulk density, water holding capacity, porosity and aggregate stability that may have been influenced by compost application. This was in particular reference to marginal soils with poor soil structure and low level of organic matter and plant nutrients. Many authors cited in the review attributed the potential benefits of compost applications to organic matter content and level of microbial activity. Such benefits included improvement of soil structure due to the increased integrity of aggregates stabilised by the interaction of micro-organisms and the mineral fraction of the soil, stabilisation of the aggregates with a subsequent decrease in bulk density, increase in porosity and increase in water filtration rate, and soil erosion prevention. Enzymatic activity was also implicated as contributing to the beneficial effects of micro-organisms, together with fungal hyphae acting as a short term binding agent and aggregate stabiliser.

In a comparative study where organic and inorganic amendments were applied to sandy soils (97% sand), Tester (1990) concluded that the decrease in bulk density and increase in porosity due to compost amendments were significant indicators of root system performance, and that these two factors represented the strength of the soil and the resistance encountered by plant roots. The study was divided in two, with one being a single application of amendment and the other as an annual application over a five-year period. The single application of amendments used compost at rates of 60 to 240 t/ha and fertiliser at N, P, K total rates of 600 kg/ha, while the annual application used compost at the same rates but fertiliser at a reduced rate of ~ 300 kg/ha. Lime was also added in both studies, as the soil pH was around 4.0. Although the results of the study found that compost amendments improved soil structure more so than fertiliser amendments, it should have been questioned whether the high rates of compost used may have posed environmental concerns (ie. nutrient leaching through to groundwater), been toxic to plants, or been practical and economical for general agricultural production systems.

Annual applications of compost can increase organic matter (Maynard and Hill 1994). This leads to a change in physical characteristics, including a decrease in bulk density of the soil, enabling plant roots to penetrate the soil more readily and scavenge a greater volume for nutrients, promotion of fine soil particle aggregation, reduced crusting after rains, and increased water holding capacity.

Compost has also been shown to assist in the suppression of plant diseases and pests, through the activity of antagonistic micro-organisms (Sotomayor et al., 1999), as well as inducing growth promotion by a direct enzymatic or hormonal effect on plant roots (Raviv, 1998).

Verma *et al.* (2013) demonstrated that surface application of compost increased P mobilisation from rock P, but also reported that plant growth and P uptake were not increased by compost plus P rock compared to compost alone. They concluded that both composts and composts with rock P can act as slow release fertiliser. These conclusions are supported by the findings of Malik *et al.* (2013) who reported increased microbial activity and concentrations of available P pools following soil amendment with three different organic sources. However they found that, while all organic amendments used were suitable P sources for plants, farmyard manure was better than poultry litter They further suggested that while organic amendments could be used as alternatives to inorganic P fertilisers, a clear understanding of the relationship among type of P amendment, microbial activity and changes in soil p fractions is required to optimise their use.

Although it would appear that composts, in lieu of inorganic fertilisers, have a potential use in plant production systems, unrestricted use of compost in an effort to realise this potential, may not be favourable for the environment or the soil resource in the longer term. In Australia, the only guidelines that exist for compost are Australian Standards, which only cover the production and not the regulation of its use. The closest guidelines available are European, but remain largely untested for Australian conditions (Wilkinson *et al.* 1998). The guidelines recommended that the benefits from compost should be long term, that composts should not damage soil or plants, and that leaching of nutrients from compost into groundwater should be minimised. In relation to the last point, it has been stated that many countries in Northern Europe have enacted legislation to protect groundwater and soil resources from over-application of nitrogenous fertilisers, manures and organic wastes (Wilkinson *et al.* 1998).

Regulatory requirements governing the processing, distribution, use and disposal of organic materials, together with all other agricultural wastes and bi-products, have also been determined by the U.S. Environmental Protection Agency (Walker *et al.* 1997).

