CLIMATE

PLANTS

SOIL

A guide to the sustainable management of soil health, nutrition and organic matter in Central Victoria

Mount Alexander Sustainability Group Inc

Australian Government

National Landcare Program

Federation University

FUTURE REGIONS RESEARCH Centre

ACKNOWLEDGEMENTS

Mount Alexander Sustainability Group acknowledges the traditional owners of the land on which the Healthy Soil Initiative is conducted, the Dja Dja Wurrung, Taungurung and Wurundjeri Woi Wurrung nations whose members, elders and ancestors have been custodians of country for many thousands of years and continue to perform age old ceremonies of celebration, initiation and renewal. We acknowledge and admire their traditions of custodianship, stewardship, kinship and connection with country and deep knowledge of the land and climate.

The Health Soils Initiative is run by the Mount Alexander Sustainability Group. It is funded by the Australian Government through the National Landcare Program Smart Farms Small Grants initiative. This guide has been developed with the support of Federation University's Future Regions Research Centre. To learn more about the initiative, please email Bill Grant via b.grant@federation.edu.au or call on 0407 882 070.

Mount Alexander Sustainability Group (MASG) is the peak sustainability organisation for the Mount Alexander Shire, delivering education, research, advocacy, and endorsement for shire wide sustainability and clean energy initiatives. MASG was established in 2006 by a passionate group of locals who wanted coordinated action on climate change and to support the Mount Alexander Shire Community to work towards a sustainable future. For further information see; www.masg.org.au

MASG would also like to acknowledge landowners and volunteers who have contributed to the project, and in particular: Deane Bellfield, Jason McAinch, Mikaela Beckley, Katie Finlay, Melissa Pollock, and the farmers and landowners who attended workshops and gave their time to work with MASG to develop Soil Health, Nutrition and Organic Management Plans.

Leader author: Bill Grant   Production: Greengraphics

Mount Alexander Sustainability Group supports other regional programs supporting sustainable and regenerative agriculture including:

- The Mount Alexander Regenerative Agriculture Group, which focuses on cropping, pasture and grazing management systems that aim to increase draw down of atmospheric carbon into soil, reduce farm emission and inputs, promote natural farm ecosystems, and improve soil organic matter and soil and plant health. For further information see: www.masg.org.au/agriculture/regenerative-agriculture/
- The Healthy Landscapes program, which aims to help landowners to identify and implement practical land management practices to improve your grazing, productivity, soil health, biodiversity, and waterway health. For further information see: www.mrsc.vic.gov.au/Live-Work/Environment/Land-Management/Healthy-Landscapes
- North Central Catchment Management Authority's Sustainable Agriculture program. See: www.nccma.vic.gov.au/projects/agriculture/

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Table of definitions and initialisations

Term	Definition
Healthy Plant ⇆ Healthy Soil Cycle	A concept recognising the importance of healthy plant growth in driving soil health, and the importance of soil health (i.e. good nutrition, pH, structure and water availability) to healthy plant growth. Addressing soil chemical, physical and biological constraints helps plants to grow well, and these healthier plants build and maintain soil health.
pH	A measure of the acidity or alkalinity of soil and water, where the value of 7.0 is neutral, and below this is acidic and above this is alkaline. Overly acidic or alkaline condition affect the availability of nutrients and chemical toxins and effect soil biology. Ideally, a soil will have a pH between 6.0-7.0, and may pose constraints to plant growth outside the range of 5.5 and 8.0. pH is a logarithmic scale, so a pH vale of 5.0 is ten times more acidic than 6.0, but a value of 4.9 is 20 times more acidic and a value of 4.0 is 100 times more acidic.
MASG	Mount Alexander Sustainability Group see: www.masg.org.au
Seasonal yield potential	The yield a plant would achieve of the only constraint to root and plant growth was the seasonal conditions (mainly the amount and timing of rainfall, as well as temperature and extreme weather events)
Soil constraint	A physical, chemical or biological impediment to root and plant growth that prevent a plant from achieving its seasonal yield potential.
Soil health	The capacity of a soil to allow roots and plants to grow to their seasonal potential. This involves the physical, chemical and biological characteristics that affect the ability of plants to grow strong and deeper roots and have access to the available nutrients and water they need. A healthy soil is 'alive' with soil microbiology and ecosystems that help to maintain a good soil structure and cycle nutrients. This requires levels of soil organic matter to feed soil ecosystems and hold water.
SOC	Soil organic carbon. A measure of the amount of organic matter and compounds in the soil, excluding larger un-decomposed organic material which is screened from samples.. SOC is a component of soil organic matter (see below), and also includes minerally associated organic carbon where organic compounds have formed binds with clay minerals.
SOM	Soil organic matter. A measure of the amount of organic material in the soil, excluding larger un-decomposed organic material which is screened from samples.
Soil profile	Describes changes in the soil texture, structure, colour and chemistry at different depths.
Sub-soil	The layer of soil immediately below the topsoil/upper soil (see below) where the texture, structure, colour or chemistry changes, and is often the point at which soil is less friable, and has lower organic matter and less root growth present. Sometimes the sub-soil will be divided into 'upper subsoil' and 'lower subsoil' to describe changes such as increased density or evidence of waterlogging further down the profile.
Surface soil.	The upper 2-5cm of soil. Sometimes referred to as the 'O-horizon' or organic layer, this layer can be rich in decomposing organic material, plant thatching and root matting. On bare soils, the surface soil can show patterns of cracking or crusting that can be indicative of water infiltration and upper soil structure.
Topsoil/upper soil	The upper layer of soil. This is typically the more friable soil layer where most plant roots grow. This layer also often has higher levels of organic matter than sub-soils and is where earthworms and other beneficial soil biology are most active. In central Victoria this typically varies from 10-40cm.
Yield gap	This is the difference between actual yield/production and what plants could produce within the seasonal constraints. It is a good indicator of soil health. Work conducted by CSIRO suggests many central Victorian farms only produce 30-50% of the seasonal yield potential. Soil constraints are a significant contributor to these lower yields.

ABOUT THE INITIATIVE

The Healthy Soils Initiative promotes better understanding of soil health and constraints in Central Victoria.

The Healthy Soils Initiative promotes better understanding of soil health and constraints in Central Victoria. It provides landowners with information and tools to assess soil health and constraints, manage soil to build improve and maintain soil health, and monitor their soils' health from season to season into the future. The initiative aims to promote practical soil health management that boosts farm productivity and helps farmers to benchmark, build and maintain soil health.

The initiative has been developed by the Mount Alexander Sustainability Group and Federation University, with funding support from the Australian Government through the National Landcare Program Smart Farms Small Grants initiative.

Research by CSIRO and others suggests that on average, crops and pastures in central Victoria only produce 30-50% of their seasonal yield potential

The initiative team has worked with farmers in central Victoria to identify constraints to healthy plant and root growth occurring in the upper 50-60cm of their soil, and develop management plans to improve plant and soil health.

Research by CSIRO and others suggests that on average, crops and pastures in central Victoria only produce 30-50% of their seasonal yield potential (i.e. what they could produce if seasonal rainfall and temperature were the only constraints to growth). Although factors such as disease, weeds and pest animals can contribute to reduced yields, the main factors limiting yields is soil fertility, depth and access of plants to water and nutrients in the soil.

A key message of the initiative is that plant health and increased organic matter and carbon down the soil profile drives soil health. This means that management to improve crop and pasture yields by improving soil fertility, aeration, drainage, pH, and water- and nutrient-holding characteristics down the soil profile will make soils healthier, deeper, more productive and more resilient to drought.

Many central Victoria soils have inherent natural constraints and 'inherited' constraints from how they have been managed in the past.

Common constraints to soil and plant health in the project area include:

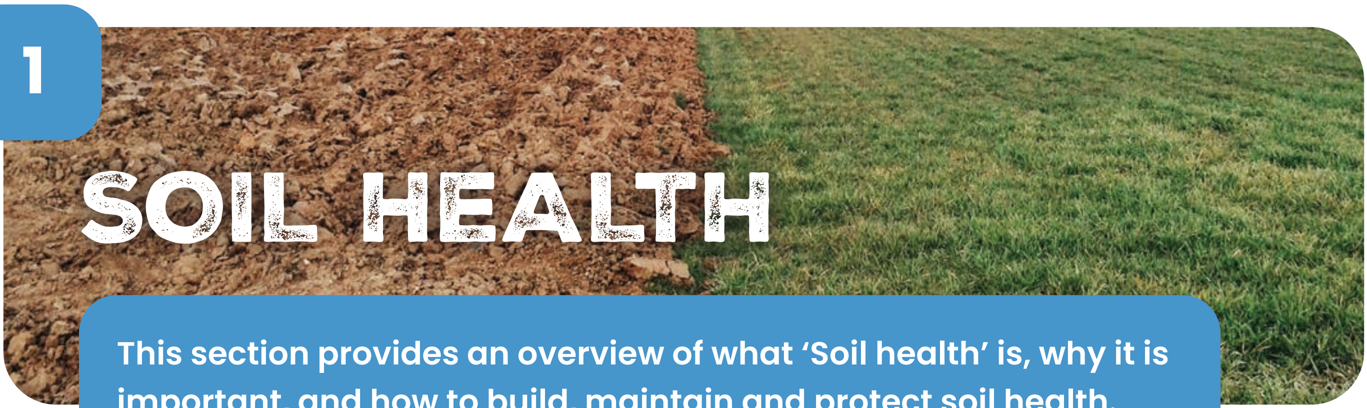
- Poorly structured and shallow soils that reduce water infiltration and air flow down the soil profile and reduce healthy root growth.
- Nutrient deficiencies. The most common deficiencies are phosphorous, nitrogen, zinc, and copper, and sometimes sulphur, potassium, molybdenum, and calcium.
- Unfavourable pH. Soil acidity is common and can reduce the availability of plant nutrients, and also result in toxicities associated with aluminium, iron and manganese.
- High sodium and low calcium levels that result in poor soil structure and heavy and compacted clays.

- Soils that are naturally shallow due to their inherent geology – including naturally shallow soils and soils with 'dispersive' clays that are very dense and impede root growth and water infiltration.
- Soils that are shallow because of heavier and compacted clay sub-soils due to historic cultivation and grazing practices.
- Low levels of organic matter and less active soil biology. Organic matter and soil biology help improve soil structure and the water infiltration and water and nutrient holding capacity of soils. They also form the basis of nutrient cycling that keeps a pool of nutrients available to plants during growing seasons.
- Climatic extremes – with typically dry and hot summers (particularly in the northern part of the project area), cold winter periods (particular to the south), and periodic droughts and extreme heat events.

The Healthy Soils Initiative has developed a series of information sheets and planning tools to help farmers assess soils, identify constraints, plan how to manage these, and monitor and continually improve soil and plant health.

Sustainable Agriculture

There is increasing focus on the need to reduce the environmental impacts of our food and fibre production systems. Supply chains and markets are increasingly requiring farmers to demonstrate adoption of more sustainable production methods. Healthy soils help to improve the efficiency of water and nutrient use and reduce the environmental impacts per unit of farm yield. Healthy sols can reduce the amounts of fertilisers and other mined soil amendments (e.g. lime, gypsum, rock dusts, guano, etc) needed for unit of farm yield, and also reduce emissions of greenhouse gases such as nitrous oxide and methane from soil. Where levels of soil carbon can be increased and maintained, there is potential for soils to act as a 'carbon sink', drawing-down the equivalent of around 100 to 220 tonnes of carbon dioxide per hectare for per every additional 1 percentage point of soil organic carbon added to the upper 20-40cm of soil. Healthier soil management also increases the infiltration and holding of soil which reduces nutrient and soil loss from farms and reduces pollution of waterways. A focus of the Healthy Soils Initiative is to increase productivity and the efficiency or production so that the environmental impacts for unit of grain, hay, meat, wool, milk or other farm products are minimised. This approach focuses on addressing soil physical, chemical and biological constraints; efficient and sensitive use of farm inputs such as fertilisers, soil amendments and other chemicals; and managing crops and pastures improve plant growth and farm yield and build and maintain soil health. The Healthy Soil Initiative recognises that every farm is different and doesn't promote a single 'right way' to manage soil health. It promotes better understanding of soil and climate constraints to plant growth and soil health, and a practical, pragmatic and flexible approach to addressing these using a range of management methods and technologies.



1

SOIL HEALTH

This section provides an overview of what 'Soil health' is, why it is important, and how to build, maintain and protect soil health.

A healthy soil will allow plants to grow as well as they possibly can within climatic and seasonal constraints, whilst also maintaining soil structure, fertility and beneficial soil biology from season to season. Most farms in Central Victoria fall well short of their potential, with crops and pastures typically yielding only 30-50% of their seasonal yield potential[1]. Although other factors such as plant disease, weed competition and pests can reduce yields, soil health constraints to root and plant growth are a major factor limiting yields and farm productivity.

Useful indicators of farm soil health are plant growth and yield per hectare as well as the depth of root growth.

What is soil health

'Soil health' is a broad term, with many definitions and components. The National Soil Action Plan defines it as *'the capacity of soil to function as a living system'*, and states that soil health *'is the product of physical, chemical and biological soil processes working together to sustain productivity, diversity, and ecosystem services'*.

Figure 1.1 (next page) shows some key physical, chemical, and biological characteristics and interactions in soil.

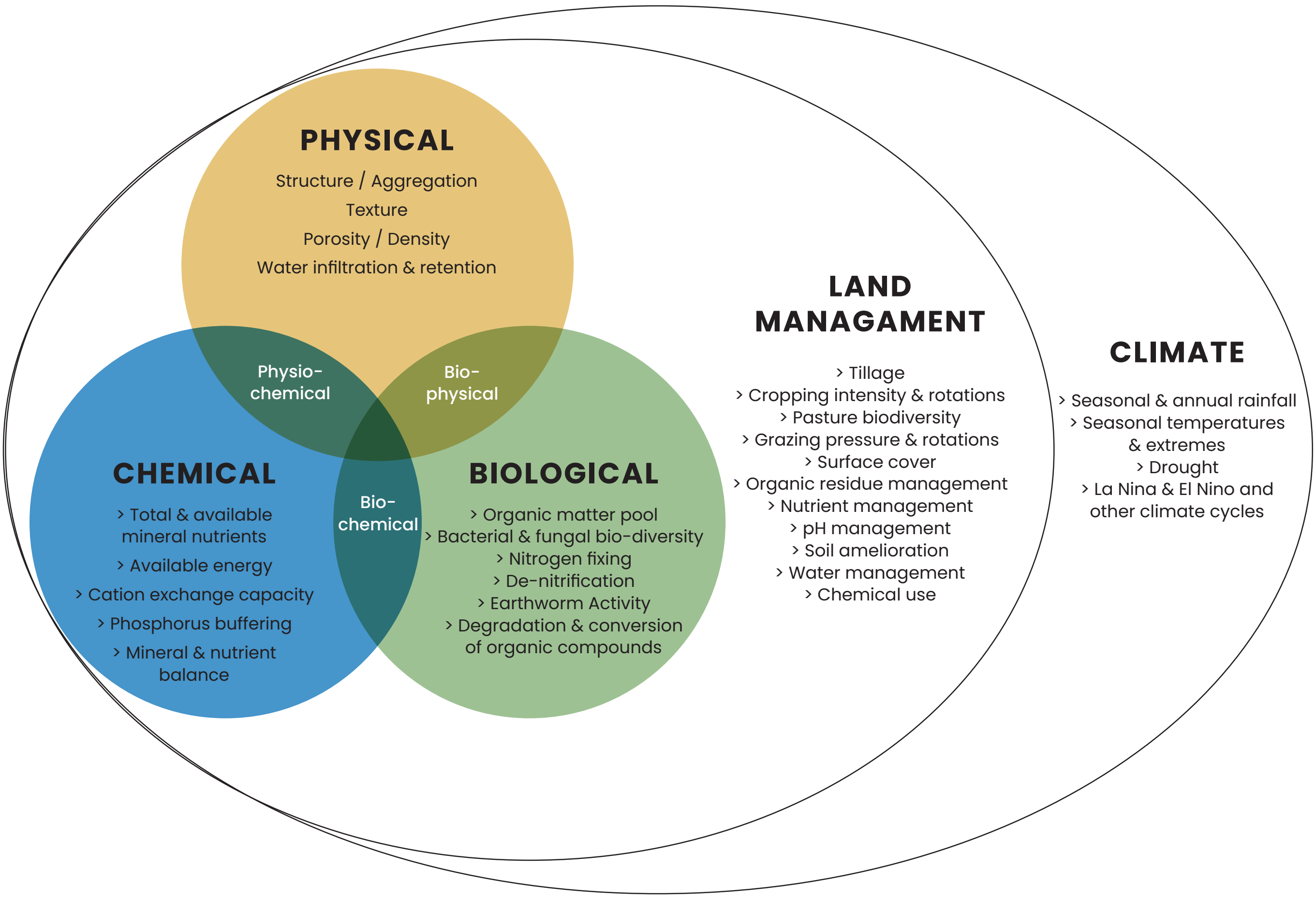
- It also shows that farm management practices and climatic and seasonal factors.
- Impact on soil health is driven by the health of plants and the depth and vigour of plant roots.
- The objective of maintaining higher yielding plants is largely compatible with the objectives of building and maintaining soil health if attention is also paid to management practices that enhance and protect beneficial physical, chemical and biological conditions in the soil.

