# A guide to managing the orchard floor.

*Minimising the environmental impact of apple & pear production*

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# Introduction

Current perennial fruit production systems can be highly productive but often contain practices that are unsustainable in the long term. The orchard floor comprises a series of interconnected systems and relationships that have a deep influence on tree health, nutrition, water availability and orchard resilience, and hence on the production of high-quality fruit. It also has a physical role in supporting orchard operations involving the movement of tractors, mobile labour/harvest assist platforms and other mechanised equipment through the orchard.

Many growers already implement practices that encourage good soil health such as compost application prior to orchard establishment, planting of inter-row swards, and use of soil amendments and/or mulches in the tree-line. Yet the benefits (above and below ground) of these various approaches are not well understood. There is also a substantial knowledge gap on how orchard floor management practices promote (or inhibit) the presence and function of beneficial organisms and how these organisms interact with trees to increase tree water and nutrient-uptake.

This publication provides information relating to the orchard floor and summarises the findings from the three-year Hort Innovation funded project *AP19006 Improved Australian apple and pear orchards soil health & plant nutrition*.

# About the project

This project set out to test key principles of a sustainable production system with different orchard floor management strategies aimed at promoting long term orchard resilience. We examined and demonstrated a range of orchard floor management strategies in the Huon Valley (Tasmania), Adelaide Hills (SA), Manjimup (WA) and Orange (NSW).

## Our key question

How does orchard floor management using cover crops (living mulches) and other locally sourced composts influence soil health and apple fruit yield and quality?

Over its short timeline of 3 years, the research demonstrated positive trends for incorporating living mulches, composts or organic mulches into the orchard design, and the results have provided a framework for further studies.

Both inter-row and tree-line treatments were examined (Table 1), and plant species used in each region reflected regional priorities.

***Table 1**: Orchard floor treatments imposed in the inter-row and tree-line.*

| Inter-row | Tree-line |
|---|---|
| Ryegrass & clover mix | Herbicide bare earth |
| Mixed flowering meadow plants | Compost |
| Native plant mix | Grass/clover mix |
| Fescue species & clover mix | Mow & throw |

Species lists for the different cover crops / living mulches in each region are provided in Appendix 1.

Multiple assessments were undertaken to determine the impact of treatments on soil physics, chemistry and biology and on the crop (Table 2).

***Table 2**: Assessments undertaken during the project.*

| Soil | Biology | Crop (years 2 & 3) |
|---|---|---|
| - compaction<br>- moisture content<br>- water infiltration<br>- aggregate stability<br>- organic carbon<br>- nutrient status | Soil: - arthropods<br>- microbial biomass<br>- microbial diversity<br>-mycorrhizal fungi<br>Crop & groundcover:<br>- pest arthropods<br>- beneficial arthropods | - growth<br>- yield<br>- fruit quality<br>- tree physiology<br>- pest/disease damage |

# Functions of the orchard floor

The traditional orchard floor has a grassy inter-row sward and herbicide treated band along the tree line to maintain a weed free strip. This enables simplicity of management, traction and stability for tractors and machinery during wetter periods and reduces soil erosion and runoff.

***Figure 1**. The orchard floor consists of the inter-row and the tree-line, with management varying between orchards.*

The orchard floor is the gateway to the tree's life support system of roots, soil, water and nutrients, and home to a myriad of life forms from micro to macro, both above and below the surface. Orchardists are becoming increasingly aware that an ecologically balanced system is essential for maintaining healthy crops and optimising fruit quality.

The orchard floor can make an important contribution to plant and animal diversity which in turn influences soil health, pest and disease management and sanitation of the orchard floor.

There is a growing appreciation of the integral importance of soil life and plant-symbiotic interactions in orchard sustainability and healthy soils. At the microscopic scale, the way that the orchard floor is managed strongly influences important soil functions such as nutrient availability, water holding capacity and microbial presence and diversity.

# Sustainable orchard floor management

Sustainable agriculture has been defined in many ways and the meaning is still evolving. The following definition provides a reasonable description: *Sustainable agriculture is managing the land so that it can continue to produce food for future generations whilst preserving the natural resources of soil, water, flora and fauna.* However, being sustainable is not just about preservation of the land, it must also be economically viable for the orchardist.

> There is real scope to achieve highly sustainable production in orchard systems due to the perennial nature of the crop and low soil disturbance.
>
> The orchard floor is a place we can really influence key sustainability principles to reduce pesticide, herbicide and synthetic fertiliser use, and at the same time improve soil structure and productivity.

## What makes an orchard system sustainable?

Fruit trees have been productively grown in the same ground for hundreds of years, demonstrating that orcharding can be a long-term sustainable system. Sustainable systems tend to be highly diverse with many different species of living organisms (flora and fauna). This diversity gives the system resilience and balance both above and below ground and means that the system rebounds quickly from disturbances or even the impact of climatic events such as high rainfall or drought. These living organisms provide both direct and broader services to the productivity and health of the orchard (Table 3).

***Table 3****: Services provided by living organisms in an agricultural system.*

| Direct services | Broader services |
| --- | --- |
| – Pollination | – Carbon storage |
| – Biological pest & disease regulation | – Regulation of soil & water quality |
| – Weed suppression | – Regulated nutrient & water availability across seasons |
| – Nutrient cycling | – Breakdown of wastes and toxins |
| – Maintenance of soil physical structure & chemical fertility | – Maintenance of genetic diversity |

### Is being sustainable just letting nature take over?

Although relying on nature, sustainable agricultural systems are still highly influenced by human intervention, and for good reason. They are artificially created systems that need our intervention to create the best balance of components to support fruit production. This might be planting the right species to improve soil function, encouraging beneficial organisms and deterring pests and disease, managing the inter-row to reduce frost risk and allow efficient harvest, or applying synthetic inputs more strategically to optimise benefit.

> The aim is to enhance the natural ecosystem using multiple tools.