A study by Cooper and Warman (1997) found that compost application increased DHA and organic carbon levels in soil. The microbial action increased the rate of the incorporation of organic matter into the soil. In a five year glasshouse experiment in Italy, fertiliser and compost treatments were applied to a sandy soil (85% sand) to examine possible benefits of long-term compost treatment of soil. Microbial activity was similar across all treatments although yields were more for the compost treatments than the fertiliser treatments. It was suggested that the microflora developed in the composted mixes consisted of qualitatively different populations offering more beneficial conditions for plant growth (hence, higher yields) and at the same time excluding the development of harmful organisms (Marchesini *et al.* 1988).

Hartley *et al.* (1996) suggest that, if CO_2 emission figures are taken as a measure of total bio-activity in the soil, then adding organic compounds in the form of compost has a substantial and lasting effect on life in the soil. They found that the type of material added was important, with grass and sawdust resulting in greater bacterial and fungal biomass in the soil than herbicide treated plots, and wooldust reducing the bacterial and fungal biomass below that seen in the herbicide plots.

According to Grobe (1997), if soil is completely compacted or too wet or dry, results with compost will be disappointing no matter how high the quality of the compost.

Surface Mulching

Mulching is the process of covering bare soil with some type of material. Mulches can be sourced from a range of materials, including organic (eg. straw, sawdust, grass, greenwaste, compost), non-organic (gravel) and synthetically produced products such as plastic, foil, or shredded rubber.

Covering soil with mulch has been shown to strongly influence crop growth and development as well as the environment (Larsson 1997). Mulches reduce water evaporation and increase infiltration, resulting in greater soil moisture (Knavel and Herron 1986; Schonbeck *et al.* 1993; Lal 1995). The use of mulch also has the potential to increase crop production and to effectively suppress weeds. As they decompose, organic mulches may improve soil physical and biological properties, reducing soil erosion, improving soil structure, minimising soil compaction, increasing water holding capacity and microbial activity, slowing the release of nutrients and controlling soil temperatures (Putnam 1990; Foshee *et al.* 1996; Buckerfield and Campbell 1998; Buckerfield and Webster 1998; Masiunas 1998). However Larsson (1997) suggests that, at least in the short term, it is difficult to achieve improved soil fertility with mulching.

In work undertaken at Tasmania's Grove Research Station, Boucher (1998) demonstrated that mulching of compacted soils with wood fines could improve water infiltration. Spent mushroom substrate has been shown to improve the environment for plant root growth by decreasing soil bulk density, increasing aggregate stability, reducing clod and surface crust formation, improving water infiltration rates, increasing the water content of the soil, and reducing diurnal temperature changes (Stewart *et al.* 1998). Some of these changes, however, were not evident until repeated applications of 80 t/ha spent mushroom substrate had been made. Taylor (1998) found that applying grape marc as a surface mulch helped retain soil moisture and suppress weeds. There was no change in soil pH during the monitoring period, which was dry. Villareal (cited in Ozores-Hampton 1998) saw increased yields in tomatoes mulched with rice straw. In addition, the rice straw prevented erosion, slowed weed growth and minimised soil compaction.

Boynton and Anderson (1956) report the effects of mulching with hay on 'McIntosh' apple tree behaviour were similar to and additive to the effects of nitrogen fertilisation. They found mulching increased potassium and nitrogen intake by the trees, however there was no effect on magnesium, calcium, phosphorous or boron. Hartley and Rahman (1994) found that mulches (straw, compost, sawdust, wooldust) had negligible effect on leaf and fruit nutrient analysis. Further work by Hartley and Rahman (1998) confirmed that even though mulches affected the chemical characteristics of the soil there was little effect on the nutrient status of apple leaves or fruit.