The best practices will depend on the farmers' objectives and priorities, the farming system, climate, and inherent characteristics of the soil. There is no single 'right' solution – there is only what is right for you and your farm.

Good indicators of soil health are plant yield and root depth. Plants should grow strongly without discolouration and the roots of cereals and other grasses such as wild oats roots should growth strongly to at least 30-40cm depth in September/October. Compare your crop yields, stocking rates and livestock production with the district average and the more productive farms in your area and consider the extent to which poor soil health is holding you back. Compare plant growth on different parts of the farm and dig to check root depth. Where yields are lower than they should be, or plants and roots are obviously stunted, use Sections 8 and 9 of this guide to identify the physical, chemical and biological constraints.

[1] Seasonal yield potential is the yield a crop pr pasture should achieve if only constrained by seasonal constraints of rainfall, temperature and evaporation.

Figure 1.1: Key interactions of soil physical, chemical and biological factors and the land management and climatic factors that impact on these interactions. Soil health management requires consideration of all of these factors, and how farm management can build and maintain soil health within a productive and profitable farming system.



Characteristics of a healthy soil

A healthy soil ensures plant roots have access to water, nutrients and air so plants can grow to their full potential within natural seasonal constraints. This requires soil to have:

- **Porosity and aeration.** Soil porosity is vital to allow soils to 'breathe'. Plant roots and beneficial soil biology need oxygen. Nitrogen fixing bacteria need access to nitrogen gas in air. Gas 'wastes' produced by root and soil respiration need to be able to escape the soil. Porosity is sometimes referred as 'soil structure'. A soil with good soil structure will have a lot of spaces or 'pores' between soil particles or 'crumbs' through which air and water can freely flow. A poorly structured or compacted soil will lack such pores and constrain root and plant growth. Unbalanced soil chemistry, high clay content and low levels of organic matter, as well as heavy tillage and traffic can all contribute to poor soil porosity.

- **Water infiltration and holding characteristics.** The better and deeper the soil structure and porosity, the more readily water can infiltrate / flow into the soil. Good infiltration means rainfall flows into the soil rather than running off the surface. Water holding capacity is the ability of soil to hold water in the root zone. This depends on the clay and organic matter content of soils. Sandy soils with low organic matter are typically poor at holding water. Clay soils are better, but some can 'swell up' when wet and become impermeable to further water infiltration. Some clays also hold water too strongly for roots to access it. Higher organic matter levels and associated soil biology in any soil will improve the structure, porosity and water holding and plant available water characteristic of soil.

- **Plant available nutrients.** Plants require a range of nutrients to grow well, particularly those in soluble forms that roots can take up in water. Deficiencies in one of more nutrients can limit plant growth and reduce the quality of pasture and crops. Nutrients in mineral form (e.g. in rocks) are not immediately available to plants, and active soil biology can help to make these more available. A healthy soil ecosystem also constantly 'cycles' plant available nutrients, giving roots constant access to these.

- **Favourable pH.** Strongly acidic and - more rarely in central Victoria - alkaline soils can reduce the plant-availability of many nutrients. Acidic soils may also develop 'toxic' levels of aluminium, manganese and/or iron that reduce plant root growth and the ability of plants to use other key nutrients (pH should be within the 5.5-8.0 range, and ideally within 6.0-7.0).

- **Organic matter.** Organic matter sustains soil biological activity and diversity. Many studies suggest soil organic matter soil (SOM) levels should be maintained above 4-6% dry weight of soil (or around 2-3% organic carbon soil (SOC)) as far down the soil profile as possible to improve soil conditions and sustain levels of biological activity. Many soils in Central Victoria have low levels or organic matter in the upper 20-30cm of soil, and even less further down the profile. This indicates shallow root growth and reduced yield potential.

- **Depth.** Many soils in central Victoria are shallow due to physical and chemical constraints as well as historic cropping and grazing practices. As a result these soils also have low levels of organic matter and beneficial biology down the soil profile, which also reduces nutrient availability and good soil structure. Shallow soils and roots give plants less access to water and nutrients, reducing their yield and making them more susceptible to dry periods and drought. A key objective of the Healthy Soils Initiative is to help farmers to make their soils deeper by improving porosity, addressing nutrient deficiencies and unfavourable pH constraints, and managing pasture and crops to build and maintain high enough levels of soil organic matter to support beneficial soil ecosystems.

A healthy soil ensures plant roots have access to water, nutrients and air so plants can grow to their full potential within natural seasonal constraints.

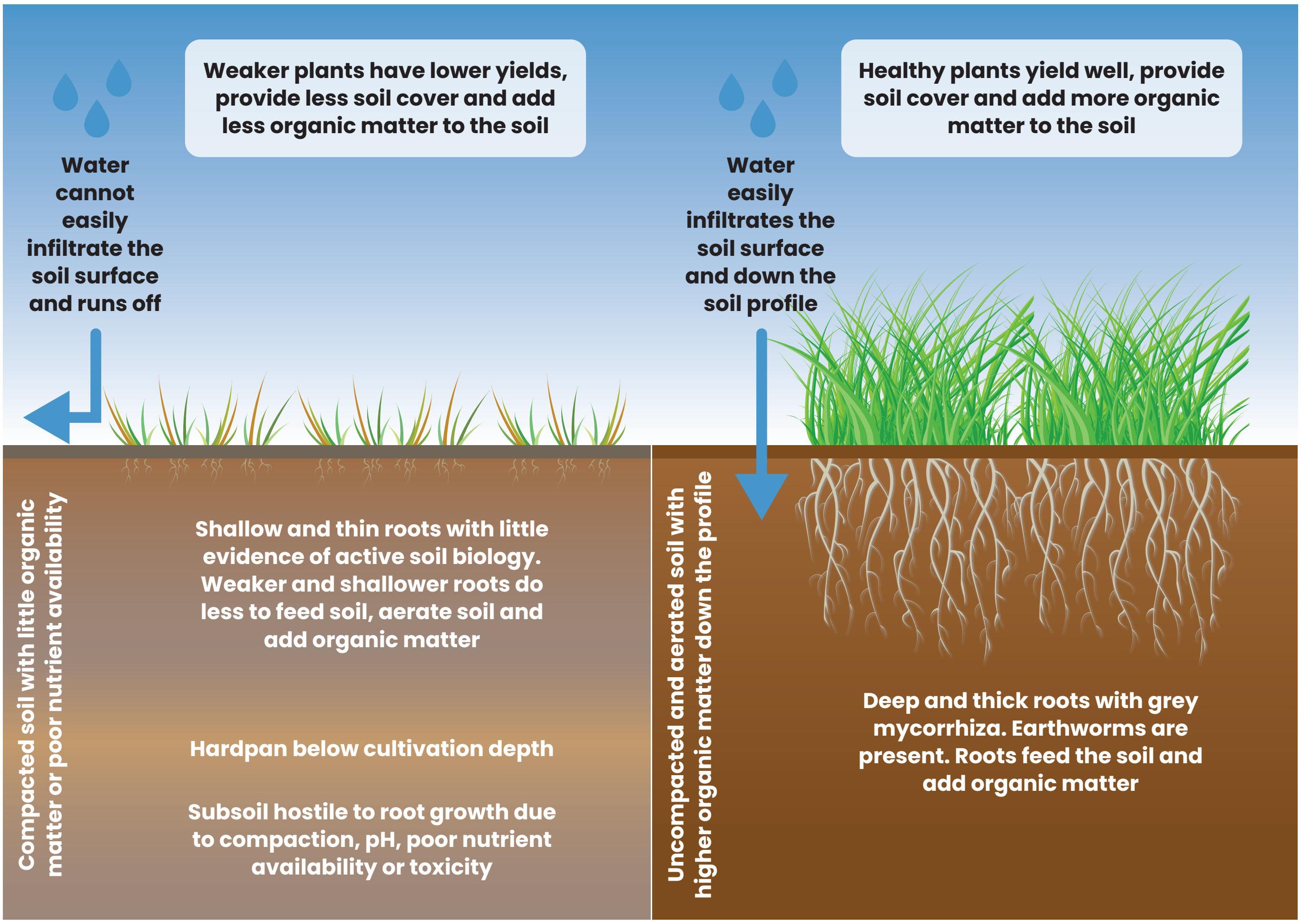
Constrained' vs 'Unconstrained' soils

Figure 1.2 compares a 'constrained' soil with poor soil structure, nutrition and pH with a healthy soil that has:

- good aeration
- good water infiltration and drainage
- good nutrient and pH levels
- healthy root and plant growth contributing to organic matter and healthy soil biology down the soil profile.

Unfortunately, many Central Victorian soils suffer from one or more of the constraints shown. This means many farmers are producing crops and pastures in shallow soils and not making the most of annual rainfall and nutrients deeper down in their soils, and are also more susceptible to dry summers and drought.

Figure 1.2 Typical soil constraints (LHS) compared to on unconstrained soil.



Good indicators of soil health are plant yield and root depth.

Plants should grow strongly without discolouration and the roots of cereals and other grasses such as wild oats roots should growth strongly to at least 30-40cm depth in September/October. Compare your crop yields, stocking rates and livestock production with the district average and the more productive farms in your area and consider the extent to which poor soil health is holding you back. Compare plant growth on different parts of the farm and dig to check root depth. Where yields are lower than they should be, or plants and roots are obviously stunted, use Sections 8 and 9 of this guide to identify the physical, chemical and biological constraints.

2

THE HEALTHY PLANT ⇆ HEALTHY SOIL CYCLE

Plant health (and yield) depends on soil health, and soil health is largely determined by plant health and nutrient and water availability.

The Health Soils Initiative promotes the identification and management of soil constraints to plant health so that healthier plant and root growth can help to build and maintain soil health.

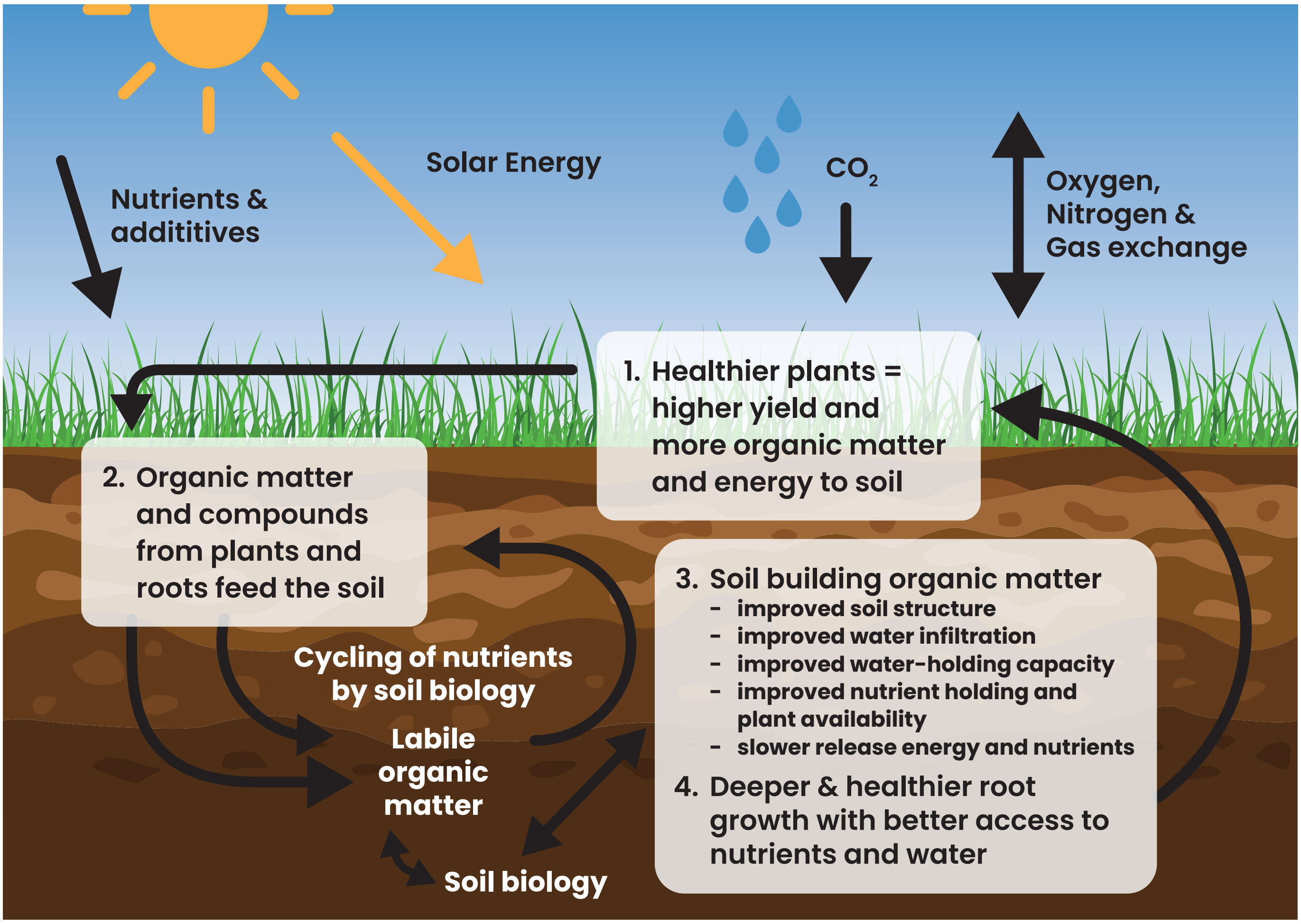
Key drivers of soil and plant health

Soil health is largely determined by soil depth and levels of: plant-available nutrients; plant-available water; and soil porosity and aeration down the soil profile. These factors are all influenced by the levels of beneficial soil microbial activity which are determined by the levels soil organic matter and soil moisture down the soil profile. The organic matter is typically provided by root and plant growth. This means that not only to healthy plants need healthy soils, but healthy soils need healthy plant and root growth too. This cycle determines the levels of plant and soil health on a farm, and can be boosted by addressing constraints to plant and root growth and working to build and maintain higher levels of soil organic matter and beneficial soil biology.

Figure 2.1 (next page) shows how healthy soils sustain healthy plant growth, and how healthy plant growth feeds soil health. This shows:

1. Healthy plants convert solar energy, nutrients and water into organic matter (or biomass) which is delivered to the soil via plant root exudates, dead plant matter, and grazing animals' manure.
2. The organic matter and nutrients in organic matter feed soil biology that break the organic matter down, making nutrients available to plants and other soil microbes.
3. Organic compounds from decomposed biomass and produced by soil biological activity help to improve and maintain soil structure/porosity through the formation of soil aggregates and the action of earthworms and insects in a healthy soil. The organic matter also improves the potential for soil to hold water and nutrients and make available to plants.
4. Improved soil health resulting from organic matter and nutrients, improves root and plant growth, and drive the Healthy Plant ⇆ Healthy Soil cycle.

Figure 2.1: The Healthy Plant ⇆ Healthy Soil cycle



The level of plant and soil health achieved over time will depend on how well plants and roots grow and how land is managed to ensure soil, roots and soil biology have access to air, water and nutrition, favourable soil pH and chemistry, and adequate levels of organic matter and biological activity to ensure cycling of nutrients and the production of soil building organic compounds.

The level of plant and soil health achieved over time will depend on how well plants and roots grow and how land is managed.

How soil organic matter and ecosystems produce soil-building organic carbon

There is increasing interest in how organic matter and soil biological activity improves the fertility, structure, and water and nutrient-holding characteristics of soils.