## How is it different to other systems?

Conventional (sometimes termed high input) agriculture has a high reliance on synthetic fertilisers and pesticides. Conventional systems tend to be less diverse than balanced agroecosystems and usually have more bare ground. There is a wide spectrum of production systems, both conventional and alternate, with a range of labels given to alternative practices, including *organic*, *low input*, *biological*, and more recently *regenerative*. However not all alternative systems are truly sustainable. For instance, organic production is widely perceived as sustainable, but this is not always the case: e.g., a grower may not be using synthetic pesticides or fertiliser, but they have created a very simple ecosystem with low diversity by repeatedly using a steam weeder or solarisation leaving the soil bare and exposed to damage and loss, thus the system is not sustainable. Regenerative agriculture is based on principles closely aligned to achieving sustainable agriculture, and regenerative practices strive to do more good than harm by actively giving back, renewing, restoring, and achieving net benefit to the system.

# The soil environment

The terms quality and health are often used interchangeably in relation to soils. Orchard soil health is related to factors such as physical structure, aggregate size, water retention and infiltration, soil chemistry and nutrient availability, and biodiversity including microbe and invertebrate (arthropod) populations.

According to soil scientist Dr Bill Cotching, the health of a soil can be identified by how the soil performs all its functions. **Management strategies that optimise multiple soil functions have the greatest potential for improving soil health**.

## Physical properties

Soil physical properties include soil texture, structure, porosity, water holding capacity and bulk density. As physical properties influence air-water relations in the soil they can have a strong impact on plant growth and microbial activity.

**Soil texture** refers to the inorganic solid material of the soil mass. There are three separate components that make soil texture: sand (0.02-2mm diameter), silt (0.002-0.02mm), and clay (≤0.002mm).

**Soil structure** is the result of aggregation of soil particles. Aggregates are naturally formed assemblages of sand, silt, clay, organic matter, root hairs, microorganisms and their mucilaginous secretions, extracellular polysaccharides, and fungal hyphae. Aggregates create the pores necessary for air exchange and water infiltration, which are essential for root growth. Strong stable aggregates resist breaking down and are vital for maintaining good conditions for root growth. When aggregates are unstable, soil pores can clog and the soil surface can crust and become impenetrable. Aggregate stability is affected by soil texture, the type and amount of organic matter present, and the nature and size of the microbial population. For example, the long strands of fungal mycelia bind soil particles together more effectively than smaller organisms such as bacteria.

**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. 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** of soil is the ability 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.

**Soil bulk density** provides an indication of soil compaction. It is significantly influenced by soil organic matter, with higher organic matter resulting in lower bulk density. It has been shown to influence nutrient uptake through its effect on physical, chemical and biological properties of soil-plant systems.

## Basic soil chemistry

Most growers will be familiar with soil chemistry from annual soil nutrient tests. 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 obtained from the soil are divided into macro [nitrogen (N), potassium (K), calcium (Ca), phosphorous (P), magnesium (Mg), and sulphur (S)] and micro [iron (Fe), chlorine (Cl), manganese (Mn), boron (B), zinc (Zn), copper (Cu), molybdenum (Mo), nickel (Ni), and silicon (Si)] nutrients. Macronutrients form the structural components of proteins, cell walls, membranes, nucleotides and chlorophyll, and have roles in energy and water maintenance. Micronutrients are required for the functioning of plant enzyme systems and play important roles in photosynthesis and reactions such as N fixation and protein synthesis.

For uptake by plants, nutrients need to be in an available form. Nutrients are taken up in an ionic, or charged, form, so to become available to plants, nutrients need to be solubilised or released from mineral sources and mineralised from organic sources. Mineralisation occurs when soil microorganisms convert organically bound elements such as N, P, and S into plant available inorganic mineral forms (in the case of N into $NH_4^+$ and $NO_3^-$). 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.

Soil fertility is a measure of the amount of available nutrients and is determined by the combination and volume of microbial populations that digest and transform these minerals to compounds readily available for plant uptake (mineralisation).

## Soil biota

The soil biota consists of a diverse array of organisms and can be divided into flora (plants) and fauna (animals).

- Plant roots and macro-algae comprise the macroflora, while soil microflora (< 5µm in size) consist of bacteria, actinomycetes, fungi and algae.
- Soil fauna is classified according to size. Macrofauna is generally defined as being larger than 2 mm (e.g. earthworms, slaters, millipedes, centipedes, beetles, spiders, ants, snails, slugs); mesofauna are 0.1 to 2mm (e.g. springtails, mites), and microfauna less than 0.1 mm in size (protozoa, nematodes).

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.

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 stabilising soil aggregates and in the decomposition of organic matter. Arbuscular mycorrhizal fungi form a symbiotic relationship with the roots of most plant species, playing a major role in enhancing soil structure and fostering the microbial community within the mycorrhizosphere, thus increasing nutrient mineralisation, and enabling increased nutrient uptake. Soil microbial biomass has been described as the "eye of the needle" through which all decomposing organic matter must pass before being transformed into plant available nutrients and soil humus (Sparrow, pers. communication); microbial activity has been suggested to mimic slow release fertiliser with minimal leaching of the plant available nutrients into the groundwater.

Earthworms transport and mix organic, mineral, and microbial soil components to deeper soil horizons, and their activities can alter the physical and chemical conditions in the soil, increasing mineral nutrient availability to plants. Other macro- and meso-fauna play a role in nutrient cycling by shredding materials into smaller pieces with higher surface area, thus providing greater access for microorganisms. Several studies have found a positive correlation between soil invertebrate biomass and diversity (particularly mites) and soil health and crop performance, demonstrating that invertebrate biomass and diversity can be used as indicators of soil health.

Microbiological indicators are now recognised as the most sensitive indicators of soil health. Soil microorganisms are incredibly dynamic as their populations respond rapidly to changes in conditions, whether man-made, or environmental such as temperature and rainfall.