For weed control, mulches are more expensive to establish and maintain than herbicides because, as the material breaks down, more must be added to maintain the necessary thickness for optimum weed control. Hence the benefits of compost/mulch utilisation must compensate for the additional expense. Ozores-Hampton (1998) reports that some economic studies indicate the increase in crop value justifies

the greater cost. Merwin *et al.* (1995) also reports that higher establishment and maintenance costs of certain organic and synthetic mulches in apple orchards were offset by their prolonged efficacy over successive years. Singh *et al.* (cited in Ozores-Hampton 1998) reported that organic mulches applied at 5 t/ha in herb production controlled weeds as effectively and at lower costs than the herbicides simazine, diuron and oxyfluorfen.

The choice of mulching materials can have an influence on soil fauna. Hartley and Rahman (1994) found that earthworm populations were increased by straw and compost, but reduced by sawdust, wooldust and herbicide. Trials in the Barossa Valley by Buckerfield and Webster (1998) showed significant increases in earthworm activity using straw under vines, with substantial savings in soil water and increases in grape yields. Biggs (1997) also reported similar effects following the application of straw under vines. Whalen *et al.* (1998) report that earthworm numbers and biomass were significantly greater in manure amended plots compared to inorganic fertiliser treated plots for the six years of the study period and the following two years. According to Peres *et al.* (1998), organic matter quantitatively increased the abundance and biomass of the earthworm community in French vineyards. These earthworm community changes were associated with an increase in granular bioturbated areas and in macroporosity in the top soil layer. Sparrow *et al.* (1999) found lower earthworm numbers in cropping paddocks compared with pasture paddocks, but also reported a loss of organic C which may have contributed to this observation. Both soil type and mulch composition impact on soil fauna. Bound (2003) observed that earthworm numbers were at least three times higher under greenwaste, compost, living grass and hemp mulches compared with herbicide strip, but numbers were also higher in clay soils than in sandy soil. Hemp mulch also increased earthworm numbers to over 1200 per m^2 compared with other mulch types which averaged 350 worms per m^2.

Use of straw mulch under vines has demonstrated significant increases in soil moisture (Biggs 1997). The additional organic matter and increased earthworm activity also improve soil conditions, leading to increased yields. Buckerfield and Webster (1998) also report that a surface mulch significantly enhanced the development of young vines, and suggest that composted matter can be considered an alternative to straw mulches. They found that a 5 cm layer of composted 'green-organics' was as effective as 20 cm of straw in conserving soil moisture undervine. However, they concluded that it is essential that only compost which complies with the Standard AS-4544 is used to reduce risks from weed seed and plant pathogens.

Combining organic manure with chemical fertiliser can increase microbial activity, however Ding *et al.* (2013) suggested that there is a threshold effect of organic manure addition on soil microbial residue build-up after finding that the highest organic inputs did not produce the highest amounts of microbial residues.

Manna *et al.* (2001) found that mulch application increased microbial activity and biomass in soil under a soybean-wheat rotation. Mundy and Agnew (2002) reported higher numbers of soil fungi under mulch treated plots compared with non-mulched. According to O'Callaghan *et al* (2001), microbial control of soil-dwelling pests and pathogens depends on the successful establishment of microbial inocula in soil. This can be achieved through adequate soil moisture and lower soil temperatures.

Cover crops / Living mulches

An alternative to organic mulches is the use of vegetative ground covers or living mulches. In vegetable production, Weston (1996) describes living mulches (or companion crops) as species that are allowed to grow at the same time as the crop. Grasses, legumes and *Brassica* species have all been used as living mulches. Living mulches have been shown to reduce soil compaction problems in vegetable production systems (Nicholson and Wien 1983; Stirzaker and White 1995). Other benefits of vegetative ground covers include increased soil organic matter, improved soil structure, reduced mechanical tillage, and decreased erosion. An important advantage is the ability of ground covers to suppress weed growth, reducing or removing the necessity of herbicides (Hanninen 1998).

According to Ingels *et al.* (1994), cover crops are now recognised as an important component of 'sustainable' production systems in most areas of California. Cover crop mulch systems modify the micro-environment of the crop, impacting on pest populations and crop yields (Masiunas 1998). Cover crops also reduce soil erosion through diminished raindrop impact and surface runoff (Sainju and Singh 1997).