The amount of organic matter in the soil largely depends on how much root and vegetative biomass and exudates added to the soil each year and how quickly this is biodegraded. Some organic matter (SOM) will be held and cycled by soil microbiology or partially protected from biodegradation within soil aggregates and by 'binding' to clay minerals, but most biomass and exudates will be biodegraded within 1-2 years of being added to the soil. This means SOM needs to be constantly replenished and that it will hit a plateau where the amount added each year is equal to the amount that degraded each year, so there is minimal net increase, just a pool of soil carbon in different stages of decomposition. It has been conservatively estimated that to maintain a 'healthy' level of 2 percentage points of soil organic matter in the upper 30cm of soil, an average of around at least 30-60 tonnes per hectare of plant and root biomass and exudates needs to be added to the soil per year. If roots provide half of this, around 15-30 tonnes per hectare or 1.5-3.0 kg per square metre of above ground plant biomass needs to be added to the soil each year. This can be achieved in central Victoria under pastures in most years, but is more difficult under cropping.

Key messages

- Healthier plants add to soil organic matter through healthier root growth, plant matter and the manure of grazing animals.
- Deeper root growth is important to increasing soil organic matter and making soils deeper, but is often constrained by chemical and physical factors.
- Organic matter helps to hold water and nutrients, and can also help to neutralise acidic soils.
- The activity of soil biology (fungi, bacteria, earthworms, insects and other organisms) cycles plant-available nutrients, aerates and manures the soil.
- Some soil fungi and bacteria produce and cycle longer-lasting organic compounds that improve soil structure and water- and nutrient-holding characteristics. This longer-lasting soil carbon can also mitigate greenhouse gas emissions.
- The combined effects of increased organic matter and 'humic' carbon are better structured, more fertile, deeper and more productive soils and healthier plant growth.
- Plant health drives soil health, so improving yields and crop and pasture management can also improve soil health and productivity.
- Soil organic matter feeds beneficial soil biology and helps to make nutrients and water more available to plants.
- Organic matter and the soil biology it feeds also help to improve soil structure and buffer soil pH.
- Healthy plants need to be able to grow deep roots and access the nutrients and water they need to achieve their potential. Many central Victorian soils have significant physical, chemical and biological constraints that need to be addressed before plants can grow deeper and healthier root systems.

3

COMMON SOIL CONSTRAINTS

Many Central Victorian soils have physical and chemical constraints to healthy plant and root growth, reducing beneficial soil biological activity.

Many Central Victorian soils have significant physical and chemical constraints to health plant and root growth, and these also reduce healthy and beneficial soil biological activity. These limit plant and root growth and reduce yields and farm productivity. Poor plant and root growth also reduces the effectiveness of the Healthy Plant ⇆ Healthy Cycle. The Healthy Soils Initiative promotes the identification and management of soil constraints so that healthy plants and land management can build and maintain soil health and farm productivity.

Physical constraints

Physical constraints are those that physically reduce healthy and deep root growth, soil aeration and water infiltration and water-holding characteristics of soil. Shallow roots reduces the organic matter content of soils further down the soil profile, and this usually contributes to poor soil structure and physical constraints. Common physical constraints include:

1. **Shallow soils.** A very common constraint to healthy plants and soils in Central Victoria is that topsoils are shallow and sub-soils are hostile to deeper root growth. Figure 2.1 shows layers or 'horizons' and are typically seen down the soil profile. This shows that most root growth occurs in the topsoil and upper subsoil layers. The depth of these layers can vary, but on a well-structured and unconstrained soil should be deeper than 40cm. However, in most parts of Central Victoria, constraints to healthy root growth are experienced in the upper 10-30cm. In some instances this is because bedrock is close to the surface, but typically is due to heavy and poorly structured clays and/or chemical constraints to deeper root growth.
2. **Compaction and poor porosity.** A common feature of central Victorian soils is that clay sub-soils are close to the surface and are prone to compaction. Many of these clays are hard-setting when dry and have poor porosity when wet. This reduces the capacity of soils to absorb and hold rainwater and drain freely. This causes much of our annual rainfall to be lost as runs off rather than infiltrating soils, and can also result in waterlogging because soil do not drain. This limits the depth of root growth, which reduces plant growth and weakens the Healthy Plant ⇆ Healthy Soil cycle.
3. **Erodibility.** Some soils with poor structure, shallow root growth, and sparse ground cover during dry periods are more prone to erosion. In particular, clays with high levels of sodium relative to calcium and other cations can be dispersive, and can result in tunnel and gully erosion.

Chemical constraints

Chemical constraints reduce root and plant growth and can impact on the nutritional value of pasture, fodder and crops. The most common constraints in central Victoria are:

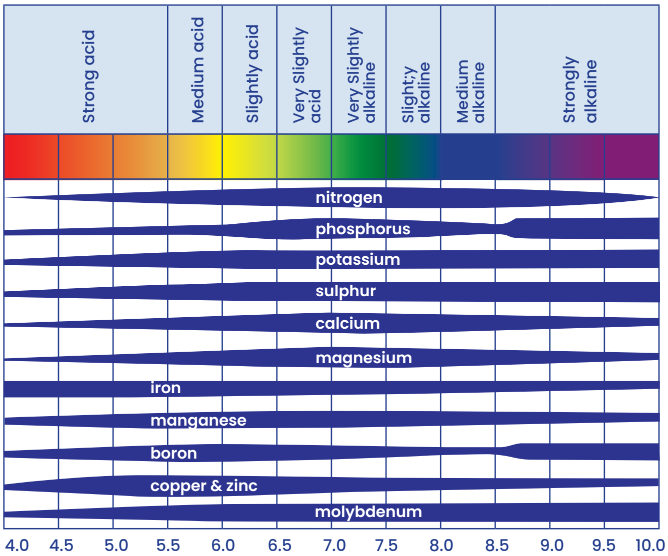
1. **Mineral nutrient deficiencies.** Most soils in central Victoria are inherently deficient in Phosphorous, and many sandier and lighter coloured soils are often low in one of more other macro-nutrients (i.e. those required in higher concentrations for healthy plant growth) such as Potassium, Sulphur or Calcium, but these typically only become deficient under cropping or high-production grazing system. Deficiencies in trace elements (i.e. those needed in lower concentrations) are also common, with many soils having low or deficient Zinc, Copper, Molybdenum and Boron that can impact on plant and grazing animal health, and can reduce how well legumes such as clovers grow and fix atmospheric nitrogen. Many nutrient deficiencies are more likely to occur on more acidic soils (pH<5.0 and where soil organic matter and soil biological activity are low).

2. **Nitrogen deficiency.** Plant-available nitrogen is essential to healthy plant growth. It is not usually present in the mineral component of soil. It needs to come from either fertilisers, dissolved in rain, fodder from other farms, or from nitrogen-fixing bacteria mainly associated with legumes such a clovers, sub-clovers, vetches, medics, lucerne, or peas. The level of available N in the soil will largely determine how well plants grow. It is highly soluble and volatile and is taken up heavily by plants, so needs to be constantly replaced to maintain yields.
3. **Unfavourable soil pH.** Soil pH measures how acidic or alkaline soils are on a scale where 7.0 is neutral and anything less than 7 is acidic and anything higher is alkaline. It is a logarithmic rather than linear scale, so a pH of 5.0 is ten times more acidic than a pH of 6.0, and pH of 4.0 is 100 times more acidic than a pH of 6.0. In most of central Victoria, soils then to be naturally acidic and become more acidic under farming systems due to accumulation of hydrogen ions in the soil when crops, fodder and animal products are taken off-farm and nitrogen gases are lost from soil. When soils are overly acidic (pH <5.5, or more acidic than vinegar) or alkaline (pH >8.0, or more alkaline than sea water), many nutrients become unavailable to plants (see Figure 3.1). Ideally soil pH will between 6.0 to 7.5, but many plants can tolerate slightly more acidic and alkaline conditions. Figure 3.2 shows typical soil pH in the upper and subsoil layers in central Victoria. This shows many soils in the area naturally have overly acidic surface and upper soils, overlying more neutral or alkaline sub-soils. Soil pH can be acidified by application of nitrogen (including from fertilisers, manures and from nitrogen fixation by plant), waterlogged or low oxygen conditions, and the removal of hay or

crops from farms. pH can be managed through:

- the application of lime, rock dust or compost that have neutralising and buffering effects
- improving soil aeration
- increasing soil organic matter
- managing nitrogen to reduce denitrification losses.

Figure 3.1: The effect of soil pH (Calcium Chloride) on the solubility and plant availability of different nutrients and potential 'toxic' elements



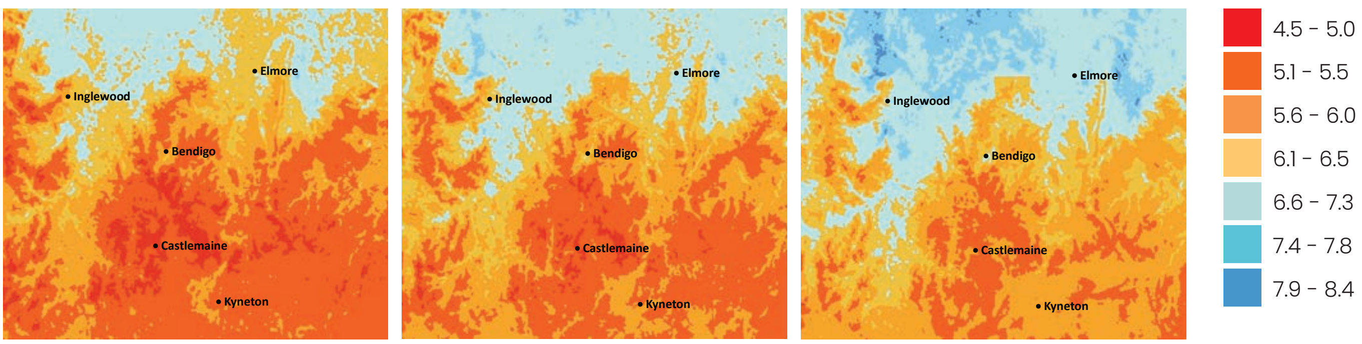
Source: Adapted from Roques et al, 2013

4. **Chemical toxicities.** When acidic soils have pH less than 4.8, aluminium and iron can damage root and plant growth, and reduce plants' ability to process other nutrients. Manganese can also have toxic effect when soils are overly acidic, particularly during and following drier periods.

5. **Poor nutrient-holding capacity.** Clays and organic matter can help to hold soluble nutrients in soil and make them available to plants. Sandy and silty soils are less able to hold nutrients, and nutrients can be 'leached; from soil by rainfall. The nutrient holding capacity of soils (measured as 'Cation Exchange Capacity') can also be reduced by overly acidic conditions.

6. **Sodic and magnesic clays.** Many soils in central Victoria have high levels of exchangeable sodium and magnesium relative to calcium. Sodic clays tend to 'disperse' when wet, forming heavy and hard-setting clays with very low porosity. High magnesium soils tend to crack deeply when dry, but swell and become heavy and impermeable to air and water when wet. If magnesic soils are not sodic (i.e. do not have high sodium levels), they can be 'self-mulching' or 'cracking' and form a good soil structure provided they do not become too wet. However, if magnesic soils are also sodic, then the dispersive effect of the high sodium levels can be amplified, resulting in heavy and poorly structured soils. This is quite common in central Victoria.

Figure 3.2: Indicative soil pH (CaCl2) at (a) 0-5cm, (b) 5-15cm and (c) 15-30cm. Local conditions will vary.



0-5cm 5-15cm 15-30cm

7. **Salinity.** Salinity tends to occur in low lying areas in landscapes with high sodium chloride in the soil and groundwater, and is often first observable as patches where salt and compaction-tolerant plants such as barley grass, progressing to salt 'scalds' where there are bare patches where only very salt-tolerant species can survive.

Biological Constraints

The biological constraints of soil are often overlooked. Greater attention is usually given to chemical and physical constraints because fertilisers and compaction management are known to immediately improve yields. However, reduced biological activity in the topsoil and further down the soil profile often contributes to chemical and physical constraints. Maintaining a healthy soil biology can reduce the need for fertilisers, tillage, and other soil amendments such as gypsum and lime and increase yields from use of fertilisers.

Active soil biology needs adequate levels of organic matter and contributes to the production of soil-building and longer lasting stocks of soil carbon and organic compounds that improve soil's structure and water and nutrient-holding capacity. Organic matter and a healthy soil microbial population also supports earthworm and other soil fauna activity, and these contribute to soil aeration and nutrient cycling – a healthy earthworm population of 100-200 earthworms per square metre can 'turn over/aerate' and 'manure/fertilise' tonnes of soil in the upper 30-40cm per hectare per day. Similarly, dung beetles in pastures can work and manure the upper soil.

A healthy soil biology typically needs:

1. **Adequate levels of organic matter and carbon.** Research suggests crop and pasture yields decline if soil organic carbon levels in the upper 30cm are less than 2-2.5% (about 4-5% soil organic matter). Organic matter provides calories and nutrients for soil ecosystems. It also helps to hold soil moisture and provides habitat for soil microbes – this is particularly important on sandy soils and 'leached'/low nutrient clays, and soils with overly-acidic soil pH. Organic matter comes mainly from roots and plant residues and manure from livestock and wildlife. Organic fertilisers, composts and manures can also be used to boost soil organic matter levels. Indicative levels of healthy soil organic matter and carbon for different soil types are shown in Table 3.1. Organic matter or carbon levels can be monitored through periodic laboratory testing or soil samples, and also through observations of the presence of soil organic matter and soil colour down the soil profile and earthworm counts when the soil during the growing season.
2. **Water, aeration, favourable pH and available nutrients.** Beneficial soil fungi, bacteria and fauna need the same conditions as healthy roots and plants. Some bacteria can still function under low oxygen conditions, but this typically results in losses of soil nitrogen, soil acidification, release of compounds toxic to roots and beneficial soil biology, and release

of greenhouse gases such as methane and nitrous oxide.

3. **Protection.** Soil ecosystems need to be protected from disturbance from tillage and dry periods. Healthy soil ecosystems include fungal and actinobacterial hyphal structures through the soil. These are complex networks of thread-like growth that can be dense like mushrooms but are often more spread out growing through soil pores to form large masses. These form an important role in making mineral nutrients available to plants and holding moisture in the soil. Deeper and more intense tillage, compaction and periods of drought can restrict growth and kill these structures and they can take years to recover. Earthworm populations are also highly sensitive to tillage, compact and dry periods. The best options to protect soil ecosystems and soils are:

Earthworm populations are also highly sensitive to tillage, compact and dry periods.

a. Reduce the depth and intensity of tillage to what is needed to establish a crop or pasture on your soil.

b. Improve soil porosity so that most rainfall infiltrates soil and maintains root growth and soil biology.

c. **Maintain some form of cover on the soil surface.** In higher rainfall areas and years living plants can be maintained, but under drier conditions, maintaining dormant grasses will support living roots and will rapidly recover with rain. Under very dry conditions and where cropping farmers need to terminate summer growth to conserve soil moisture, a 'mulch' of dead organic matter will provide protection.

d. **Maintain soil moisture.** A soil organic matter 'mulch' on the surface and soil organic matter in the soil will reduce evaporation and hold more water. In drier areas and years, cropping farmers that have retained stubble or dead pasture as surface cover can terminate summer weeds to conserve soil moisture down the profile.

4. **Sensitive chemical use.** Soil ecosystems can also be impacted by some farm chemicals – many fungicides and some insecticides can have short- or longer-term impacts. Fertilisers can have short-term impacts but will generally boost soil healthy by improving plant health. Similarly, where herbicides reduce the need for tillage, any short-term negative impact is usually more than made up for by longer term benefits from reduced disturbance

and compaction and healthier plant growth. Generally, if soil organic matter and moisture levels are high enough, soil ecosystems will cope with and recover from sensitive use of most farm chemicals.

5. **Repair.** We experience dry summers and periodic droughts. Heavier clay soils often need tillage to improve crop and pasture establishment and increase yields. These factors usually deplete soil health and soil organic matter. As a result, many soils in central Victoria have low levels of soil organic matter and less active soil biology. Monitoring soil health through observation, earthworm counts, and/or field or laboratory tests can help determine if soil organic matter and biological levels are high enough. Options for repairing soils that have low organic matter and biological activity include:

    a. Greater retention of biomass. In pasture, this means growing more biomass, avoiding overgrazing, and getting more biomass into the soil through manure and light integration into the soil (e.g. through livestock trampling, slashing, rolling or other termination and light surface integration). In crops this means retention of crop residues, and potentially, where rainfall allows, under-sowing crops with late spring germinating legumes or other species that can be integrated into soil after harvest. Fodder crops that leave large amounts of biomass and active plants after hay cutting can also be used to boost organic matter. Where rainfall is adequate, periodic biomass 'cover' or 'green manure' crops can also be used.

    b. Addition of organic fertilisers and soil amendments such as compost. These can top up soil organic matter levels and also provide a concentrate of soil-improving 'humic' compounds and nutrients.