There are many tests now available for testing the size, activity and identity of the microbial population in the soil. The Australian Soil CRC is developing practical soil tests specifically to help growers make decisions based on soil health indicators (https://soilcrc.com.au/spotlight-on-emerging-soil-technologies/).

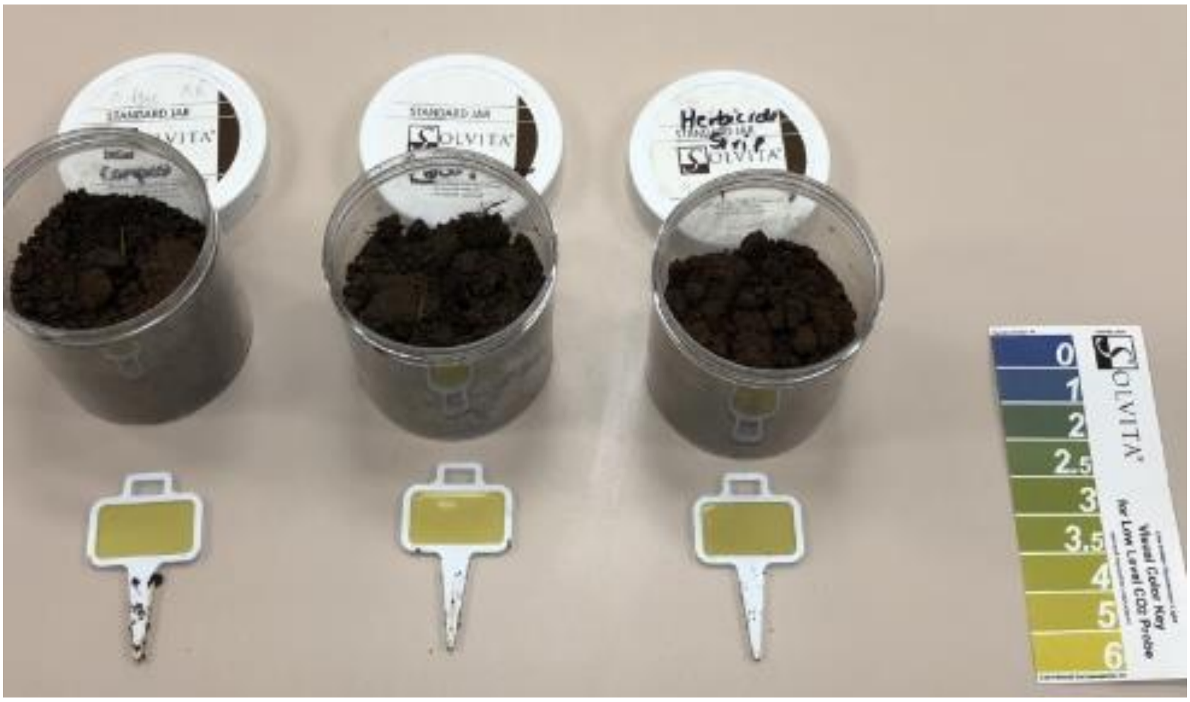


***Figure 2**. Field measurement of microbial respiration (Photo credit: Jessica Fearnley, NSW DPI)*

## Soil organic matter

Soil organic matter (SOM) is a heterogenous mixture of plant and animal litter in various stages of decomposition, living microbial biomass and its detritus, and humus which is the final product of decomposition. It is a major source of nutrients such as phosphorus, sulphur and nitrogen and the main food that supplies carbon and energy to soil organisms. SOM has physical, chemical and biological functions (Table 4), and dynamic interactions occur between these three major functions.

***Table 4**. Functions of soil organic matter*

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

The speed of decomposition of SOM is determined by the soil organisms present, the physical environment, and the quality of the organic matter. Different products are released in the decomposition process: carbon dioxide ($CO_2$), energy, water, plant nutrients and resynthesised organic carbon compounds. The simpler organic molecules such as sugars, amino acids, and cellulose are valuable food sources for many organisms and are readily consumed, hence do not remain in the soil for long.

## The importance of plant roots

According to soil scientist Dr Bill Cotching, soil structure is as much about growing roots as the physical structure - actively growing plant roots exert a pressure of 2,000 kilopascals, helping to break up clods and improve structure. Clods indicate a lack of biology and/or root material in the soil.

***Figure 3**. Good soil structure showing roots and macropores (left) and 'dreadlock' roots with adhering soil particles held together by the biotic glue produced by bacteria and fungi (right).*

Root exudates provide a food source for microorganisms, particularly those that form symbiotic relationships such as mycorrhizal fungi and nitrogen fixing bacteria. Protozoa and nematodes that graze on bacteria are also more abundant in the rhizosphere. The rhizosphere is the soil zone immediately surrounding the roots, i.e. 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. 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.

# What we found

The key question for this research was: *How do different orchard floor management practices influence soil health, yield and fruit quality*?

## Impact on soil properties and biology

The inter-row treatments revealed very little change in the soil parameters measured, suggesting that any fit for purpose ground cover will provide benefits in the inter-row. Despite the relatively short time frame that treatments were implemented in this project, we did observe some positive differences between treatments in the tree-line compared to the herbicide control plots (Table 5).

***Table 5:*** *Effect of orchard floor treatments on key soil health indicators*

| **Soil Health Indicator** | | **Effect of tree-line treatments compared to herbicide plots** |
|---|---|---|
| **Soil microbiology** | Soil microbial carbon | Increased in compost plots |
| | Bacterial species diversity | Increased in grass/clover plots |
| | Microbial respiration | Highest in living grass/clover at NSW site |
| **Soil Macro fauna** | Earthworm numbers | 440% increase in grass/clover plots |
| **Soil Physical Characteristics** | Aggregate stability | Trend for improved aggregate stability in all tree-line cover treatments (compost, living grass/clover, mulch) meaning better soil structure |
| | Soil bulk density | Trend for reduced soil bulk density in all tree-line cover (compost, living grass/clover, mulch) meaning less compaction |
| | Hydraulic conductivity | Trending for improved hydraulic conductivity in all tree-line cover treatments (compost, living grass/clover, mulch) |
| | Infiltration rate | Improved infiltration rate in compost plots |
| **Soil Chemistry** | pH | Grass clover plots less acidic |
| | Nitrate nitrogen | 3 times higher in compost plots |
| | Ammonium nitrogen | 2.2 times higher in grass/clover plots |
| | Phosphorus | 2.2 times higher in compost plots |
| | Potassium | over 3 times higher in compost plots |

One conclusion we can draw is that keeping the soil bare through regular herbicide application exposes organisms to temperature fluctuations and soil erosion - ground cover in the tree-line is important to protect the soil microbes.