Up to 40% of the nitrogen fertiliser applied to orchards each season can be lost by leaching. This loss of

soil nutrients can be minimised by the use of deep rooted cover crops to retrieve and recycle the lost nutrient (Stork and Jerie 1996). Several authors have suggested that autumn established cover crops prevent nutrients from leaching during winter months by capturing excess nitrate and by recycling nutrients (Eckert 1991; Paine and Harrison 1993; Shepherd and Lord 1996). When balanced nutrient resources are available, apples and living groundcovers compete for nitrogen and tree growth is inhibited (Shribbs and Skroch 1986). However, different species exhibit different degrees of competition and nutrient uptake. Shribbs *et al.* (1986) report that cocksfoot (*Dactylis glomerata* L.) and red sorrel (*Rumex acetosella* L.) inhibited growth of 'Golden Delicious' apple trees more than Kentucky bluegrass (*Poa pratensis* L.). The more competitive ground covers had greater mass, which probably increased nitrogen capture.

The most often reported disadvantage of vegetative ground covers is that of competition for water and nutrients between the crop and cover vegetation, resulting in reduced crop growth. In particular, if a cover crop has increased growth during the early spring, soil moisture may be depleted (Drost and Price 1991), and this is likely to be to the detriment of the crop. Working with a range of cover crops, Glenn *et al.* (1996) and Welker and Glenn (1988) reported reduced growth in peach; Shribbs and Skroch (1986) and Merwin and Stiles (1994) found growth depression in apple trees, and Forshee *et al.* (1995) in young pecan trees. In a four year study by Ingels *et al.* (1994) 20-25% more water was used by resident vegetation and strawberry clover compared with a bare floor in an almond orchard. While summer-active cover crops in orchards compete directly with the cash crop for water, winter cover crops have relatively little impact on soil moisture (Ingels *et al.* 1994). One way of avoiding this problem of competition is perhaps to use summer dormant species. Ingels *et al.* (1994) suggest that summer dormant perennial grasses have potential value in orchards and vineyards and conclude that, in spite of these problems, the soil improvements resulting from cover crops may lead to more efficient use of water, especially on sandy soils (Ingels *et al.* 1994).

Bradshaw and Lanini (1995) report that the effect of cover crops on coffee are both species and site specific. Parker and Meyer (1996) found great differences between cover species and stress the need for identification and selection of non competitive vegetative covers. Both grasses and legumes are reported to have both beneficial and detrimental characteristics. Determining an appropriate cover crop for a given system will depend on finding a species which effectively inhibits the wide diversity of weed species and life forms found in orchards without competing with the trees (Bradshaw and Lanini 1995).

Mulches, either organic or cover crops, also improve pest control by attracting and supporting populations of beneficial parasites and predators. These natural enemies include predators of aphids and mites, such as lady birds, lacewings, syrphid flies, predatory bugs, and parasitic wasps and flies (Alway 1998). Ingels *et al.* (1994) also suggests that cover crops may provide food or shelter to beneficial insects, mites and spiders, and may compete with and suppress weeds. Any proliferation of beneficial invertebrates is likely to result in reduced pest pressure, assisting in the reduction in pesticide use.

Impact of soil organic matter on crop growth and yield

Impact on tree growth

There is a scarcity of literature available on the impact of increasing organic matter on growth in perennial tree crops. In relation to application of mulches in perennial cropping situations, reports on crop growth are conflicting. In studies on a range of different mulch materials, Bound (2003) reported an increase in tree trunk cross-sectional areas (TCSA) with green-waste or hemp straw mulches, but observed different results with composted bark and bark/fishwaste mulches in two different orchards on different soil types. Using a range of organic mulches in a pecan orchard Foshee *et al.* (1996) found the trunk cross-sectional areas (TCSA) of mulched trees were larger than those in un-mulched plots, and increased linearly as mulch depth increased (10, 20 or 30 cm). They concluded that common yard-waste mulches (leaves, grass clippings, clipped limbs, pine nuggets) can be used effectively to increase growth of young pecan trees.