Table 3.1: Indicative levels of soil organic carbon (% by dry weight) that can be expected on soils with good management in central Victoria. Note that a level of at least 2% is typically needed to maintain a level of soil biological activity that results in higher yields. Increasing and maintaining soil organic carbon levels will be more difficult under cropping, on sandy soils and in drier areas.

Soil type	Pasture		Cropping	
	Topsoil	Sub-soil	Topsoil	Sub-soil
Clay	>3-4%	>2%	>2%	>1%
Loam	>2-3%	>2%	>2%	>1%
Sandy	>1.5-2%	>0.5-1%	>1%	>0.5%

Note: Topsoil depth varies and is typically the upper 10 to 30cm where soil texture is typically more friable, has darker colour, and where most root growth occurs. Sub-soil occurs below this to a depth of 50-60cm or more, and is a zone where healthy root growth can be achieved with management of subsoil constraints. Plant health, productivity and drought resilience will be better with deeper topsoil and less constrained sub-soils. Note also that there are few soils with sandy sub-soils in central Victoria.

Management options

Table 3.2 summarises common soil constraints, causes and management options. These are discussed further in other information sheets.

Table 3.2: Common soil constraints, causes and management options

<table>
<tr><th>Common soil constraints</th><th>Causes</th><th>Management options</th></tr>
<tr><td colspan="3">Poor soil structure and aeration</td></tr>
<tr><td>Shallow and compacted soils impede deeper root growth and limit the flow of water and air down the soil profile. Shallow rooted plants have less access to nutrients and water and struggle in our typically dry late spring, summer and early autumn.</td><td rowspan="2">• Soils with naturally compaction-prone surface and heavy subsoil clays are common throughout Central Victoria.
• Sodic dispersive soils are common, resulting in soil compaction (see below)
• High magnesium and lower than optimal calcium levels can result in dense soils when wet.
• Historic and current traffic management and tillage practices can increase compaction.
• Traffic and livestock during wet conditions
• Surface compaction
• Surface sodicity (see below)</td><td rowspan="2">• Reduced and less intensive tillage.
• Retention of organic matter from stubbles and haying off pastures.
• Maintenance of surface cover of living and dead plant matter,
• Reduced livestock/grazing pressure, particularly when the soil is wet, or pasture growth is poor.
• Controlled traffic to isolate tyre compaction.
• Application and integration of gypsum and/or compost
• Deep ripping with or without ameliorants such as gypsum and compost.</td></tr>
<tr><td>Poor infiltration of water and air. This is related to compaction but can also be caused by surface crusting and sodicity (see below). Poor water infiltration reduces the availability of water and run off can cause erosion. Poor aeration reduces root growth and beneficial biological activity.</td></tr>
<tr><td>Sodicity, dispersion and salinity. Many soils and subsoils in Central Victoria have sodicity or high sodium relative to calcium cations in the soil. This has the effect of making the clays 'dispersive', which means they don't naturally form aggregates and become compacted and non-porous. This reduces water infiltration. Salinity is less common in the area, occurring in isolated areas mainly in low lying areas such as drained or temporary wetlands.</td><td>• Naturally high levels of sodium and lower than optimal levels of calcium
• Rising salt from water table in lower lying areas after wet periods</td><td>• Addition of sources of calcium such as gypsum and, on acidic soils, lime.
• Increased organic matter.</td></tr>
</table>

Common soil constraints	Causes	Management options
Poor nutrient availability		
Low mineral nutrient **Low soluble and plant available nutrients**	• Most Central Victorian soils are inherently deficient in phosphorous (P) as well as many other essential and 'micro' nutrients such as sulphur, copper and zinc. Some soils 'bind up' nutrients in mineral forms resulting poor nutrient availability. Other soils do not readily hold nutrients resulting in leaching and low nutrient availability. • Nutrients removed by crops, hay and animal products need to be replaced to maintain soil health.	• Use soil and plant tissue testing to identify deficiencies. • Use fertilisers or other sources of nutrients. • Increase nitrogen-fixing legumes in pastures • Include legumes in cropping rotations. • Use sources of nutrients such as manures, compost, crushed rock tested for nutrient content, hay/ fodder, and lick blocks to add nutrients to the farming system. • Balance pH and increase organic matter levels to help make nutrients more available on most soils • Use nutrient budgeting to ensure nutrients removed in farm products are replaced. • Use deep rooted plants species such as perennial grasses and forage shrubs and trees can help to bring deeper soil nutrients into the farming system. Less productive areas could be planted out with such species.
Poor nutrient holding capacity	• Lower clay content • Low cation exchange capacity of clays • Low organic matter content	• On clays – improving soil porosity and increasing organic matter content • On lighter soils – increasing organic matter content. Potentially adding clay/rock materials or biochar. • On all soils – improving the depth of healthy root growth. making soil pH more neutral.

Common soil constraints	Causes	Management option
Other factors		
Unfavourable pH. pH measures how acidic and alkaline soils are. Most plants and beneficial soil biology prefer pH between 5.5 (acidic) and 8.0 (alkaline), with most favouring conditions between pH 6.0-7.5. Many central Victorian soils tend to be acidic, and common farm practices can result in increasingly acidic conditions over time. Overly acidic conditions reduce nutrient availability and biological 'turn over' of nutrients and can result in aluminium and iron toxicity.	• Many soils in Central Victoria tend to be naturally acidic. • Harvesting crops and hay removes alkaline ions, leaving acidic hydrogen ions in the soil. • Application of more volatile nitrogenous fertilisers such as urea, MAP and DAP can increase acidification. • Nitrogen losses following legume crops or pasture. • Poor soil aeration and waterlogging. • Increased organic matter usually has a pH buffering effect, but under anaerobic conditions can result in acidification. • Some rock dusts applied for slow-release nutrients can result in acid conditions as they weather.	• Lime is commonly used to correct acidity, The Calcium in lime can also help soil structure on sodic and high magnesium soils. • Improving soil structure and aeration may reduce acidification. • Less/more efficient use of nitrogenous fertilisers. • Increase levels of more stable/less labile organic matter.
Low organic matter and limited biological activity. Organic matter and biological activity in soils (bacteria, fungi, earthworms and other organisms) improves soil structure and porosity, water holding capacity, and the availability of nutrients. Levels of organic matter down the soil profile are also a good indicator of healthy and deeper root growth.	• This is usually a symptom as well as a cause of poor soil health and occurs due to not enough organic matter being added to and retained by soil. • Insufficient plant and root biomass growing and being left in the paddock. • Lack of stubble retention and integration into the soil. • Overgrazing by stock and wildlife. • Periodic drought.	• Increase root and plant growth by addressing nutritional, pH and physical constraints. • Stubble retention. • Reduced grazing pressure through livestock and wildlife management. • Managed rotational grazing. • Periodic 'green manure' and cover crops when seasonal conditions allow for them. • Rolling or light integration of crop and pasture residues to put organic matter in contact with surface soil • Chemical rather than mechanical termination of pastures over summer to conserve soil moisture in years prior to cropping. • Sensitive use of farm chemicals

Key messages

1. Physical, chemical and biological soil constraints down the soil profile reduce root and plant yields and farm productivity. In many cases production can be significantly increased by addressing these constraints.
2. Sub-soil constraints deeper than 10-20cm are often not considered in conventional soil tests by agronomists, but these often limit the depth of root growth and a plant's access to water and nutrients. This reduces production and makes plants more susceptible to drought.
3. Common physical constraints include shallow topsoil, compaction, poor soil water infiltration and drainage, poor aeration, and erodibility.
4. Healthy soil biology helps to hold and cycle plant available nutrients throughout the growing season, and includes soil-building fungi, bacteria, earthworms, insects and other organisms that help maintain soil structure.
5. Common chemical constraints in central Victorian soils are:
   a. Nutrient deficiencies
   b. Unfavourable and usually over-acidic pH
   c. Sodic and magnesic soils
6. Common biological constraints are:
   a. Low levels of organic matter and carbon in topsoils and particularly sub-soils.
   b. Poor root growth due to other constraints.
7. Soil health needs to be protected from, and repaired after, disruptions such as dry and drought periods, water logging, and heavy cultivation.
8. Healthier soils are more resilient to disruptions.

4

SOILS OF THE REGION

An overview of common soil types in the Central Victorian Healthy Soils Initiative project area and options for managing these.

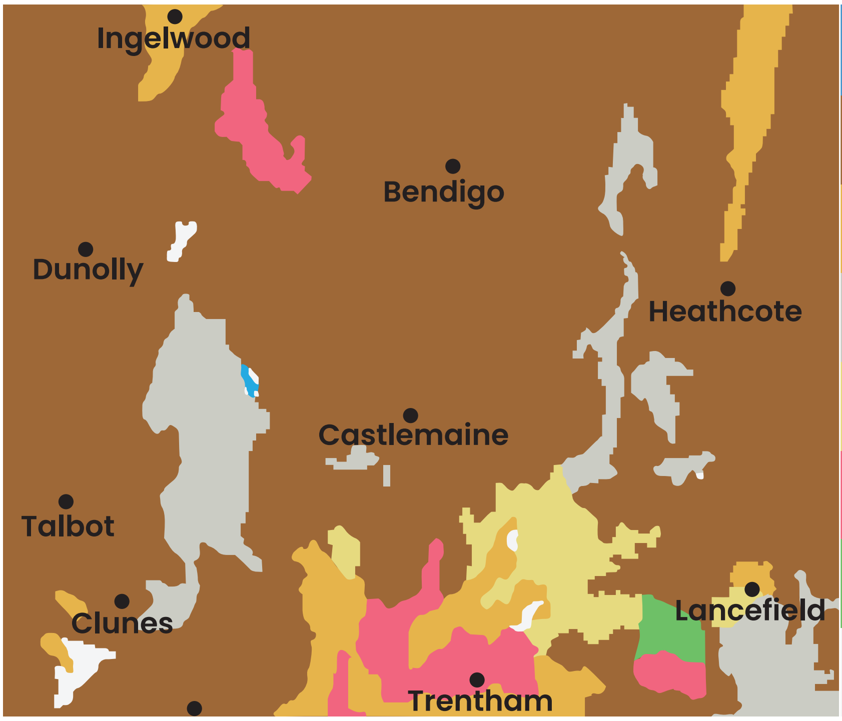
Figure 4.1 shows a generalised map of the common soil types in the Health Soils Initiative project area. This is indicative of broad categories of soil and provide a guide about the types of soil that may be present in a particular area. In reality, there can be considerable variability in soil characteristics and more specific soil types across a single paddock.

Table 4.1 describes the soil types and key management challenges and opportunities. Note this this map generalises soil types and does not show variability that occurs across terrain and even in individual paddocks. It is common for the depth of topsoils and even soil types to vary across individual farms.

The healthy Soils Initiative strongly promotes digging holes of at least 50-60cm on different parts of your farm to see how deep soils are and how soils vary across the farm. It is suggested that you focus on areas where plant growth is observed to be poor, but also dig some holes where plants are growing well to see what the differences are. The key indicators to look at is how deep plant roots are and how compacted surface and subsoils are. Factors to look for include:

- The depth, texture and colour of topsoil/upper soil (which is the layer of soil in which most roots grow and is usually, but not always, darker in colour, more friable and of lighter texture than clay subsoils. In some soils there is a very strong contrast in texture and/or colour of the upper and sub-soil, and some soils will have more than two distinct layers within the upper 60cm of soil. The upper layer of the topsoil under pasture and minimum tillage cropping land is typically darkest, indicating higher surface organic matter content.
- The texture and colour of the subsoil where root growth typically becomes weaker or close to non-existent. If this occurs less than 50cm from the surface, the soil has constraints. In many parts of the project area, subsoil constraints are experienced at between 20-40cm of depth and sometimes less. In most areas (but not all), this is due to the subsoil being a dense and compacted clay. The colour of the subsoil can indicate constraints. A pale grey or yellow clay subsoils often suggest poor nutrient availability, and blue-grey or red 'mottling' in heavy clays often indicates waterlogging and low oxygen conditions.
- pH testing using a field kit is also useful to assess whether excessive soil acidity (this is quite common in the project area), or alkalinity (less common) is a likely factor in shallow root growth.

Figure 1: Indicative soil map of the project area



Dominant soil types

Sodosols	Also found: Chromosols
Chromosols	Also found: Dermosols, Kurosols, Sodosols
Vertosols	Also found: Chromosols, Sodosols
Kurosols	Also found: Chromosols, Vertosols
Ferrosols	Also found: Tenosols, Chromosols, Vertosols, Dermosols
Tenosols/ Chromosols	Also found, Ferrosols, Sodosols
Dermosols	Also found: Sodosols, Chromosols, Vertosols

Source: Adapted from https://portal.ansis.net/

Table 4.1

Soil type	Typical characteristics and issues in the project area district	Management options
Sodosols Also found: Chromosols	These soils are most common in the district. They have significant constraints, but with good management these soils can be productive. They tend to be shallow loams or clay loams overlying heavy, grey dispersive sodic (high sodium) clays. High sodium levels cause clays to 'disperse' and lack structure/porosity, restricting deeper root growth. These soils are typically susceptible to compaction and may have compaction layers from historic cropping practices. In many areas the upper clay-loam layer is a hard-setting clay. In granitic soils around Harcourt from Sutton Grange through to Lockwood, upper soils are often a shallow sandy-silt clay overlying a sodic clay. Where soils are strongly sodic, surface crusting can occur. In most areas, surface and subsoils tend to be acidic and prone to acidification. Clays and clay-loams have good water- and nutrient-holding potential and can typically maintain higher levels of longer-lasting organic carbon.	**Challenges:** • Shallow upper soil and root growth • Compaction • Poor water permeability • Mineral nutrient deficiencies Acidity/ acidification – with potential for nutrient deficiencies and aluminium toxicity. • Tunnel and surface soil erosion **Management options include:** • Reduce tillage and traffic to reduce compaction. • Use of sources of calcium such as gypsum and lime (on acidic soils) to reduce the effects of sodicity. • Increase organic matter down the soil profile to improve soil aggregate formation and porosity. • Manage soil fertility and pH constraints. • Strategic tillage with or without ameliorants such as gypsum or lime (if acidic) or compost.