However more time is needed to quantify these changes, as building up good soil health is a gradual process.

## Impact on tree growth, crop load and fruit quality

Tree-line treatments had no effect on tree growth, measured as increase in trunk circumference, blossom density or crop load.

There were small differences in fruit soluble solids and dry matter content, although these differences were not consistent across the two seasons. Fruit firmness was higher in the grass/clover plots compared with the herbicide plots in both seasons. Fruit from the grass/clover plots showed slightly more redness than the other plots, while fruit from the compost plots had the least redness. Starch pattern index (SPI) showed a slower rate of conversion of starch to sugar in the grass/clover plots across both seasons.

There was no difference in mean fruit weight between the tree-line treatments in 2022, but in the 2023 season fruit in the grass/clover tree-line plots was 11g lighter on average than in the herbicide plots. One explanation for this difference is that the grass in this season was well established and growing vigorously and hence was competing with the trees for water and nutrients – potentially if these plots had been mown regularly there may have been no effect. This is worth exploring in future studies.

A visual difference was observed in autumn 2023 between mulched treatment rows and non-treatment rows where the tree-line had become overgrown. Trees in the mulched plots retained their leaves longer than those in the overgrown non-treatment rows (Figure 4). Later leaf fall has also been observed in trees planted on fertile soils such as river flats, so this suggests improved nutrient availability in the mulched treatment plots.

***Figure 4**. Delayed leaf fall in third leaf trees in mulched plots (left) compared with overgrown tree-line (right).*

### Competition

Many orchardists are concerned about competition for water and nutrients from ground cover plants on the orchard floor, particularly in the tree-line, reducing yield and fruit quality. However, the results from both the intensive research site and the regional demonstration sites suggest that the impact of living mulches in the tree-line is not necessarily detrimental to fruit quality. Further studies examining tree-line living mulch mixes and their vigour will alleviate this concern. Another option is the use of summer dormant species, however in an irrigated orchard these species do not always become dormant.

There is also concern that a vegetated tree-line provides habitat for pest species and tall vegetation growing up into the lower branches of the trees can create a humid microclimate, thus increasing disease pressure. Managing the tree-line vegetation by mowing, or even an occasional herbicide application, can ameliorate these problems.

## Managing pests

The research sites were monitored as part of a collaboration with project AP19002 S*trengthening cultural and biological management of pests and diseases in apple & pear orchards*. Several lessons arose from this collaboration in relation to management of pests within the orchard and the benefits of groundcovers:

- arthropod species change with orchard floor plant species, so arthropod abundance and diversity can be manipulated by altering ground cover composition;
- within the tree line predators such as earwigs in tree canopies and spiders on the orchard floor were encouraged by living mulches;
- movement of beneficial fauna from the inter-row towards the vegetated (living mulch) tree-lines was observed, providing potential to have a greater impact on economically important pest species;
- non-pest ground dwelling mite populations increased in the tree-line where compost was applied;
- costs and benefits for pest management can be quantified but may be site specific;
- pesticide applications can undo any improvements in numbers of beneficial insects;
- the treatments applied within this project did not trigger any changes in fruit damage.

Conclusions from this study in relation to pest management include:

- use of groundcovers in the inter-row and tree-line can potentially aid in suppressing ground dwelling pest species (i.e., LBAM during winter) and canopy borne pests such as woolly apple aphid during the production season;
- promoting biodiversity of orchard natural enemies can be achieved through adoption of inter-row vegetation management practices such as adapting mowing schedules or use of no-mow flowering strips;
- application of compost or mulch within the tree-line is recommended to provide harbour for ground-dwelling predators and detritivores.

# Improving the orchard floor

The way that the orchard floor is managed has a strong influence on soil structure and functions such as nutrient availability, water holding capacity and microbial presence and diversity. Practices such as reducing herbicide use and adding organic matter to the soil will assist in increasing soil life. Non-living organic materials such as compost, and/or mulches such as straw or mower clippings can contribute to orchard soil health. However, living mulches such as  grass/clover swards with actively growing plants is critical to healthy microbial communities that support nutrient cycling.

For a truly sustainable orchard we need to put in place practices that enable a return to complex systems with strong food webs and beneficial trophic interactions. The starting point is to increase biodiversity within the orchard, and simple methods for achieving this include:

- ☑ increasing soil organic matter
- ☑ incorporation of compost into soil prior to planting new blocks
- ☑ diversifying orchard floor vegetation for a range of root architectures
- ☑ minimising herbicide use
- ☑ use of cover crops / living mulches
- ☑ applying organic mulches in the tree row
- ☑ mow and blow (throw) inter-row vegetation into the tree row
- ☑ reducing frequency of mowing
- ☑ planting of flowering hedgerows around the orchard and/or between blocks
- ☑ planting of multiple tree species
- ☑ use of biocontrol strategies for pest control rather than pesticides

## Selecting species for the orchard floor

The plants growing on the orchard floor have a large influence on what happens both in the soil and above ground - ideally there should be a mix of species with a range of root architecture and each species should fulfil a range of functions. Deep-rooted species will bring leached nutrients to the surface and assist with breaking up compaction layers. Above ground, the plants of the orchard floor provide a home and/or a food source for pollinators, predators and other beneficial insects.