Compost mulches have been shown to promote the growth of both young and established vines, even in irrigated soils with adequate organic content (Biggs 1997), and in olives (Bound 2003). In comparing cultivation, bare soil and straw treatments, Cockcroft and Tisdall (1974) found that straw treatments produced the most vigorous trees, whereas Hartley and Rahman (1994) found that a range of mulches including straw, compost, sawdust, and wooldust had negligible effect on tree growth. Biggs (1997)

reported a 50% increase in growth of young almonds under 15 cm of mulch. Similarly, Goulart *et al.* (1996) reported an increase in canopy volume in blueberries following mulching with a 10 cm layer of rotted sawdust.

These reported differences may be due to a multitude of factors including soil type and initial condition, along with origin, maturity and application thickness of the mulch material

Crop yield and quality

There have been numerous reports discussing the effects of organic composts and mulches on crop yields. Hartley and Rahman (1994) found that mulches (straw, compost, sawdust, wooldust) had negligible effect on tree growth or fruit yield. However, Goulart *et al.* (1996) found blueberry yield and berry size was increased by rotted sawdust mulch.

By incorporating composts into soil Bound and Wilks (2003) observed increased yields in potato and lettuce crops, however when lime was added to the compost instead of fertiliser, yields were reduced. They also reported an increase in growth of grapevines following the addition of mulch along the rows, however the type of mulch affected the amount of growth, with fully composted mulch producing the most growth, and a gradation in growth with semi-composted and then raw mulch. However all mulch types produced more growth than un-mulched plots.

Boynton and Anderson (1956) saw an increase in fruit size of 'McIntosh' apple in plots mulched with hay, and Baxter (1970) found straw mulch around apple trees doubled the fruit yield in the 5th and 6th years when compared to a cultivation treatment for weed control. In addition to seeing an increase in fruit size at harvest in apple and peach trees following mulching, Hartley *et al* (1996) found that mulched apple trees carried relatively higher return bloom in the season following a heavy crop.

The impact of mulching on leaf nutrient levels reported by Bound (2003) agrees with the findings of Hartley and Rahman (1994) who found that mulches had negligible effect on leaf and fruit nutrient analysis. While there were variations between mulches in the levels of soil nutrients in year one, by year two these differences were no longer evident. This suggests that once mulches begin to degrade, nutrients are released into the system and become available for uptake by plants.

The disease suppressing effect of organic material supplements has been reported by several authors. In mulched vineyards, Biggs (1997) reported a 50% increase in grape yields without a change in juice quality. Mundy and Agnew (2002) reported a lower incidence of bunch rot on grapes from mulched plots compared with un-mulched plots. Hemp mulch has been shown to reduce the incidence of powdery scab in potatoes (Bound and Wilks 2003).

In comparing three low growing ground cover species with bark mulch and herbicide, Hartley *et al* (2000) found that ground covers reduced tree growth and fruit yield in the first year. Bound (2003) reported a reduction in crop load and yield in two apple orchards in the first year of study on living mulches (*Dactylis glomerata* and *Festuca ovina*), but there was no effect in the second year once the grasses had become established. Fescue (*Festuca longifolia*) has been found to reduce apple yield after three years, but this treatment also reduced the proportion of small reject apples (Hartley and Rahman 1998). However, *Dichondra* ground covers have been shown to cause no decrease in fruit yields when grown under well established apple trees (Harrington *et al.* 1999). These authors also saw no differences in soil carbon, nitrogen or pH.

Neilsen *et al.* (1999) found that greater vegetation competition in apple orchards decreased yield, but had few effects on leaf and fruit nitrogen levels. They also reported that potassium levels in leaves and fruit increased with increasing vegetative competition, as did titratable acidity of stored fruit, red ground colour and fruit firmness, however total soluble solids (TSS) was reduced at harvest. Atkinson and Crisp (1983) also showed the yield of both young and mature apple trees was reduced by grass between the tree rows.