Soil type	Typical characteristics and issues in the project area district	Management options
Vertosols Also found: Chromosols, Sodosols	With good management, Vertosols are typically naturally friable and good farming soils that are often used for cropping. They tend to be deeper brown or dark grey clay that is naturally friable and forms deep cracks when dry. Surface soils can be magnesic and even slightly sodic, so have potential for compaction. Some soils have calcareous and alkaline subsoils, but these are not common in the project area.	**Challenges:** • Has potential for surface compaction. **Management options include:** • Reduce tillage and traffic to reduce compaction. • Increase organic matter down the soil profile to improve soil aggregate formation and porosity. • Manage soil fertility and any pH constraints.
Kurosols Also found: Chromosols, Vertosols	These soils have strong texture contrasts between the upper soil (usually sandy or sandy loam) and sub-soil (usually a heavy and acidic clay, often with high sodium and/or magnesium relative to calcium).	**Challenges:** • These soils are often shallow, with the subsoil clay restricting deeper root growth. • Sandy upper soils with low organic matter content do not hold water or nutrients, so shallow rooted plants are prone to dry periods and nutrient deficiencies. • Acidic subsoils also restrict root growth. **Management options include:** • Build and maintain organic matter through increased retention of plant residues and management of livestock and wildlife grazing to maintain cover over dry and cold 'green drought conditions. • Consider growing 'green manure' or cover crops on soils with very low organic matter. • If financially viable, manage subsoil constraints by addition of lime with deeper ripping.
Dermosols Also found: Sodosols, Chromosols, Vertosols	Dermosols in Central Victoria are mostly clays and clay loams of volcanic origin occurring mainly in the southeast of the region. They can contain a lot of basalt rocks. They are generally well drained and friable when wet. They are often moderately deep soils, and don't have a distinct change in surface and subsoil down the profile. They can tend to become acidic.	**Challenges:** • Prone to compaction • Prone to acidification • Can have high rock content. **Management options include:** • Reduce tillage and traffic to reduce compaction. • Increase organic matter down the soil profile to improve soil aggregate formation and porosity. • Manage soil fertility and pH constraints

Soil type	Typical characteristics and issues in the project area district	Management options
Chromosols Also found: Dermosols, Kurosols, Sodosols	These soils have an abrupt colour and texture contrast between upper soil and subsoil. In the project area they tend to have a red-brown or yellow-brown topsoil. Subsoils tend to be heavy clays but are not strongly acidic like Kurosols (see below) nor sodic like Sodosols (above), and are often a bright or light yellow-orange colour. In the district these are often hard setting clays at the surface and are prone to compaction. These soils often have a high magnesium content relative to calcium, making them less permeable when wet.	**Challenges:** • Prone to compaction • Subsoils can be lower in nutrient and very compacted. **Management options include:** • Reduce tillage and traffic to reduce compaction. • Increase organic matter down the soil profile to improve soil aggregate formation and porosity. • Manage soil fertility and any pH constraints. • Deep ripping with or without ameliorants such as compost and gypsum (if magnesic) or lime (if acidic).
Ferrosols Also found: Chromosols, Vertosols, Dermosols	With good management, these are typically good farming soils and are often used for cropping, including potato and other vegetable growing. They are often deep friable clays with a high iron content, giving them a strong red colour. They are often relatively 'recent' geologically compared to many other soils in the area and are the result of surface volcanic activity and the weathering of basalt. As a result, they often have higher levels of available mineral nutrients, but can become acidic. They generally have excellent capacity to hold water, nutrient and carbon/organic matter. The high clay content can make the soil prone to compaction by livestock and vehicle traffic, when wet, but the natural friability of the soil makes compaction risk less of an issue than many other clay soils in the area.	**Challenges:** • Although these soils can be naturally friable due to swelling and contracting when wet and dry, these can be heavy clays and prone to compaction. • Soils can tend to acidity and have higher than desirable sodium, aluminium and iron content/ • High iron clays can reduce the availability of soil water to plants and, if soil become highly acidic, can create toxicity and nutrient availability problems for plants. • Management options include: • Manage tillage and vehicle and livestock traffic to avoid compaction. • Build and maintain soil organic matter – this will help with soil structure/ compaction and water availability. • Manage acidic pH if necessary.

Soil type	Typical characteristics and issues in the project area district	Management options
Tenosols Also found: Chromosols, Ferrosols, Sodosols	Tenosols in Central Victoria are generally shallow (<50cm) stoney loam or sandy soils overlying weathered mudstone, basalt or granite outcrops or gravel. They often occur on hillsides and rises in the south-eastern part of the region and on the 'granite country' running from Harcourt to Lockwood. Some more geologically recent volcanic areas have a mix of shallow tenosols and deeper chromosols, ferrosols and sodosols, and typically low-lying areas in the shaded areas are deeper soils.	**Challenges:** • The soils are inherently shallow and often on slopes. They reduce the potential for deeper root growth and can dry rapidly. It can be hard to maintain living or dormant plants during extended dry periods, leaving areas exposed to erosion. **Management options include:** • These areas are generally less productive, and consideration could be given to fencing areas to keep stock off them and revegetating with trees or shrubs. Perennial fodder plants shrubs such as lucerne and salt bush could be grown in fenced off areas, and lightly grazed during periods where there are 'feed gaps'.

Key messages

1. Many soils in central Victoria have significant constraints to deeper root growth and healthy plant growth. These constraints hold back the Healthy Plant ⇆ Healthy Soils cycle and limit further improvements in soil health.
2. Identifying and addressing soil constraints allows the Healthy Plant ⇆ Healthy Soils Cycle to improve and maintain soul health.
3. Common constraints include:
    a. Shallow topsoils overlying poorly structured and compacted clays. These impede deeper root growth and reduce water infiltration.
    b. Inherently low soil nutrient availability, and particularly phosphorous, as well as commonly sulphur, zinc, copper, molybdenum and boron, and sometimes calcium and potassium.
    c. Overly acidic soil pH which make essential nutrients less available to plants, and can result in levels of aluminium, manganese and iron that have toxic effect on root development and nutrient uptake.
    d. Heavy sodic and magnesic clays that contribute to poor soil structure and compaction.
    e. Clays with high iron levels that can make soil moisture less available to roots.
    f. Low levels of soil nitrogen because of constrains to healthy legume growth and nitrogen fixation.
    g. Low levels of soil organic matter and biological activity down the soil profile.

Key messages continued

4. These constraints can be managed through a range of strategies including:

    a. Application of sources of nutrition (fertilisers, manures, etc) and soil amendments such as gypsum, lime, compost.

    b. Infrequent strategic tillage to loosen compacted soil and integrate soil amendments.

    c. Sowing and promoting growth of plants with hardy 'clay breaking' and nitrogen fixing roots.

    d. Avoiding overgrazing by livestock and wildlife to maintain an average minimum pasture plant height of at least 5cm.

    e. When the seasonal conditions allow it, maintaining a cover of living or dormant plants and roots

    f. During dry periods, retaining crop and pasture residues to ensure the soil surface remains covered

    g. Increasing organic matter and beneficial soil biological activity (such as earthworms);

    h. Controlling vehicle and livestock traffic to reduce compaction

    i. Minimising the intensity of any tillage at sowing to reduce the depth and amount of soil disruption

    j. Maintaining soil surfaces so that there is more water infiltration and less run-off.

    k. Using good seasons to increase root depth and plant health and add more biomass to soil.

    l. Protecting soils during drought, and repairing them afterwards.

5. Although soil maps can provide an indication of your soil type, soil profiles typically differ across the landscape. Most farms a range of soils with differences in the depth of topsoils and the characteristics of subsoils. Most obviously these will involve texture and colour differences, but pH and nutrient levels can also vary. The only reliable way to assess your soil characteristics is to dig holes or take soil cores and assess changes down the profile.

5 MANAGING CLIMATE CONSTRAINTS

The Central Victorian climate poses some significant constraints to building and maintaining soil health.

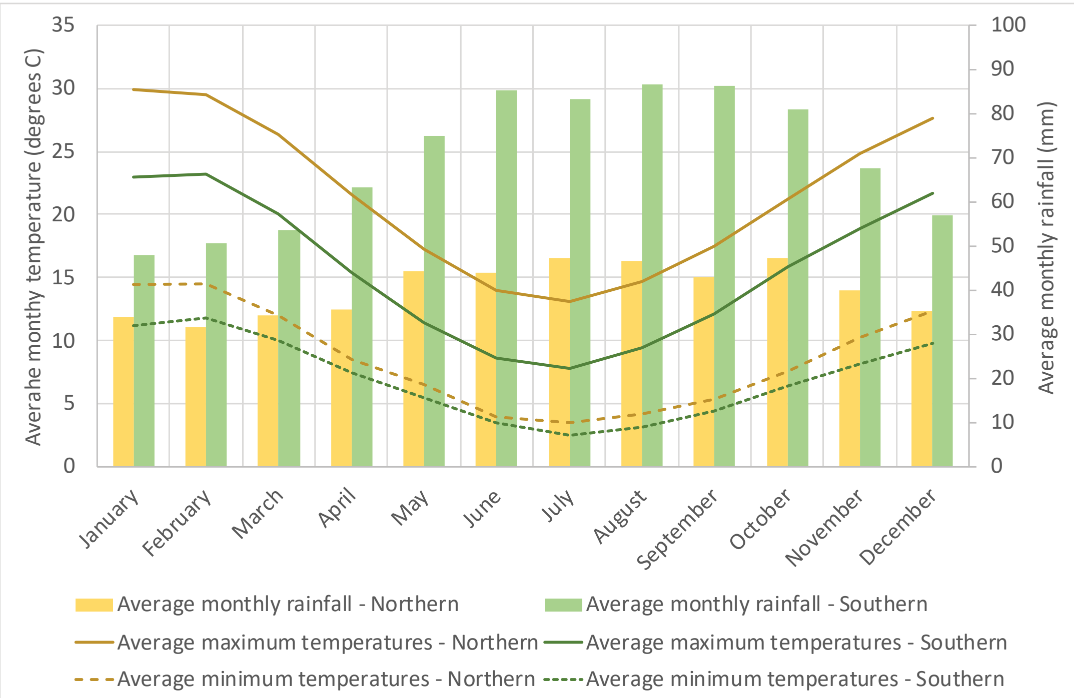
Management practices that are effective in higher rainfall and/or more temperate climates may not be as effective in drier and hotter areas.

The Healthy Soils Initiative covers an area with diverse climatic conditions. The southern area (from Kyneton to Clunes) has higher average annual rainfall (>650-750mm) and milder summer conditions, but cold winter months that can stunt plant and root growth. To the north (Elmore to Inglewood) winters are less severe, but annual average rainfall is less (~450-500 mm per year) and summers can be very dry with periods of extreme heat and drought that make it hard to maintain living groundcover on unirrigated land.

In the north, lower annual rainfall and typically dry and hot summers limit the ability to maintain living plant matter over summer. In addition, cropping farmers typically want to conserve soil moisture over summer by controlling weeds and are unlikely to benefit from cover crops over summer if these deplete soil moisture. During and immediately periods of extended drought conditions soil health and levels of organic matter are likely to go backwards, and effort may be needed to repair damage.

In the south, rainfall is typically higher and more reliable. Although summers can be dry and drought periods occur, pasture areas can usually

Figure 5.1: Average monthly rainfall in the north and south of the project area.



be managed to retain soil cover and remain green or dormant cover over most summers provided soils allow deeper root growth and areas are not overgrazed.

Central Victoria also experiences periodic strong El Nino and Indian Ocean Dipole affected weather patterns typically resulting in mild or severe drought conditions every few years. Dry soils bare of living plants and roots can severely set back efforts to build soil health because it depletes soil organic matter and damages the soil ecosystems that cycle nutrients, improve soil structure, and help hold organic matter in the soil.

A challenge during dry periods can be to retain ground cover to protect soils from baking sun and erosion

A challenge during dry periods can be to retain ground cover to protect soils from baking sun and erosion.

Under pasture systems, soil and grazing management and promotion of drought tolerant perennial species can improve water infiltration and achieve deeper root growth and help to carry living and dormant (alive but not growing) grasses and other species over most summers. Allowing areas to 'hay off' without heavy grazing by livestock or wildlife can also provide protective soil cover. During periods of extended drought, even this can be difficult.

Under cropping systems, the challenge of maintaining protective cover and using living or dormant drought- tolerant species to protect and feed soils is harder. In many instances. Farmers want to conserve limited soil moisture for the following crop, so are reluctant to carry growing plants over summer. In such instances, retaining as much crop residue straw as possible can help to protect soils. Even this can be a challenge under crops such as canola and peas that leave sparce residue.

During favourably spring and 'wet' summer and 'early autumn' conditions, biomass inputs to soils can be boosted and cover crop and green manure crops can be considered. Under pasture systems, work can be done to promote deeper root growth through the selection of plant species, grazing management and addressing sub-soil constraints. Under cropping systems, summer pastures, cover crops and green manures can usually be carried over milder summers if soils are deep and managed to retain rainfall.

The main objectives of making soils and plants less susceptible to dry periods are to: protect surface soils from 'baking' heat, make soils and plant roots deeper, and increase the amount of rainfall that infiltrates and is available to roots.

Key management options are:

1. **Improve soil water infiltration by improving soil structure/porosity.** This allows better water infiltration and deeper root growth. Soil porosity can be improved by managing livestock and vehicle traffic to reduce compaction, increasing organic matter in the soil, and on heavy sodic or magnesic clays the addition of calcium as gypsum, lime (on acidic soils) or other amendments. Strategic tillage may also be used to break up heavily compacted soils and integrate organic matter and soil amendments such as gypsum, lime and compost.
2. **Maintain a surface ground cover of living, dormant or dead 'mulch' plants** that will slow water flow and improve surface porosity
3. **Where tillage is used, working along contours** (i.e. across slopes rathe than up and down them) will also slow water flow and increase water infiltration.
4. **In pastures, promote a diversity of perennial and annual summer and winter active plants**, including deeper rooted grasses, nitrogen fixing legumes and other herbs with deep roots and good feed quality. Consideration needs to be given to constraints to deeper root growth such as soil compaction, hostile pH, and lack of nutrients. Some plants, including many legumes and the nitrogen fixing bacteria they host, are sensitive to overly acidic pH, aluminium toxicity and poor availability of trace nutrients. If these constraints are present on your farm, you may choose to sow more tolerant plants and apply appropriate levels of lime and fertiliser so deep rooted and nitrogen fixing plants can become better established.
5. **Avoiding over-grazing by livestock and wildlife** – particularly in summer and during winter months where plant growth can be slow. This main mean resting areas that have slower growth, reducing stocking numbers and culling or fencing to reduce wildlife grazing pressure.
6. **In cropping systems, consider longer rotations** that include a mix of legumes, cereals, oilseeds, fodder/hay crops and pasture or ley 'rest' phases. In areas with more reliable seasonal and summer rainfall, consideration can be given to under-sowing or strip-sowing crops with summer active plants that will not compete significantly with crops, but will provide living or dormant ground cover and fodder into summer months.
7. **When seasonal conditions and outlooks allow, use favourable seasons to increase the amount of biomass added to soils.** This includes 'locking up' paddocks for periods to allow deeper roots to develop and cutting hay and/or managing grazing so that these roots remain alive and plants are grazed when they have high feed quality.
8. **In drier areas and seasons, termination of summer growth may be needed** to preserve soil moisture for the following crop and add biomass to the soil. If this is done it is important to maintain a surface groundcover of dead organic matter over summer to protect soil from baking heat and erosion.

Managing Soil Health during and after drought

Central Victoria is no stranger to drought. Summers are often dry and periodic El Nino can result in low rainfall over the autumn to early summer growing period, sometimes for several years in a row. Dry summers and extended period of drought not only affects agricultural productivity but also has significant impacts on soil health. Observed and predicted climate trends for northern and central Victoria are for reduced and less reliable average growing season rainfall, more frequent extreme summer heat events and more frequent intense summer rainfall events. This means soil management strategies that promote deeper root access to soil moisture and conserve summer rainfall will become more important to maintaining yields.

Drought has direct and indirect impacts on soil health, including:

1. **Soil Moisture Depletion.** Extended periods of dry weather lead to a decrease in soil moisture levels. This dehydration affects levels of organic matter, soil biology and soil structure, making soils more susceptible to erosion and compaction.
2. **Risk of bare and unprotected soil over dry periods.** This exposes soil erosion from wind and summer storms, as well as baking heat and drying that kills soil biology and depletes soil organic matter.
3. **Disruption of soil ecosystems.** Extended drought can result in the death of more complex fungi and bacteria that hold and cycle carbon and nutrients, earthworms and other beneficial soil-building organisms. When the drought breaks there can be population explosions of more opportunistic bacteria that rapidly consume organic matter and draw down nutrients for a while. It can take several months or more for more complex and beneficial soil ecosystems to become reestablished and consecutive dry years can impact soil health for years.
4. **Loss of Soil Organic Matter:** Drought accelerates the decomposition of soil organic matter, leading to a decline in soil carbon levels. Reduced organic matter content diminishes soil fertility and water-holding capacity.
5. **Nutrient Imbalance:** Drought disrupts nutrient cycling in the soil, affecting the availability of essential nutrients for plant growth when the drought breaks. Nutrient imbalances may occur, leading to deficiencies or toxicities in plants, e.g. acidic soils with high manganese levels can experience manganese toxicity after hot and dry periods.

Effective soil management during drought is essential for mitigating the negative impacts and maintaining soil productivity. Some strategies for managing soil health to improve drought resilience include:

1. **Make soils deeper:** Address sub-soil constraints such as compaction, hostile pH and low nutrition.
2. **Conservation Tillage:** Adopt conservation tillage practices such as minimum tillage or no-till to reduce soil disturbance and minimise moisture loss. Conservation tillage helps maintain soil structure and organic matter content, enhancing drought resilience.
3. **Mulching:** Retain plant residues or apply organic mulches such as straw, hay, or compost to conserve soil moisture and regulate soil temperature. Mulching also prevents soil erosion and suppresses weed growth, promoting soil health during drought.
4. **Cover Cropping:** Plant cover crops during fallow periods to protect the soil surface, improve soil structure, and enhance soil fertility. Cover crops contribute organic matter to the soil and reduce erosion risk during drought.
5. **Soil Amendments:** Apply soil amendments such as organic matter, compost, or gypsum to improve soil structure and nutrient availability. Soil amendments enhance soil water-holding capacity and promote microbial activity, aiding in drought recovery.
6. **Crop and pasture selection:** Choose drought-tolerant plant varieties and rotations suited to local soil and climatic conditions.