***Figure 5****. Different orchard inter-row plantings.*

Plant species selected need to be robust and resilient to traffic, but not invasive and competitive, and provide shelter without creating a negative environment for pest and disease. A myriad of invertebrates (insects, millipedes, spiders, and earth worms) and microbes live at the soil boundary and below, and these organisms are strongly influenced by the plant species on the orchard floor. They are an essential part of the cycling system for leaf litter and prunings that contribute to soil and tree health. These in turn are influenced by other orchard management practices including irrigation and nutrient applications.

As root exudates from actively growing plants provide a food source for soil microbes, the abundance and diversity of the soil microbial community is likely to be increased by ensuring full ground cover with a range of plant species. There is normally a decline in carbon availability with increasing soil depth, and this has been attributed to the vertical soil distribution of microbial communities. The dominant factor influencing microbial biomass and activity at different depths appears to be plant root distribution, with the presence of deeper rooting species resulting in higher microbial populations and diversity deeper in the soil profile.

Any ground cover, even weeds, as a living mulch is preferable to bare soil, but the more diverse the plant species on the orchard floor, the greater the diversity of root architecture (fibrous, spreading and tap roots). There is evidence that the more diverse the plant species, the greater the diversity in soil organisms.

A useful tool developed for vineyards can be found here: https://www.covercropfinder.com.au/tool.php?id=1

A living mulch dominated by perennials is logical in an orchard situation, as it enables the inter-row sward to be maintained without the need for reseeding each year. Use of annual species requires either reseeding every season, adding to the costs of maintaining the orchard floor, or allowing the annuals to flower and seed. Although one benefit of this will be reducing mowing costs, it will require a change in mind set and acceptance of an 'untidy' orchard.

There are multiple criteria to be considered when selecting species for planting in the orchard inter-row and/or tree-line, and these are listed in Table 6.

***Table 6****: Considerations when selecting plant species for living mulches in the orchard.*

| Inter-row | Tree-line |
|---|---|
| - easy and fast to implement | - easy and fast to implement |
| - rapid establishment of sward | - established rapidly |
| - ease of maintenance after establishment | - longevity and maintenance |
| - longevity | - productive organic matter source |
| - range of root architecture | - food source/habitat for beneficial insects/mites |
| - traffic resilience and provide sufficient grip for tractors/equipment | - avoid tall growth habits that can reduce air flow and promote disease unless willing to manage |
| - aids in reducing soil compaction | - improved soil structure & water infiltration |
| - improves water infiltration | - improved water retention |
| - nutrient recycling | - nutrient recycling and availability |
| - habitat for beneficial insects and mites | - increased soil biology |
| - floral diversity to provide food sources for a diverse range of natural enemies / pollinators | - maintain/improve fruit quality |
| | - sustainability |

## Pros and cons of different orchard floor management options

Any management option applied to the orchard floor will have both positive and negative impacts, so the question to ask when deciding on options for managing the orchard floor is:

Do the benefits outweigh any negative impacts?

The experience and results from the research trials and regional demonstration sites are summarised in Table 7.

***Table 7:*** *Pros and cons of different orchard floor management options*

| Orchard floor treatment | Pros | Cons |
|---|---|---|
| **Bare earth Strip** | - Easy to maintain | - Does not contribute to soil health<br>- Herbicide can be a health risk to workers<br>- Expense of regular application of herbicide – labour and chemical costs<br>- Potential for erosion of bare soil |
| **Native plants** | - Encourage native fauna<br>- Can be drought resilient | - Difficult to establish<br>- Less competitive particularly if a large weed seed bank is present<br>- Slow growth rate<br>- Can be expensive |
| **Living Mulches** | - Contribute to soil health<br>- May encourage beneficial insects, mites and pollinators<br>- Establishment easiest in Autumn | - Mowing of vigorous species can be costly<br>- Tall species can create easy access into the tree canopy for pests and/or encourage disease by creating a more humid environment<br>- Can pose a significant risk of damage to the orchard from bushfires |
| **Non-Living Compost/Mulch/ Mow & Throw** | - Add organic matter and contribute to soil carbon<br>- Suppress weeds if applied thickly with good coverage<br>- Use locally sourced with low transport costs to reduce cost or grow your own (mow & throw) | - Fine compost breaks down quickly and acts as a seed bed for weeds<br>- High cost of regular replacement of imported materials<br>- Can potentially act as a wick in bushfires |

# Monitoring your orchard soil health

There are many simple ways of keeping track of the condition of your soil, from commercially available soil test kits to simple tests using everyday equipment. Although depending on what you find it may still be useful to send some samples to a commercial laboratory for a full analysis.

## Indicators of good soil health

Healthy soil attributes to work towards include:

- ☑ good levels of organic matter;
- ☑ abundant populations of earthworms (10-12 per spadeful), macro- and meso-arthropods;
- ☑ thriving populations of micro-organisms - bacteria, fungi, protozoa, and nematodes;
- ☑ nutrient cycling to provide plant available nutrients;
- ☑ 100% ground cover with a diverse mix of species;
- ☑ small & large pore spaces for air & water;
- ☑ good soil aggregation;
- ☑ good water infiltration rates (>100 mm/hr);
- ☑ absence of a compaction or crusting layer.

## Change for the better

With soil health indicators, it is important to recognise that there is a difference between changed and improved soil properties due to a treatment. Soil health testing is not so much about absolute values but showing how a soil is responding to change, whether that change is time or a new management practice. So, watch for changes over time but make sure you are consistent in the time of year you take a sample, the way you take a soil sample, and the lab you use if you are sending samples for laboratory analysis.

Remember that if you change the way you manage your orchard floor, results won't be seen immediately – so to know whether the change was beneficial you need to monitor what is happening over time.

## Principles for assessing your soil health

Assessing your own soil health can be a simple process - there are multiple tests that you can do yourself, or you can send samples to a commercial laboratory.