Working with black currants (*Ribes nigrum*), Larsson (1997) found that cover crops can compete so severely with the black currant bushes that fruit yield is reduced. Tworkoski *et al.* (1997) report that competition with grass will reduce fruit yield and yield efficiency in young peach trees, largely by interfering with nitrogen availability and uptake. They suggest that internal sink competition and competition among plants can interact to affect the partitioning of dry mass and nitrogen within the current-year growth of peach trees. Putting this into practical terms, they suggest that peach trees with more competition from grass may require less fruit thinning than trees with less competition. However

Bound (2003) found no negative effects of living grass mulches in an apple orchard over three years.

Using bio-fertilisers to improve sustainability in orchard crops

In addition to improving microbiological activity in the rhizosphere, nitrogen fixing bacteria and arbuscular mycorrhizal fungi have been found to significantly enhance the growth and production of several fruit plants (Aseri *et al.* 2008).

In an examination of nitrogen-fixing bacteria and AMF used either alone or in combination, Aseri *et al.* (2008) found a combined application of *Azotobacter chroococcum* and *Glomus mosseae* was most effective, not only in enhancing the rhizosphere microbial activity and concentration of metabolites and nutrients, but also in assisting the establishment of pomegranate plants under field conditions. They also reported improved plant growth and fruit yield as long as 5 years after inoculation at planting.

Root inoculations of *Bacillus* M3 and OSU142 and *Microbacterium* FS01 have been reported to promote tree growth and yield in apple trees (Karlidag *et al.* 2007). However these authors found growth responses varied with different combinations of these bacteria. Many PGPR strains are able to produce the plant growth regulators indole-3-acetic acid, cytokinin and other plant hormones in the rhizosphere, hence they suggest that increases in growth and yield they observed may be due to the production of plant growth regulators and an increase in available nutrients in the rhizosphere.

Cavalcante *et al.* (2012) reported improvements in fruit size and quality of passion fruit following treatment with both simple biofertiliser brewed through anaerobic fermentation from fresh bovine manure and enriched biofertiliser brewed from fresh bovine manure plus protein and nutrient sources. They found that the simple biofertiliser promoted optimum supplies of K, Ca and S whereas N, P, K and Ca were optimised in the enriched biofertiliser, hence they concluded that bovine biofertiliser could be an important key to reducing chemical fertiliser use while still maintaining fruit quality and profitable returns.

The use of biofertilisers need not be restricted to soil applications. Esitken *et al.* (2003) reported a 30% yield increase in apricot following a full bloom application of *Bacillus* OSU142; application in the following year resulted in 90% yield increase. In addition these authors reported increased shoot length and higher N, P, K, Ca and Mg content of leaves. They concluded that the better nutrition in the treated trees may have promoted flower bud formation and/or decreased the abortive flower ratio. Karakurt and Aslantas (2010) concluded that the growth increase effects observed in their studies of four strains of PGPR on several apple cultivars could be explained by the production of plant growth regulators by the bacteria. Sudhakar *et al.* (2000) reported an increase in mulberry leaf yield and higher leaf protein content following foliar application with nitrogen-fixing bacteria. Of the three bacteria studied they found *Azotobacter* was more beneficial than *Azospirillum* or *Beijerinckia*. After finding no ill effect on silkworm rearing they concluded that foliar application of biofertilisers, especially *Azotobacter* could safely be used with half the normal dose of chemical nitrogen fertiliser to improve mulberry leaf production.

In summarising the work of other researchers, Sudhakar *et al.* (2000) concluded that the advantages of foliar applications of biofertiliser over soil applications were substantial and included:

- fixation of nitrogen at the site of its utilisation
- nitrogen fixers encounter less competition from other microorganisms and environmental factors on the phylloplane (leaf surface) compared to the rhizosphere
- reduction of foliar diseases as a result of nitrogen fixers antagonising the pathogens.