Rehabilitating soil health after drought requires targeted interventions to restore soil fertility and resilience. Some additional strategies for managing soil health after drought include:

1. **Soil testing:** Conduct soil tests to assess nutrient levels, pH, and organic matter content post-drought. Soil testing provides valuable insights for developing tailored nutrient management plans and restoring soil fertility.
2. **Soil fertility and pH management:** Apply balanced fertilisers and soil conditioners based on soil test recommendations to replenish nutrient reserves and correct imbalances.
3. **Restore soil organic matter.** Implement practices such as greater retention and integration into the soil of crop and pasture biomass and compost application to replenish soil organic matter lost during drought.

Key messages

1. The central Victorian climate can be a significant constraint to the Healthy Plant ⇆ Healthy Soil cycle.
2. Management practices developed and promoted in milder and higher rainfall areas on better native soils may not be as applicable in parts of central Victoria, so climate as well as soil constraints need to be considered and managed.
3. Extended dry periods, drought and summer heat conditions can make it hard to maintain living and dormant plants and can result in rapid loss of soil organic matter.
4. Overgrazing by livestock and wildlife over summer periods can reduce the potential for dormant plants to survive and respond to summer and autumn rains.
5. Bare soil is also prone to baking heat and erosion.
6. Cold winter conditions slow plant growth and can result in overgrazing by livestock and wildlife and reduce root growth and the potential for plants to grow vigorously in spring. Shallow roots also make plants more susceptible to dry conditions and reduce how much biomass plants can add down the soil profile.
7. Climate constraints can be managed by:
    a. Improving the water infiltration. This can be achieved by reducing compaction, maintaining a cover of living, dormant and dead plant matter over the soil surface, and creating surfaces and contours that slow the flow of water across land.
    b. Improving the soil water-holding and plant-availability characteristics of soil. This can be done by increasing the organic matter content of soil.
    c. Managing grazing by livestock and wildlife to maintain at least 5cm high ground cover and allow plants to grow deeper roots.
    d. In cropping systems in lower rainfall areas or forecast drier years, managing summer weeds so that stored soil moisture from any summer and pre-sowing rain is conserved for the following years' crop. This may involve chemical or physical termination that leaves a 'mulching' layer of dead organic matter lying on the surface.
8. Soils need to be protected in bad seasons and may need to be repaired after extreme disruptions to soil health.
9. Good seasons can be used to add more biomass to soil.

6 MANAGING SOIL NUTRITION AND FERTILITY

Soil nutrition and fertility is a key driver of the Healthy Plant ⇆ Healthy Soil Cycle. It involves both the presence of nutrients in the soil, and the availability of these nutrients to plants in adequate and balanced amounts. Without adequate nutrition plant and root growth will be weak and will produce less biomass and cycle fewer nutrients to feed the soil. This section outlines how to assess, improve and maintain soil nutrition and fertility.

Available and balanced nutrition

Soil nutrients need to be soluble plant available forms that can be taken up by roots. They also need to be balanced - deficiencies in one nutrient can reduce the ability of plants to make use of other plant available nutrients, or can result in growth of pasture and crops deficient in some nutrients. This means it is important to assess nutrient availability, potential deficiencies, and factors potentially reducing their availability such as pH, poor soil ecosystem health, and levels of other elements that can make some nutrients less available to plants.

'Macro-' and 'micro-' nutrients

Macro-nutrients are those that plants need in higher concentrations. These are mainly nitrogen, phosphorous and potassium, as well as sulphur and calcium. There are the nutrients provided by the most commonly used synthetic fertilisers and soil amendments, and the ones most rapidly depleted by yields taken off farms. Most plants feed heavily on these nutrients and soils are likely to be become deficient in them unless nutrients are replaced through application of some form of fertiliser and management of pastures and crop rotations to 'fix' nitrogen.

In central Victoria, most soils are inherently low in total and plant available phosphorous, and prone to deficiencies in sulphur and calcium when yields are removed from farms. Unlike other nutrients, nitrogen is not present in mineral material to any significant extent. Plant available N in soil comes from added fertilisers, decomposing organic matter, nitrogen fixing bacteria (which are mostly associated with rhizobacteria that colonise and form nodules the roots of legumes), animal manure, and nitrates dissolved in rainwater. N and P deficiencies are typically the most significant constraint to the Healthy Plant ⇆ Healthy Soil cycle and adding some form of these is often needed to kick-start the cycle.

Micro-nutrients or 'trace elements' are also essential to healthy plant growth and reproduction, but are required at lower concentrations in the soil. In central Victoria, many farmed soils are prone to deficiencies in zinc, copper, molybdenum and boron.

Deficiencies and toxicities in central Victoria.

Table 6.1 details: the main nutrients required for healthy plant growth and key issues and management factors in central Victoria. Table 6.2 provides a quick checklist of symptoms and management of nutrient deficiencies and toxicities in crop and pasture plants.

Table 6.1

Nutrient deficiency	Symptoms/signs in grasses and cereals	Symptoms in clovers, medics and other legumes	Made worse by	Improved by
Macro-nutrients				
Nitrogen (N) Commonly deficient in cropped and pasture areas without periodic strong legume growth and root nodulation. Often indicated by uneven and pale green pasture growth with darker green and more rigorous growth near dung and urine 'patches'. N is essential to plant growth and yield, and new shoots will 'steal' N from older leaves. N is vital to protein production, seed set and plant reproduction.	• Less vigorous plants are smaller, spindly, paler and with yellowing and 'burnt tips' of older leaves.\ • May redden during cold conditions. • Cereal plants have fewer tillers. • Pale leaves do not die until the plant does (unlike P and K deficiencies), but the ends may become 'burnt'. • Stems are soft.	• Less vigorous plants are smaller, spindly, paler and with yellowing of older leaves. • Note: poor nitrogen in legumes typically indicates other factors impacting on root nodulation and growth.	• Poorly aerated, overly wet and waterlogged soils can lose nitrogen to the atmosphere. • Leaching of nutrient (typically on sandy soil) • Low nutrient holding and exchange capacity of soils. • Low organic matter and inactive soil biology. • Soil acidity and trace element deficiencies that reduce nodulation of legumes. • Removal of crops, hay and animal products	• Addition of sources of N (fertilisers, manures, composts, guano) • Improved soil porosity, aeration and drainage • Promotion of legumes in pastures and crop rotations. • Legume rick cover crops or green manures in rotation. • Correction of pH and mineral deficiencies impacting on nitrogen fixing bacteria and root growth • Managed rotational grazing • Improved root depth and strength • Retention or additional of organic matter with balanced carbon-to-nitrogen characteristics

Nutrient deficiency	Symptoms/signs in grasses and cereals	Symptoms in clovers, medics and other legumes	Made worse by	Improved by
Macro-nutrients				
Phosphorous (P). Inherently common on most soils in Central Victoria. Occurs following cropping, hay cutting and under most intensive animal production systems. Often indicated by darker growth near dung and urine patches. P is essential to healthy plant growth. Note that some native plants, including native grasses can be sensitive to higher rates of P.	• Stunted growth • Dark green-purple colour on stems and base of stunted and pale leaves. • Older leaves become pale and die. • Strong response to addition of poultry manure or P fertiliser test strips.	• Poor legume growth, with pastures dominated by grasses rather than clovers during spring. • Distinctly smaller leaves with green-purple colour. • Older leaves become pale and die.	• Most soils in Central Victoria tend to be naturally deficient in P. • Acidic soils typically have less soluble and available P. • Acidic soils high in ferrous and aluminium (common in central Victoria) can have high Phosphorous Buffering Indices (PBI), and will make P less plant available. • Over-liming can result in P fixation by calcium, making P less available • Removal of crops, hay and animal products will deplete P.	• Addition of sources of P (fertilisers, manures, compost, rock phosphate, guano) • Correction of pH and mineral deficiencies limiting root growth • Increasing N has a positive effect • On acidic clays with high PBI, addition of lime or gypsum can make P more available to plants • On alkaline soils, addition of S can make P more available • Deeper and stronger roots • Healthy soil biology and particularly root-mycorrhizal activity

Nutrient deficiency	Symptoms/signs in grasses and cereals	Symptoms in clovers, medics and other legumes	Made worse by	Improved by
Macro-nutrients				
Potassium (K). Deficient on some soils in central Victoria, and tends to be come deficient under cropping. K is essential to growth and seed set, but N and P are often more limiting.	• Uneven pasture growth with more rigorous growth from dung and urine 'patches' • Symptoms most apparent during cold periods. • Stunted growth, yellowing of older leaves. • Leaf edges curl 'under'/ 'downwards' from middle stem/vein, have 'wrinkles' and may develop red blotches. • Older leaves become pale/ yellow and die, with necrosis first at tips and along veins. • Stems are soft. • Strong response to addition of potash or compost test strips.	• Uneven pasture growth with more rigorous growth from dung and urine 'patches' • Younger levels are stunted with small white or yellow 'spots' on outer edges. • Stunted growth, yellowing of older leaves. • Edges of leaves can turn down and become necrotic (i..e die)	• Soil compaction and poor aeration • Low cation exchange capacity • Low levels of organic matter • Low soil temperature	• Addition of sources of K, such as potash, compost, manures • Improved soil porosity and aeration • Maintaining pH 'buffering' organic matter and healthy soil ecosystems. • Retention and addition of organic matter and manures

<table>
<tr><th>Nutrient deficiency</th><th>Symptoms/signs in grasses and cereals</th><th>Symptoms in clovers, medics and other legumes</th><th>Made worse by</th><th>Improved by</th></tr>
<tr><td colspan="5">Macro-nutrients</td></tr>
<tr><td rowspan="2">Sulphur (S). S is essential to growth. Crops, and particularly oilseeds, can deplete S levels. In the past, S in superphosphate met demand, but MAP and DAP fertilisers do not provide S. Gypsum will provide S.</td><td>• Younger leaves on established plants become pale and stunted.
• Whole plants can be pale, spindly and stunted.</td><td>• Pale younger leaves and plants and stunted growth.
• Poor nodulation of roots</td><td rowspan="2">• Low soil organic matter
• Acidic soil (pH <5)
• Removal of S ‘hungry’ crops (e.g. Canola)
• Waterlogging and compacted/ poorly aerated soils</td><td rowspan="2">• Building and maintaining higher levels of organic matter.
• Cover crops/ green manures with deep rooted brassicas with the biomass grazed or returned to soil.
• Addition of sources of S, such as fertilisers, gypsum, potash of sulphate, manures and compost.</td></tr>
<tr><td colspan="2">• Note, in Canola and other brassicas (including some mustard weeds), leaves can be red and pale. and flowers pale or grey-ish instead of yellow.</td></tr>
<tr><td rowspan="2">Calcium (Ca). Many central Victorian clay soils are low in Ca, but serious deficiencies are less common. In the past Ca in superphosphate met demand, and use of lime or gypsum will provide Ca.
High levels Ca can result in P deficiency, but this not common in central Victoria.</td><td>• Poor/stunted root growth and darker coloured roots.
• Weak young/new shoot growth.</td><td>• Poor root growth and poor nodulation.
• Weak young/new shoot growth.
• May show signs of N deficiency.</td><td rowspan="2">• Overly-acidic soil pH
• High Mg and P relative to Ca
• High levels of N fertiliser can result in Ca deficiency in plants on low Ca soils.
• Water stress.</td><td rowspan="2">• Neutralisation of pH (with lime also directly adding Ca to soils)
• Use of gypsum
• Addition of materials containing Ca, such as poultry shed manure, basaltic rock dust.</td></tr>
<tr><td colspan="2">• Note that clay soils deficient in Ca and where Mg and Na levels are high will often have poor structure and low water infiltration. Gypsum is often added to address this, and lime added to acidic soils will also have a positive effect.</td></tr>
</table>

<table>
<tr><th>Nutrient deficiency</th><th>Symptoms/signs in grasses and cereals</th><th>Symptoms in clovers, medics and other legumes</th><th>Made worse by</th><th>Improved by</th></tr>
<tr><td colspan="5">Micronutrients/trace elements</td></tr>
<tr><td>Copper (Cu)</td><td>• New/young leaves are curled inwards and are pale.
• Leaf margins may be irregular/ serrated.
• Poor grain-set.</td><td>• Stunted pale young leaves and poor growth.
• Poor seed set.
• Reduced root nodulation.</td><td>• Highly acid or alkaline pH
• Removal of crops, hay and animal products</td><td rowspan="2">• More neutral soil pH
• Addition of fertilisers or sources of Cu and Zn
• Provision of lick blocks containing Cu and Zn
• Active soil biology
• Retention and addition of organic matter and manures</td></tr>
<tr><td>Zinc (Zn). Commonly deficient on many central Victorian soils, and depleted by cropping.</td><td>• Stunted and pale growth, particularly of younger leaves
• Younger leaves may become 'mottled' and have dead patches.
• Older leaves may yellow</td><td>• Stunted growth, with less height in clovers.
• Small and curled leaves, with a purple colour
• Mottling with bronze spots on newer leaves and white 'dead' spots as these leaves get older.
• Reduced root nodulation.</td><td>• Overly alkaline pH
• Removal of crops, hay and animal products</td></tr>
<tr><td>Boron (B). Sometimes deficient and can limit legume (clover, sub-clover) growth and reproduction in particular. Depleted by cropping.</td><td>• Slow growing and twisted or dead tips on newer leaves.</td><td>• Stunted and malformed younger leaves, with red and yellow tints and imperfect/dead edges.
• Older stem may look 'swollen'/ thick.</td><td>• Highly acidic or alkaline pH</td><td>• More neutral soil pH
• Maintaining pH 'buffering' organic matter and healthy soil ecosystems.
• Addition of micro nutrient fertiliser to soil or in animal fodder additives.</td></tr>
<tr><td>Magnesium (Mg). Not commonly deficient on central Victorian soils.</td><td>• Weak growth.
• Yellowing of older leaves and yellowing between veins
• Leaves may have red or bronze colour
• Leaf curl inwards</td><td>• Weak growth.
• Older leaves become yellow/ red-bronze and die.</td><td>• Acidic soils
• Removal of crops, hay and animal products</td><td>• More neutral soil pH
• Maintaining pH 'buffering' organic matter and healthy soil ecosystems.
• Addition of micro nutrient fertiliser to soil or in animal fodder additives.</td></tr>
</table>

Nutrient deficiency	Symptoms/signs in grasses and cereals	Symptoms in clovers, medics and other legumes	Made worse by	Improved by
Micronutrients/trace elements				
Molybdenum (Mo). Sometimes deficient and can limit legume (clover, sub-clover) growth and reproduction in particular. Depleted by cropping.	• Yellowing of older leaves • Curling of younger leaves • Poor seed set (particularly legumes)		• Acidic pH	• More neutral soil pH • Maintaining pH 'buffering' organic matter and healthy soil ecosystems. • Addition of micro nutrient fertiliser to soil or in animal fodder additives.
Toxicities and nutrient imbalances				
Manganese (Mn). Mn is an essential element, but is rarely deficient in central Victoria where most soils have high Mn levels. It is more commonly a cause of 'toxicity' on acidic soils after dry periods.	• Deficiency results in stunted leaves that become pale or variegated prematurely, with pale leaves between darker veins • Toxicity can result in dead edges and spots on leaves, crinkled leaves		• Highly alkaline pH can cause deficiencies. • Acidic pH and dry conditions can result in 'toxicity'. • Application of acid-forming fertilisers can increase toxicity effect.	• Neutralising pH • Maintaining pH 'buffering' organic matter and healthy soil ecosystems.

Nutrient deficiency	Symptoms/signs in grasses and cereals	Symptoms in clovers, medics and other legumes	Made worse by	Improved by
Micronutrients/trace elements				
Aluminium (Al) toxicity. Occurs on highly acidic soils (ph <4.5). Common on many central Victorian soils.	• Similar symptoms to P deficiency • Roots are stubby and with thickened and brown root tips and no/few root hairs. • Poor nodulation in legumes		• Occurs on highly acidic soils with pH < 4.5	• Neutralising pH with lime • Maintaining pH 'buffering' organic matter and healthy soil ecosystems.
Iron (Fe) toxicity. This is not common and occurs on highly acidic soils (pH <4.5). High Fe clays can also reduce water availability to plants	• Fe toxicity reduces P uptake, so symptoms are the same as for P deficiency. • Water stressed plants despite clay still being plastic can be a sign that high Fe content is reducing water availability.		• Occurs on acidic soils with pH <5.0 Low organic matter and poor porosity will further reduce water availability to roots.	• Neutralising pH with lime • Increasing soil organic matter and soil porosity.