Determine what you want to monitor for change over time and stick to the following:

1. Monitor at the same time each year from the same place (GPS on your phone or a flag in the ground);
2. Use the same laboratory for analysis each season;
3. Take several samples from across the orchard block;
4. Record your results and compare to results from previous seasons;
5. Collect and store a sample of soil in an icecream container each year for a physical comparison of your soil condition across seasons.

## A simple toolkit for measuring orchard soil health

**Essentials**

- Record sheet
- Phone or camera
- Spade
- Large plastic sheet or tray
- Clean ziplock bags for collecting soil for laboratory analysis
- Clean ice cream container with lid for storing soil
- Cotton undies or calico strips

**More specialised** (see Table 8 for further details)

- Infiltration rate: PVC pipe (30 mm diameter X 150 mm long) marked at 100 mm and 125 mm
  stopwatch or your phone with timer
  plastic cling wrap
  mallet and block of wood
  ruler
- Compaction: soil penetrometer, or
  a 4-6 mm steel rod, or
  length of heavy fencing wire (3 mm diameter and approx. 50 cm long)
- Aggregate stability: baking tray,
  bottle of distilled or rain water,
  shallow glass or dish
- Soil Biology: Solvita respiration kit & screw top glass jar

***Figure 6**: Measuring soil health parameters in the orchard.*

*Table 8: Monitoring and interpreting soil health measures*

| Soil Health Indicator | How to measure | Interpreting the results |
| --- | --- | --- |
| **Soil Organic Matter (SOM)** | Laboratory soil test. | Local agronomist or Industry Development Officer.<br>Compare to a typical soil in your region: https://www.applesoils.com/<br>Monitor changes from season to season. |
| **Nutrient levels** | Laboratory soil test of major nutrients, micronutrients, pH and EC. | Local agronomist or Industry Development Officer.<br>Compare to a typical soil in your region: https://www.applesoils.com/<br>Monitor changes from season to season. |
| **Earthworms and other soil arthropods** | The best time to count earthworm populations is early in the spring, or after the soil has wetted up in the autumn.<br>Count earthworms when it is warm and after rain to provide the best population estimates. Avoid taking samples when the soil is very dry. Soil should have been wet for a few days prior to sampling.<br>Dig a soil pit of around 20 cm (spade width) deep and wide onto a mat. Sort what you find in your soil into juvenile and adult earthworms; other arthropods. Record the numbers. | Typically, 10-12 per spade full is considered a healthy population.<br>Monitor numbers from different parts of your orchard over several seasons.<br>More information: How to count earthworms (pdf 321 KB). |
| **Soil Structure** | **Visual soil assessment (VSA)**<br>Watch this YouTube video on visual soil assessment from NSW DPI https://www.youtube.com/watch?v=Rv2BYMjnW-g<br>Use a score card such as the FAO VSA Field Guide for orchards https://www.fao.org/3/i0007e/i0007e03.pdf | **Visual soil assessment:**<br>The FAO guide will help you interpret soil texture, soil structure, soil porosity, soil colour (mottles) earthworms, rooting depth, crusting, ponding and erosion. |
| | **Collect and store**<br>Collect an intact sample of orchard soil with your spade and store in an ice cream container until next season. | **Collect and store**<br>Compare soil collected each season to visually see if the structure is changing. |

| Soil Health Indicator | How to measure | Interpreting the results |
|---|---|---|
| **Soil Aggregate stability** | Collect a few handfuls of soil from the orchard, usually from the top 10 cm. Allow the soil to air dry completely – usually takes around 3 days. Place three pea sized aggregates (4 – 6 mm diameter) into 20 – 40 mm of rain or distilled water. Watch carefully for the first few minutes, then observe in an hour and again in 24 hours. | How much the soil 'disperses' and makes the water cloudy will indicate how stable your soil aggregates are.<br>Watch a video: https://www.youtube.com/watch?v=xuXFQDzXNQU<br>Read more here: https://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_bonding_aggregation_qrg |
| **Soil compaction / soil 'strength'** | A penetrometer is tool for measuring soil compaction. Simple tools for measuring soil compaction include your spade, a steel rod (8-10 mm diameter) or heavy gauge fencing wire (3 mm) about 50 cm long.<br>A laboratory test of soil bulk density usually carried out for research purposes. | Visually observe the soil in the pit you have dug. Examine the rooting pattern. Take a photo. This will be a reference point as to whether soil compaction is restricting root growth.<br>Using a tool: The readings from a penetrometer can be compared from year to year. Readings greater than 1.5 MPa indicate root growth is restricted.<br>How much force do you need to push a spade, steel rod or wire into the soil? Do you reach a point where it is hard to push through? Is it easier to push in once you have passed this point (compaction layer) or does it get progressively harder (increasing compaction with depth)?<br>*Compare your results with a spot in the orchard where compaction is not a problem – such as under a hedgerow or fence line.* |
| **Water Infiltration** | A PVC pipe is hammered into soil to a depth of 100 mm. The pipe is then gently filled to 25 mm depth. The time it takes for the water to soak into the soil will be a measure of the soils water infiltration rate. | Read more here: https://www.hort360.com.au/wordpress/wp-content/uploads/2020/11/Measuring-Soil-Water-Infiltration.pdf<br>Watch a video: https://www.youtube.com/watch?v=awvoKMQCSbY https://www.youtube.com/watch?v=xuXFQDzXNQU |

| Soil Health Indicator | How to measure | Interpreting the results |
|---|---|---|
| **Soil Biology** | Calico strips or cotton undies are buried for 6 – 8 weeks (see below for a description of the method).<br><br>Respiration test using a commercial kit for example from Solvita: https://solvita.com/ | Visual comparisons of undies or calico strips:<br>1. Compare results from different orchard blocks. Faster or more breakdown means a more active fungal population in your soil;<br>2. Take photos each year and compare results.<br><br>Compare respiration results from different orchard blocks and each season. |
| **Ground Cover** | Take photos of ground cover in both tree-line and interrow. Easiest if you use a set measure of the area you photograph such as a square frame (quadrat). | Visual comparison of species and ground cover present. |

## Cotton degradation test of soil microbial activity

Bury calico strips (or cotton undies) for 6-8 weeks to provide an indication of microbial activity – predominantly fungal as they feed on cellulose (Figures 7&8).