Bacillus subtilis strain EBW4 has been used as a biological treatment of apple replant disease (ARD). Utkhede and Smith (1993) reported consistent performance over three years of this *B. subtilis* strain on growth of newly planted apple trees, suggesting that the mechanism may be through production of antibiotics that are inhibitory to pathogens isolated from ARD soils. They also report that this strain has the ability to control crown and root rot of apple trees caused by *Phytophthera cactorum*.

Observing a positive response in apple seedling growth, nutrient uptake and soil fertility following soil inoculation of locally isolated strains of *Azotobacter*, *Azospirillum* and AMF, Singh et al. (2013) concluded that multi-inoculation of synergistically *interacting* species caused rhizosphere modification through changes in root colonisation and microbial counts.

In a comparison of bio-organic fertiliser which was a combination of manure composts and antagonistic microorganisms, and organic fertiliser, Qiu *et al.* (2012) *reported* an 83% suppression of *Fusarium* wilt in cucumbers which led to a three-fold reduction in yield loss. They concluded that biofertiliser application was an effective approach to suppress *Fusarium* wilt through inhibition of the soil-borne pathogens and recovery of microbial populations damaged by *Fusarium*.

According to O'Callaghan *et al* (2001), microbial control of soil-dwelling pests and pathogens depends on the successful establishment of microbial inocula in soil. This can be achieved through adequate soil moisture and lower soil temperatures. Bound and Wilks (2003) reported higher soil moisture content in lettuce *plots* showing the higher levels of microbial biomass.

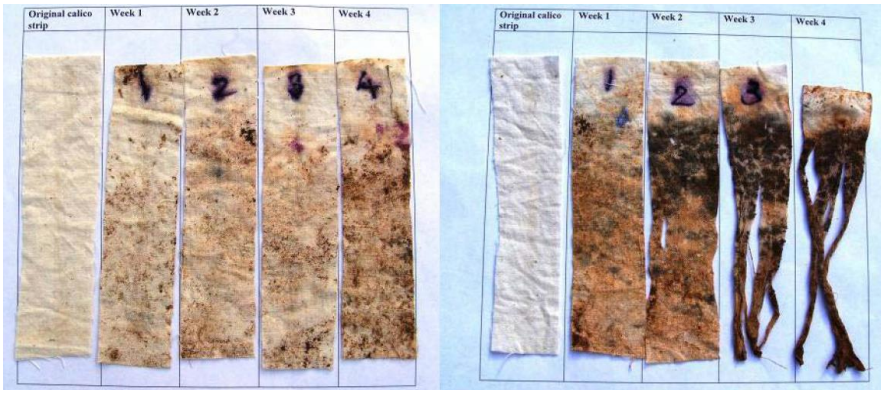
Easy methods to assess soil health

It is difficult to test for soil biology as numbers and species can change rapidly with temperature, moisture and nutrient supply. Common tests include:

- Berlese funnel for determining meso and macro fauna speicies and abundance
- Microbial activity through respiration, DNA assaya and enzymes
- Nematode diversity
- Fungi/bacteria ratios
- Cotton strips to measure decomposition rate

While many methods of assessing soil life and health require complex analysis and are out of reach of most growers, there are some simpler methods that growers can employ as indicators of soil health and level of biological activity.

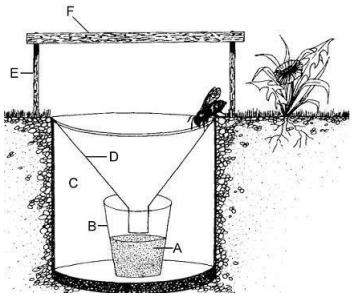
(i) As fungi play a dominant role in degradation of the cellulose in plant organic matter, the cotton strip assay described by Correll et al. (1997) can be used to give an overview of soil fungal activity.