Note: Silicon or silicate deficiency has been recognised as a potential factor in reduced plant growth, but it is rarely a limiting factor on most soils in Central Victoria. Calcium Silicate rock dusts can be applied as a source of calcium and as an alternative to lime, and other rock dust products typically contain silicate and other nutrients, but the silicate component can be expected to have limited benefit on most soils, crops and pastures in the region. Test strips of products could be trialled to determine whether there is a response from plants.

Table 6.2: Symptoms of nutrient deficiency in pasture and cropping grasses, cereals and legumes. D= deficiency, T= toxicity

Symptom	Possible deficiency (D) or toxicity (T)												
	N	P	K	S	Ca	Cu	Zn	B	Mg	Mn	Mo	Al	Fe
Poor/slow growth	D	D	D	D					D			T	T
Leaves of clovers are small and have a green-purple colour		D					D					T	T
Grasses and cereals have a dark green-purple colour on the stems and base of paler leaves		D										T	T
Pale and stunted young leaves				D		D	D		D	D			
Pale older leaves that remain alive, young leaves not pale	D						D				D		
Older leaves become pale and die, young leaves not pale			D										
Uneven pasture and crop growth on previously grazed areas with patches of darker healthier plants amongst paler and less vigorous plants	D	D	D									T	T
Cereals and grasses develop a reddish colour during colder periods	D			D					D				
Strong growth after addition of poultry manure or N P K fertilisers	D	D	D									T	T
Leaf edges curl 'under'/ 'downwards' from middle stem/ vein, have 'wrinkles' and may develop red blotches and become necrotic (i.e. die)			D										
Younger clover leaves are stunted with small white or yellow 'spots' on outer edges.			D				D						
Flowers of canola and mustard/ brassicas are pale grey-yellow rather than yellow				D									
Poor nodulation of legume roots				D	D	D						T	T
Poor /stunted root growth, with roots forming fewer branches and hairs and having dark rather than white tips					D							T	T
Weak young/new shoot growth				D	D		D						
'Soft' stems	D		D									T	T

Symptom	Possible deficiency (D) or toxicity (T)												
	N	P	K	S	Ca	Cu	Zn	B	Mg	Mn	Mo	Al	Fe
New/young leaves are curled inwards and are pale						D			D		D		
Grass and cereals; leaf edges are serrated and uneven						D							
Stunted and pale growth, particularly of younger leaves													
Younger leaves may become 'mottled' and have dead patches.							D						
Slow growing and twisted, reddish or dead tips on newer leaves. Older stem may look 'swollen'/ thick.								D					

pH and soil chemistry

Soil pH and other soil chemical and biochemical processes can affect levels of plant available nutrients. Figure 2 shows how soil pH effects nutrient availability, and Figure 3 shows indicative soil pH at different soil depths in central Victoria. These show that the acidic and acidification-prone soils in much of central Victoria are likely to suffer nutrient deficiencies and Al, Fe and Mn toxicities.

Neutralising and managing soil acidification can be an effective strategy for addressing nutrient deficiencies. However, if crops are removed, deficiencies in N, P and several micro-nutrients can be expected to occur on many soils in central Victoria.

Soil and plant tissue tests

The Healthy Sols Initiative suggest initial and then periodic testing of soils to identify levels of nutrients present in the soil and the availability of these to plants. Most soil testing laboratories offer different 'suites' of tests for different parameters, and it is suggested that after initial more detailed testing, periodic testing focuses on nutrients that were found to be deficient or excessive in the initial testing. More frequent testing may be needed in cropping or intensive pasture systems, and precision testing can be used to better target use of fertilisers and lime. Similarly measurement of harvest data using equipment that links yield measuring equipment linked to precise geo-location can help vary application of fertilisers to replace nutrients removed in crops and as well as pin-point underperforming areas.

Plant tissue testing, along with yield measurements, can be used to determine how well plants are taking up available nutrients. Commercially, these tests are most valuable if they identify deficiencies in crops and pastures that can be corrected using foliar fertilisers.

The role of soil ecosystems in soil nutrition

Nutrients 'locked up' in insoluble mineral form or undecayed organic matter are not immediately available to plants. These nutrients are only released through either slow weathering of soil minerals or faster decomposition by soil bacteria, fungi and root enzymes. This means that nutrients added in less soluble forms or made less soluble due to soil pH or reactions with other soil chemistry, typically need the action of healthy soil ecosystems and root growth to be converted into plant-available forms. A soil without a healthy soil ecosystem will give plants less access to these nutrients. Degradation of soil biomass also provide energy to plant roots.

Soil ecosystems also 'hold' and 'cycle' nutrients, with the constant production of chemical compounds and dead 'necromass' supplying a pool of plant available nutrients in the root zone. This means that soluble fertilisers added to soil are often first taken up by soil ecosystems and then released/cycled to provide a constant pool of nutrients for plants. Without the healthy soil ecosystem, many of these nutrients would be lost in water percolating into deeper soil or as gases released to the atmosphere.

Nutrient replacement

Removing yield from farms removes nutrients from the soil. If these are not replaced, then the levels of plant available nutrients will be determined by the rate at which the are released from insoluble minerals and organic matter in the soil. This may be possible in low intensity pasture systems, but yields and production will typically be well below seasonal yield potential. The inherently low phosphorous levels of most central Victorian soils, as well as low nitrogen and trace elements, will often constrain plant growth and the Healthy Plant, Heathy Soil cycle. Increasing the depth and strength of root growth and promoting more complex and active soil ecosystems will give plants more access to nutrients in the soil, but it may be hard to achieve this unless the Healthy Plant ⇆ Healthy Soil system is given a 'kick start' with the addition of nutrients or other soil amelioration promoting root growth.

Table 6.3 summarises indicative amounts of nutrient removed by different crops and pastures. This can be used as a guide to see how much nutrient is removed from your farm per hectare based on yields. These need to be replaced through the addition of nutrients or 'weathering' of soil minerals if yields are to be maintained. If farmers choose to not use synthetic fertilisers, then nutrients need to be supplied through application of manures, guano, compost, rock minerals or other non-synthetic fertilisers. It is important to know the nutrient composition and plant availability of these products to inform the rates at which they need to be applied and how much nutrient will likely be available to plants in the first year. Some compost and mineral rock products contain nutrients that will be slowly released for years, but will not be immediately available to plants. It should be noted that the import of hay, straw or grain feed on to farms will bring nutrients onto farms and make most of them fairly immediately available to plants via dung and urine. Table 6.3 provides some indication of how much might be introduced to the farm, but stock raised on these fodder will remove some of the nutrients when sold.

Table 6.3: Indicative nutrient removal by different crops and animal production

Crop / product	Units	Indicative net nutrient removed per unit of crop/produce (kg/unit)				(g/unit)						
		N	P	K	S	Ca	Mg	Cu	Zn	Mn	Mo	B
Wheat	tonnes	23.0	3.0	4.0	1.4	0.4	0.4	3.0	15.0	30.0	1.8	2.0
Barley	tonnes	20.0	2.9	4.4	1.1	0.4	0.4	3.0	15.0	25.0	1.8	2.0
Oats	tonnes	16.0	3.0	4.0	1.5	0.4	0.4	3.0	15.0	30.0	1.8	2.0
Canola	tonnes	49.0	6.5	9.2	9.8							
Lupins	tonnes	13 - 51.0	3.8	8.8	3.1	1.0	1.0	6.0	25.0	9.0	2.0	10.0
Chickpeas	tonnes	20 - 34.0	3.8	8.9	1.8	1.0	1.0	6.0	25.0	9.0	2.0	10.0
Faba beans	tonnes	14 - 39.0	3.8	9.8	1.4	1.0	1.0	6.0	25.0	9.0	2.0	10.0
Field peas	tonnes	13 – 37.0	4.0	8.2	2.0	1.0	1.0	6.0	25.0	9.0	2.0	10.0
Oaten hay	tonnes	11.0	3.0	20.0	2.0	8.0	8.0	4.0	20.0	9.0	1.0	4.0
Medic/ clover hay	tonnes	15-30	3.0	25.0	2.0	9.0	9.0	5.0	20.0	15.0	1.2	25.0
Burnt wheat stubble	tonnes of stubble	5.0	0.5	7.5 (if ash lost)	1.5 (if ash lost	-	-	-	-	-	-	-
Animal products												
Meat	100kg live weight	3-4	0.7	0.2	0.4	1.4	<0.1	-	-	-	-	-
Milk	KL	5-6	1.0	1.4	0.3	1.2	0.1	-	-	-	-	-
Greasy wool	100 kg	17	<0.1	1.5	2.9	0.1	<0.1	-	-	-	-	-

(Sources: Harries et al, 2021; Seymour et al, 2018; Gourley et al, 2012)

Nitrogen is lost in water run-off and groundwater, and as gas emissions. Nitrogen losses from highly soluble and volatile forms in some fertilisers and manures can be greater than 50% of that applied. Losses can be reduced by applying less soluble and volatile forms of fertiliser and having higher levels of soil organic matter and healthy soil ecosystems. If no legumes are grown extra N fertiliser may be needed. Other less soluble and volatile nutrients may need to be added at rates of up to 10% higher than their losses in farm produce.

Many central Victorian soils are 'leached' and deficient of plant available nutrients just below the root zone.

Nutrient availability can vary at times when plants have their greatest need. In drier areas and seasons, there can be a nutrient 'draw down' effect in the weeks after the autumn break caused by soil bacteria decomposing organic matter and using available nitrogen, phosphorous and other macro nutrients. A late autumn break can result in a lack of available nutrients at the time of seed germination and early growth. Application of some form of immediately available N and P fertiliser when sowing can help. Plants have high nutrient demand in spring and when setting seed. Crops and pastures showing signs of nutrient deficiency can be improved through topdressing or foliar application of appropriate fertilisers.

Sub-soil constraints

Many central Victorian soils are 'leached' and deficient of plant available nutrients just below the root zone, so there is not an abundance of nutrients for plants. Many central Victorian soils are also poorly structured and some have overly acidic pH that further reduce root access to nutrients. Assessing and addressing such constraints is often necessary to establish deeper rooted crops and pastures. Pale colour, poor soil structure/high soil strength and a lack of deeper roots are a good indicator of such constraints. Field and laboratory testing can pinpoint deficiencies and pH constraints. Strategies to address such constraints include use of soil amendments (fertilisers, lime, gypsum, compost, organic matter), strategic tillage to break up soil and integrate amendments, and sowing deep-rooted perennial and annual species known to do well on soils with low nutrition, acidic pH and poor structure.

Nutrient and soil fertility management options

Table 6.4 summarises options for improving soil nutrition and fertility by maintaining levels of nutrients to meet plants' needs. To ensure soil health and nutrient replacement, a combination of strategies is recommended, including:

- Yield monitoring, nutrient budgeting and nutrient replacement to ensure crops and pastures are performing.
- Monitoring of signs of nutrient deficiencies in crops and pastures (see Tables 1 and 2).
- Tests strips of fertilisers, lime (on acid soils) and other soil additives to see how crops and pastures respond.
- Periodic soil testing, with more frequent testing if yields are high or areas are underperforming.
- Plant tissue testing to confirm or identify nutrient deficiencies in underperforming areas.
- 'Precision farming' techniques to identify areas with lower fertility, as well as areas that have produced high yield.
- Management of vehicle and livestock traffic to minimise compaction.
- Ensuring soil organic matter and pH levels to at least 30cm are adequate.

Table 6.4: Soil fertility management practices

Fertility management practice	What it involves	Factors to consider
Soil testing	• Soil testing • Plant tissue testing • Nutrient budgeting • pH correction	• The costs of testing. • The numbers of parameters you need to test for. • What areas of the farm are underperforming or are otherwise indicative of other areas (to focus and reduce testing costs)
Plant tissue testing	• Collecting and testing plant material to test for quality and deficiencies. • Underperforming areas can be tested and deficiencies addressed through topdressing or foliar fertilisation.	
Nutrient budgeting	• Application of nutrients according to nutritional demands of previous years' production and anticipated yield of the crop of pasture.	• Yield history and anticipated nutrient demand of current or proposed crop or pasture. • Potential losses of nutrients additional to those removed by farm produce. • 'Imports' of nutrients onto farm from purchased fodder. • Nutrients from legumes (nitrogen) and 'weathering' of soil minerals.
pH correction	• Soil testing.	• Overly acidic or alkaline soils reduce the availability of many essential nutrients or cause Al, Fe and Mn toxicities. On acidic soils, pH neutralisation typically involves application of lime. Acidification can also be addressed through efficient use and management of nitrogen, increasing soil organic matter, and improving soil aeration. • Strongly alkaline soils are not common in central Victoria and removal of crops of hay will typically have an acidifying effect.
Synthetic fertilisers	• Use of formulated fertilisers that have concentrated forms of plant nutrients to replace nutrient losses and provide nutrients for existing or proposed crop/ pasture. • These typically require low rates of application, can be applied with precision at sowing or as foliar sprays, and have immediate effect and predictable effect on soil nutrition.	• Efficient use to avoid losses to air and water. • Use of less volatile or soluble forms that have both immediate and slower release nutrients. • If undertaking carbon accounting of farm emissions, some N fertilisers can add to assumed and actual greenhouse gas emissions. • Some fertilisers are associated with soil acidification due to their chemistry and removal of higher yields.
Manure, guano or 'organic' treatments	• Use of products to replace or increase a range of nutrients.	• Proven performance of products by independent research.

Fertility management practice	What it involves	Factors to consider
Compost Rock dusts 'Bio stimulants'	• Manures and guano products typically have higher and more plant available forms of nutrients. • Many commercial composts derived from municipal garden and food organic waste have lower levels of nutrition, but are a soil conditioner that can improve soil health and gradually release plant available nutrients over several years. • Rock dusts typically have lower levels of plant-available nutrients and will release these over years of soil biology and chemistry is suitable. • Bio-stimulants are said to give plants greater access to nutrients through improved root growth and fungal and bacterial interactions.	• The total and plant-available nutrients (and potential contaminants) in products. Products will often have a wide range of nutrients, but may be in low concentrations or in insoluble and non-available forms. • The rate of release of nutrients. Nutrient release from rock dusts is often reliant on soil biological activity. • The availability of nutrient at seedling establishment, early growth and seed setting stages. • The rates that need to be applied to meet nutrient needs and the costs and practicality of this.
Pasture and crop rotation diversity	• Mixed pastures and crops or cropping rotations that include nitrogen fixing legumes and plants with root systems that can access deeper nutrients and deposit these in biomass in upper soil. • Pasture phases in cropping rotations allows accumulation of nutrients and active soil biology to provide more nutrients to crops.	• The plants best suited to soil and climate (e.g. acid and drought tolerant species). • Factors that may reduce legume nodulation and growth (e.g. pH, low soil fertility, soil compaction, deficiencies of key micro-nutrients, aluminium toxicity). • The potential for mixed species plantings to become future crop weeds. • Relative competitiveness of different species and appropriate sowing rates. • For mixed grains crops, the ripening times of different species and potential to be harvested at the same time without loss of grain. • Availability of harvesting and seed screening equipment for multi-species grains crops.