Make sure that you mark the burial site!

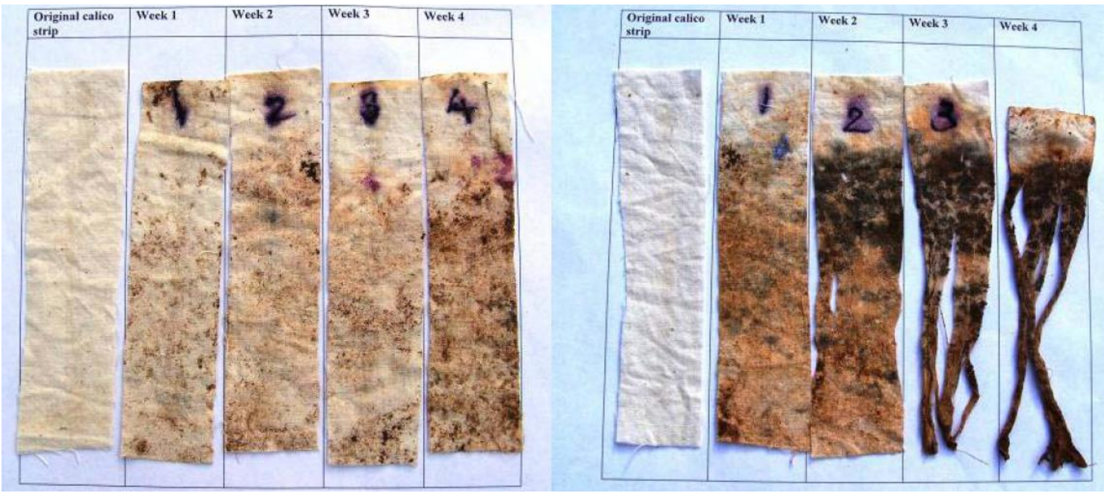


***Figure 7***: *Calico strips showing low biological activity (left and high biological activity (right).*

***Figure 8***: *Cotton undies for checking soil biological activity. Note lack of degradation of synthetic elastic and thread in photo on right.*

## Other resources to help you monitor orchard soil health

Sampling your soil for laboratory testing (Washington State University)
https://treefruit.wsu.edu/soil-sampling-for-tree-fruit-orchards/

5 Soil testing techniques every farmer should know (AHDB – Soil Association UK):
https://www.youtube.com/watch?v=TMXghhKStvE

## A spade is your best friend!

One of the most valuable tools to see what is happening in your soil is a spade!

### Dig a hole so you can see the subsoil

- Moss on the surface is a sign that soil is not very active.
- Do plant roots penetrate through to the subsoil?
- Are old inactive roots decomposing (evidence of bacteria and fungi)?
- Does the soil smell earthy (actinomycetes- soil bacteria that decompose organic matter)?
- Is the soil dark in colour (soil organic carbon)?
  - Grey and yellow soil colour indicate anaerobic soils.
- Smell - hydrogen sulphide is an indication of lack of air (anaerobic conditions).
- Is the soil well structured (soil aggregation)? – test by putting aggregates in water, if they hold together the soil structure is stable.

### Look for evidence of organisms

- Bury calico strips (or cotton undies) – the rate of decomposition gives an indication of fungal activity as fungi break down the cellulose in the cotton. Wooden stakes can also be used.
- Set pitfall traps for macrofauna (2-20 mm size including woodlice, earthworms, beetles, beetle larvae, centipedes, millipedes, slugs, snails, ants, and harvestmen) & mesofauna (0.1 to 2 mm size including nematodes, mites, springtails, earthworms, small spiders, pseudoscorpions).
- Look for tunnels and faecal piles (bioturbation) - indicates presence of earthworms and/or beetles.
- Count earthworms – 10-12 per spadeful is good!
- Examine nodules on clovers and other legumes - a bright pink/red internal colour indicates active nitrogen fixing bacteria.

# Appendix 1 – Living mulch species

***Table A1.1****: Species in each mix and planting rates in Tasmanian trial sites.*

| | Common name | Rate |
|---|---|---|
| **Ryegrass/clover sward** | | |
| Victorian ryegrass } | | 8 kg/ha |
| Kingston ryegrass } Huon #2 mix from | | 12 kg/ha |
| USA red clover } Nutrien Ag | | 5 kg/ha |
| USA white clover } | | 2 kg/ha |
| ‘Apex’ white clover | | 1 kg/ha |
| **Clover/grass mix** | | |
| *Festuca rubra* | Creeping red fescue | 5 kg/ha |
| *Festuca ovina* | Sheeps fescue | 5 kg/ha |
| *Festuca rubra ssp Commutata* | Chewings fescue | 5 kg/ha |
| *Dactylis glomerata cv. Summadorm* | Cocksfoot | 5 kg/ha |
| *Trifolium fragiferum cv. Palestine* | Strawberry clover | 3 kg/ha |
| *Trifolium repens cv. Apex* | White clover | 3 kg/ha |
| **Flowering meadow mix** | | |
| *Phacelia tanacetifolia* | Lacy phacelia / Blue tansy | 4 kg/ka |
| *Fagopyrum esculentum* | Buckwheat | 5 kg/ka |
| *Coriandrum sativum cv. Santo* | Coriander | 3 kg/ka |
| *Plantago lanceolata cv. Tonic* | Plantain | 4 kg/ka |
| *Trifolium michelianum* | Balansa clover | 2 kg/ka |
| *Brassica sp.* | BQ mix | 2 kg/ka |
| *Raphinus sativus acanthiformis* | Daikon radish | 3 kg/ka |
| *Cichorium intybus* cv. Commander | Chicory | 2 kg/ka |
| **Native flowering mix** | | |
| *Microleana stipoide* | Weeping grass | 2 kg/ha |
| *Viola hederacea* | Native violet | 0.5 /m |
| *Einardia nutans* | Climbing saltbush | 0.3 /m |
| *Geranium solanderia* | Native geranium | 0.3 /m |
| *Goodenia elongata* | Lanky goodenia | 0.3 /m |
| *Arthropodium milleflorum* | Vanilla lily | 0.3 /m |
| *Calocephalus lacteus* | Milky beauty-head | 0.3 /m |