Low biological activity High biological activity

(ii) Soil invertebrate biomass and diversity, *particularly* of mites, is often positively correlated with soil health (Coleman et al. 2004; Axelsen and Kristensen 2000) and crop performance (Baker and Crisp 2009) and can therefore be used as one indicator of soil health and a potential correlate with cherry crop yield and quality.

Soil macro-invertebrates can be examined by the use of a pitfall simple trap



A. Polypropylene or ethylene glycol (antifreeze)
B. 6-8 ozplastic cup
C. 2L can
D. Funnel
E. Supports (e.g. nails)
F. Rain roof

(iii) The *soil* quality index for apple orchards developed by Glover *et al.* (2000) has potential for use in any perennial orchard crop. These authors modified the soil quality index originally propose by Karlen *et al.* (1994a, b) to reflect the cultural requirements of apple orchards as opposed to grain production systems. Soil quality was evaluated in terms of four soil functions:

1. *accommodating water entry;*
2. *facilitating water movement and availability;*
3. *resisting surface structure degradation; and*
4. *supporting fruit quality and productivity.*

All four functions were given an equal weighting of 0.25 as they were *assumed* to be equally important. They then developed a framework relating specific soil quality indicators to the four soil functions and assigned numerical weights to surface quality indicators based on their importance to the soil function under consideration (see Table 4).

Table 4: Relative importance of soil properties in the soil quality index (source Glover et al. 2000)

Property	Soil indicator	Weight	Soil function affected
Biological	Soil organic carbon	0.2125	1. accommodate water entry 2. facilitate water movement & availability 3. resist surface structure degradation 4. sustain fruit quality and productivity
	Earthworms	0.0750	1. accommodate water entry 2. facilitate water movement & availability
	Microbial biomass carbon	0.0300	3. resist surface structure degradation 4. sustain fruit quality and productivity
	Microbial biomass nitrogen	0.0300	3. resist surface structure degradation 4. sustain fruit quality and productivity
Chemical	Cation exchange capacity	0.0500	4. sustain fruit quality and productivity
	Total nitrogen	0.0250	4. sustain fruit quality and productivity
	Nitrate-nitrogen	0.0250	4. sustain fruit quality and productivity
	Extractable phosphorous	0.0250	4. sustain fruit quality and productivity
	Electrical conductivity	0.0250	4. sustain fruit quality and productivity
	pH	0.0250	4. sustain fruit quality and productivity
Physical	Aggregate stability	0.2000	1. accommodate water entry 3. resist surface structure degradation
	Water-filled pore space	0.1150	2. facilitate water movement & availability 3. resist surface structure degradation 4. sustain fruit quality and productivity
	Bulk density	0.1000	1. accommodate water entry
	Porosity	0.0625	2. facilitate water movement & availability
	Total	1.0000	

(iv) Examining nodules on legumes. If a red colour is observed on cutting nodules then nodules are active

(v) A no fail- method is to use a spade to dig a hole and observe the topsoil and subsoil
- old inactive decomposing indicates presence of bacteria and fungi
- evidence of bioturbation indicates macrofauna such as earthworms and beetles
- .an earthy smell indicates the presence of actinomycetes
-dark soil colour indicates soil organic matter.

Conclusions

It is possible to move away from conventional agriculture with its heavy reliance on pesticides and fertilisers to a natural system that builds soil health. The common misconception that sustainable agriculture means a return to old farming methods needs to be addressed. By using the term biological rather than sustainable brings the emphasis back to where farmers need to be looking in the future. Biological farming works with natural systems and processes to build optimum soil and plant health, while also incorporating the best of conventional farming methods to maintain production levels and quality.

There are advantages and disadvantages to any system, and the key is to achieve a balance to enable the production of high quality crops without degrading the environment. To ensure its use for future generations, we need to take on a stewardship role to conserve and rejuvenate our valuable soil resource.

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