***Table A1.2****. NSW regional site flowering meadow mix.*

| Bee Friendly Mix | Beneficial Insect Mix |
|---|---|
| Blanketflower (*Gaillardia pulchella*) | Blanket Flower (*Gaillardia aristata)* |
| Blue Flax (*Linum perenne*) | California Poppy (*Eschscholzia californica*) |
| Blue-thimble-flower (*Gilia capitate*) | Candytuft (*Iberis umbalatta*) |
| California Poppy (*Eschscholzia californica*) | Common Dill (*Anethum graveolens*) |
| China aster (*Callistephus chinensis*) | Coriander *(Coreopsis sativum*) |
| Chinese hound's tongue (*Cynoglossum amabile*) | Dense Blazing star *(Liatris spicata)* |
| Common Poppy (*Papaver Rhoeas*) | Garden/Dwarf Cosmos *(Cosmos bipinnatus)* |
| Garden Tickseed (*Coreopsis tinctoria*) | Mayfield Giants (*Coreopsis lanceolate)* |
| Korean Mint (*Agastache rugose*) | Menzies' baby blue eyes (*Nemophila menziesii*) |
| Lance-leaved coreopsis (*Coreopsis lanceolate*) | Queen Anne’s Lace *(Ammi majus)* |
| Menzies' baby blue eyes (*Nemophila menziesii*) | Rock Cress (*Aubrieta hybrid)* |
| Moroccan Toadflax (*Linaria maroccana*) | Shasta Daisy (*Chrysanthemum maximum)* |
| Purple coneflower (*Echinacea purpurea*) | Sweet alyssum *(Alyssum benthamii)* |
| Sweet alyssum (*Lobularia maritima*) | Wallflower *(Cheirianthus Chieri)* |
| Tidy tips (*Layia platyglossa*) | Wild bergamot (*Monarda fistulosa*) |
| Wallflower (*Cheiranthus allionii*) | |
| Wild bergamot (*Monarda fistulosa*) | |

***Table A1.3****. NSW regional site native herbaceous mix, sourced from* Native Seeds Australia*.*

| Common name | Species name |
|---|---|
| Burra Weeping grass | *Microlaena Stipoides var. Burra* |
| Common Tussock grass | *Poa labillardieri* |
| Curly Mitchell grass | *Astrebla lappacea* |
| Evans Wallaby grass | *Rytidosperma caespitosa* |
| Griffin Weeping grass | *Microlaena Stipoides var. Griffin* |
| Kangaroo grass | *Themeda triandra* |
| Native Wheat grass | *Anthosachne scabra* |
| Oxley Wallaby grass | *Rytidosperma bigeniculata* |
| Purple Wire Grass | *Aristida personata* |
| Scent Top grass | *Capillipedium spicigerum* |
| Silky Bluegrass | *Dichanthium sericeum* |
| Silky top Lemon Scented grass | *Cymbopogon obtectus* |

***Table A1.4****. SA regional site flowering meadow mix.*

| Common name | Species name |
|---|---|
| Sweet alyssum | *Alyssum benthamii* |
| Queen Anne's Lace | *Ammi majus* |
| Common Dill | *Anethum graveolens* |
| Rock Cress | *Aubrieta hybrida* |
| Wallflower | *Cheirianthus chieri* |
| Shasta Daisy | *Chrysanthemum maximum* |
| Mayfield Giants | *Coreopsis lanceolate* |
| Coriander | *Coreopsis sativum* |
| Garden/Dwarf Cosmos | *Cosmos bipinnatus* |
| California Poppy | *Eschscholzia* |
| Blanket Flower | *Gaillardia aristate* |
| Candytuft | *Iberis umbalatta* |
| Dense Blazing Star | *Liatris spicata* |
| Wild Bergamot | *Monarda fistulosa* |
| Menzies' Baby Blue Eyes | *Nemophila menziesii* |

***Table A1.5****. SA regional site native species mix.*

| Common name | Species name |
|---|---|
| Kneed wallaby grass | *Rytidosperma geniculatum* |
| Wallaby grass | *Rytidosperma caespitosum* |
| Weeping grass | *Microlaena stipoides* |
| Windmill grass | *Chloris truncata* |
| Red-leg grass | *Bothriochloa macra* |
| Woolly New Holland daisy | *Vittadinia Gracilis* |
| Lemon Beauty Heads | *Calocephalus citreus* |
| Yellow buttons | *Chrysocephalum apiculatum* |

***Table A1.6***. *WA regional site flowering meadow mix.*

Phacelia scorpion weed
Coriander
Marigold
Equine mix sourced from Bells Pasture Seeds and sown at 12kg/600m$^2$ consisting of:
- Ryecorn cereal
- Everlast ryegrass
- Fescue
- Cocksfoot
- Balansa clover
- Arrowleaf crimson clover
- Cadiz serradella
- Chicory
- Phalaris

***Table A1.7***. *WA regional site native species mix.*

| Common name | Species name |
|---|---|
| Wallaby grass | *Austrodanthonia caespitosa* |
| Weeping grass | *Microlaena stipoides* |
| Spear grass | *Austrostipa sp* |
| Running postman | *Kennedia prostrata* |
| Pink everlastings | *Rhodanthe chlorocephala* |
| Fan flower | *Scaevola crassifolia* |
| Slender Lobelia | *Lobelia tenuior* |
| Native Bluebell Creeper | *Billardiara fusiformis* |