<table>
<thead>
<tr><th>Fertility management practice</th><th>What it involves</th><th>Factors to consider</th></tr>
</thead>
<tbody>
<tr><td>Selection of pasture and crop plants</td><td>Selection of plant species that are naturally deeper rooted and tolerant of soils with poor soil structure, and potentially acidic pH and low sub-soil nutrition.</td><td>In pasture systems, some locally indigenous perennial native grasses are adapted to poorly structured, acidic and low nutrition soils, as well as lower summer rainfall, and have reasonable feed value if managed using strategic rotational grazing. These can be a valuable addition to stands of pasture, but some are sensitive to applied phosphorous fertiliser.
In cropping systems, some canola varieties can form deep roots if they are sown early and deeper soil moisture is available. These can act as 'clay breakers'
Some soil amelioration may be needed to help establish deeper root growth.</td></tr>
<tr><td>Strategic rotational grazing management</td><td>Establishing and maintaining deeper rooted perennial pastures using longer rest periods and shorter and intensive grazing to increase production and maintain living roots and surface groundcover that protects soil and builds soil organic matter (see information box)</td><td>Fencing and watering infrastructure needed for 'cell' grazing.
Labour and other costs required to move stock, temporary fencing, water troughs, etc.
Pasture monitoring and grazing management to optimise the quantity and quality of feed produced.
Management of grazing by wildlife.
Use of destocking and supplementary feed during seasonal 'feed gaps'</td></tr>
<tr><td>Biomass 'crops'</td><td>Inclusion in rotations of biomass crops or pasture phases that add a lot of biomass to the soil. This might include not cutting as much hay or straw in some years or resting pasture in areas without grazing to increase biomass.
On soils with very low organic matter (<2% in upper 20-30cm), 'green manure' or cover crops can be grown and integrated into soils.</td><td>How modifications to current practices could increase biomass to soil (e.g. cutting less hay or straw on areas with low (<2%) soil organic carbon; better integrating biomass into soil; under sowing of crops with late spring/ early summer active plant that will not compete with crops but will produce biomass and cover into summer – noting that these may need to be terminated to conserve soil moisture)
Whether the longer-term benefits justify the costs of green manure crops and, in cropping systems, a year out of production.</td></tr>
</tbody>
</table>

Fertility management practice	What it involves	Factors to consider
Sub-soil amelioration to promote deeper soil health, fertility and root growth	• Use of strategic tillage and often added soil amendments such as gypsum, lime and/or compost/ organic matter to promote deeper root growth.	• The costs of amelioration (e.g. >$400-1,500/ha) compared to expected annual yield increases and the number of years the amelioration will improve production. • This should only be considered on significantly constrained soils in areas where there is potential for significant yield increases for higher value-crops/ pastures. Yield increases of 20-30% are commonly achieved, but on very constrained soils in higher rainfall areas, >100% yield increases have been achieved.
Earthworms and dung beetles	• These 'soil engineers' distribute organic matter and nutrients down the soil profile and aerate soil. • They need adequate organic matter, moisture and lack of disturbance (tillage and some pesticides can impact populations)	• Suitability of climate and soil type – they do better under higher rainfall and milder summer conditions. • Dung beetles, obviously need adequate livestock manure, and earthworms need annual addition of organic matter during the growing season. • Neither beetles nor earthworms tolerate intensive tillage deeper than 5-10cm. • Beetles are sensitive to some insecticides. • Earthworms can be impacted by some insecticides, nematicides and fungicides, but generally tolerate sensitive use of chemicals if there are good levels of soil organic matter and a healthy soil ecosystem.

Strategic rotational grazing

Strategic rotational grazing involves establishing pastures with deep-rooted perennial plants, as well as self-sowing annuals, and then managing these with 'long' rest periods and shorter periods of more intensive grazing based on rates of seasonal pasture growth. This increases overall fodder production and quality, maintains living deeper roots, and drives nutrient cycling and organic matter accumulation via the Healthy Plant ⇆ Healthy Soil cycle. If pasture is grazed for longer periods of grazing plants are continually grazed as they grow and this reduces the ability of plants photosynthesise and provide the energy needed to maintain larger and deeper root systems. Under strategic rotational grazing systems, plants are grazed once and then rested which allows them to immediate regrow supported by their extensive root systems and then provide energy to root.

There are different rotational grazing models. Some use very long rest periods (months) and intensive 'cell' grazing for 1-3 days, where stock are concentrated on an area at a high stocking rate. This typically requires small grazing cells and constant movement of stock, temporary fences, and drinking troughs. These systems are favoured by those wanting to build and maintain high levels of soil organic matter, but can reduce how much fodder is converted to livestock products due to lower quality feed at the time of grazing and trampling of fodder/biomass.

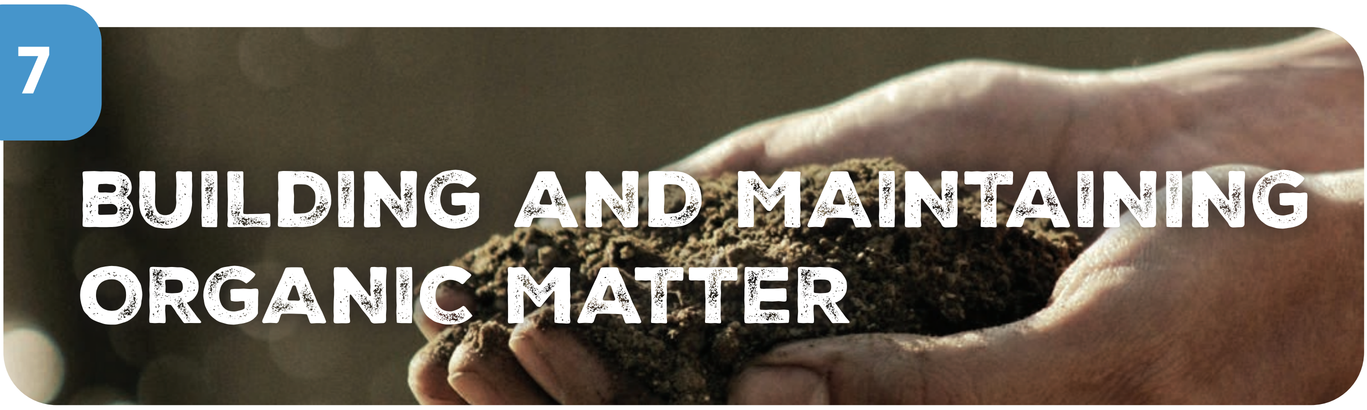
Other less labour-intensive grazing systems use systems where seasonal growth is monitored and areas rested until they achieve a target height and feed quality (e.g. average plant height of 12cm), and then grazed for periods until pasture is reduced to a minimum height (e.g. 4-5cm). This requires less infrastructure and labour and can result in better conversion of higher quality fodder into livestock products because areas are grazed according to heights/stage of growth rather than set longer periods in which plants might start to lose feed quality and become 'rank'. Meat and Livestock Australia provide a range of tools for rotation and pasture management, including a 'Pasture Ruler' to gauge heights for grazing and resting pastures (see: MLA Tools & Calculators and MLA Pasture Ruler).

A challenge in central Victoria is to manage pasture during 'feed gap' periods in summer when conditions are often too dry and hot to grow, and in winter when pasture growth can be very slow. Depending on the size of the farm and stock numbers, consideration need to be given to destocking and using supplementary feed (hay, grain) during these periods to keep stock numbers and grazing pressure low on areas susceptible to overgrazing (i.e. any area with poor coverage and average plant height less than 3-4cm). Conversely, if stock numbers are too small to manage pasture growth during spring/early summer resulting in plants becoming rank and haying off), consideration can be given to cutting hay or silage.

The impacts of grazing pressure from wildlife during feed gap periods also need to be considered. Fencing, culling and restricting access to drinking water can be used to reduce kangaroo and wallaby numbers during these periods.

Key messages

1. Most central Victorians have at least one significant nutrient deficiency constraint to the Healthy Plant ⇆ Healthy Soil cycle. Addressing these constraints can 'kick start' soil health.
2. If you remove yield from your farm, it needs to be replaced.
3. In most cases, the natural 'weathering' and release of nutrients from soil minerals cannot replenish the nutrients remove by yield, so some form of additional nutrition is needed.
4. It is possible to farm without adding nutrients, but in central Victoria, this will typically result in low and often declining plant and soil health and yields.
5. There are a range of fertilisers and sources of nutrients available. There is little scientific research-based evidence that judicial use of synthetic fertilisers within a conservation farming system damages soil health and it usually improves plant growth and, through this, soil health. Farmers opting not to use synthetic fertilisers can use products such as manures, guano, rock-mineral products and composts, as well as promote greater nitrogen fixation by legume rhizobacteria and other nitrifying bacteria.
6. Correcting soil pH, increasing levels of soil organic matter and biological activity, and deepening root growth can improve the availability of plant nutrients.
7. Initial and periodic soil testing of upper and sub-soils' nutrient, organic matter and pH levels are recommended to identify actual and likely deficiencies.
8. Nutrient budgeting can be used to estimate the levels of nutrients removed in farm yields and the extent to which these need to be replaced to maintain levels of production.



7

BUILDING AND MAINTAINING ORGANIC MATTER

Soil organic matter (SOM) is vital to the Healthy Plant ⇆ Healthy Soil cycle. However, central Victorian farmers face soil and climate constraints that can make it difficult to build and maintain higher levels of SOM. The practices farmers can successfully use to build and maintain SOC will therefore vary according to their situation. This section details why SOM is important and options for building and maintaining SOC according to your farming system and objectives.

> **SOM provides the energy and nutrients soil ecosystems need to hold and cycle nutrients for plants and improve soil structure.**

Why SOM matters

SOM provides the energy and nutrients soil ecosystems need to hold and cycle nutrients for plants and improve soil structure. It holds water in the root zone in sandy soils and can make water and nutrients more available to plants on clay soils. Plant roots are a good source of soil organic matter, and the levels of SOM down the soil profile are a good indicator of both how deep roots are growing and how well deeper soils are function and creating a 'root friendly' environment.

Farmer experience and research suggests that maintaining a level 'healthy' level of SOM down of soil organic carbon at or above 4% SOM or >2% soil organic carbon (SOC) in at least the upper 20-30cm of soil has agronomic yield benefits. This will usually improve water and nutrient availability and make plants more drought resilient. Higher levels of SOM/SOC can be achieved and are a good buffer against losses during drought or cropping. However, a level of 4% SOM or 2% SOC is a good 'rule of thumb' target or indicator of the biological health of your soil. The depth to which this level of organic matter is achieved is a good indicator of healthy root growth and whether the soil is benefiting fully from the nutrient and water holding and cycling characteristics of organic matter and the soil ecosystems it supports.

As discussed previously, sandier soils tend to have capacity to hold less SOM than clay and clay-loam soils. In central Victoria, most soils have high clay content and potential to hold at least 3-4% SOM. Ideally, this level of SOM will be achieved in at least the upper 30cm of soil, with levels of at least 1-2% below this. This will be easier to achieve under well managed pasture and less intensive cropping systems in higher rainfall areas, but will be more of a challenge under more intensive cropping and drier areas. In these areas, it is suggested maintaining a level of SOM of at least 2% in the upper 20-30cm of soil should be a soil health objective, with levels of 1-2% below this.

It is suggested that SOM levels in the upper and sub-soil should be laboratory tested as part of initial soil testing, and periodically re-tested when nutrition testing is undertaken. However, it is also possible to visibly assess whether healthy levels of SOM are present by looking for darker soil colour and evidence of larger organic matter particles, earthworms and roots deeper down the soil profile. Smell can also be an indicator of organic matter and biological activity, indicated by a mildly strong and 'sweet' earthy smell. No/little or a 'chalky' or 'metallic' smell suggests low organic matter and a 'rank' smell can indicate the presence of organic matter in a low oxygen (compacted or waterlogged) soil.

Constraints to building and maintaining SOC

Anything that reduces plant health and root depth or removes organic matter from the paddock constrains the capacity for soils to build and maintain SOC. This includes familiar constraints such as:

- Soil compaction
- Low fertility
- Lack of access to water
- Hostile soil pH
- Overgrazing

It also includes harvesting of hay and straw that doesn't leave much biomass (i.e. cutting close the ground – ideally harvesting should aim to leave at least 15-20 cm of standing straw biomass per hectare).

How to build and maintain SOC

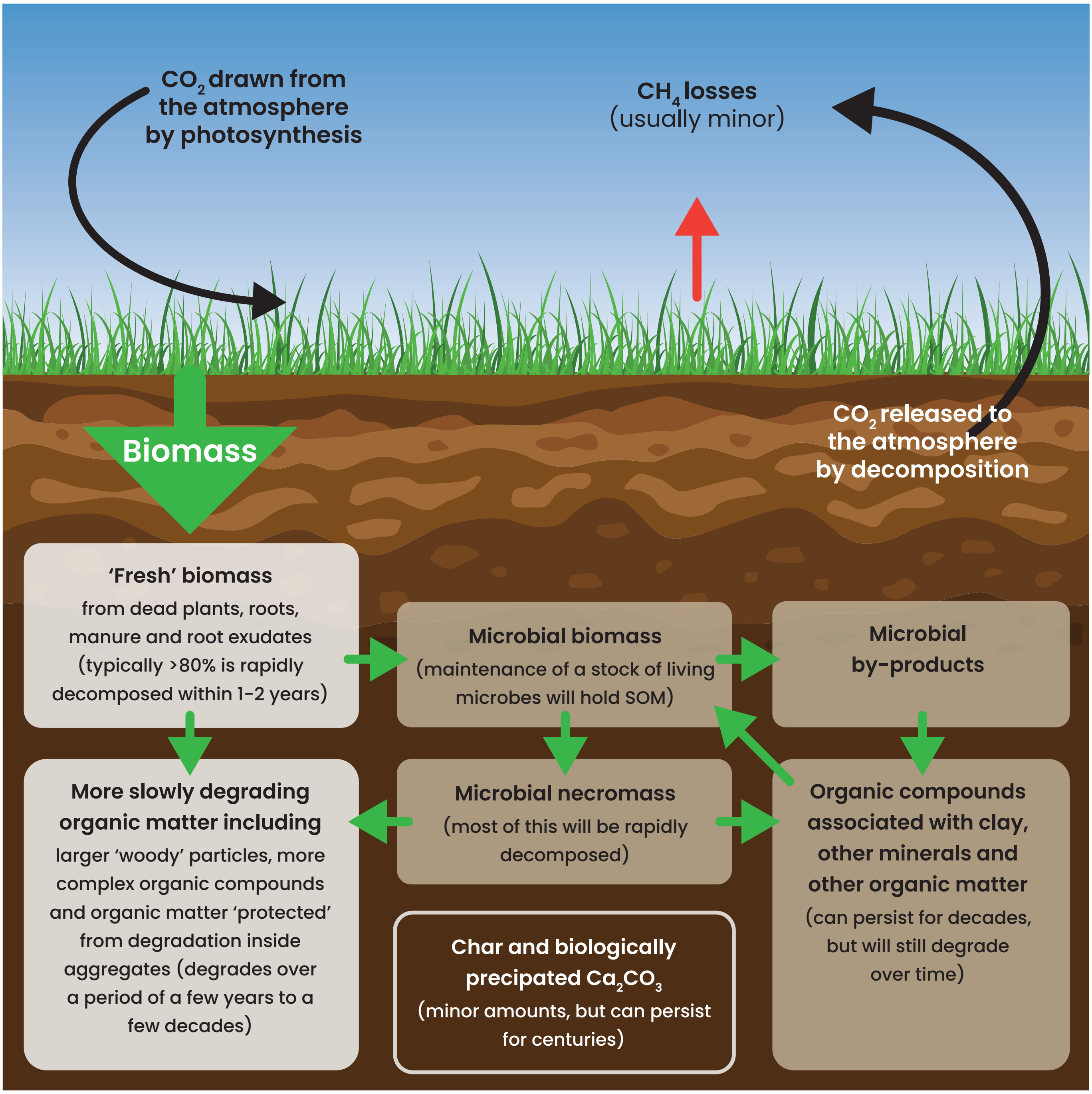
Maintenance of SOC requires constant addition of biomass to the soil and protection of the physical, chemical and biological characteristics of soil that help to hold carbon for longer.

Figure 7.1 shows how biomass added to soil is mostly decomposed within the first few years and is released and lost from the soil as carbon dioxide, water and other gases. Some SOM will be held for longer and cycled by soil ecosystems, but it will continually be biodegraded and lost from the soil within a few years. A small fraction of added biomass will be converted to longer-lasting forms and bind of 'associate' with clay minerals and can remain in the soil for decades. This means that most SOM/SOC is made up of pool of degrading

material and the level of SOM/SOC will reach a 'plateau' where the average amount degraded from the pool each year will equal the average amount added each year.

The extent to which organic carbon is retained by soil will depend on soil type (clays can retain more than sandier soils) and the health and activity of the microbial population down the soil profile. Shallow and drought prone soils will grow and retain less SOC than deeper soils that maintain better soil moisture. Ultimately, the amount of SOC will depend on how much biomass is added to the soil each year, and the SOC level will hit a plateau dependant on average added biomass, average rate of decay and any extreme disruptions to the soil that result in rapid losses of SOC.

Figure 7.1: The fate of biomass added to soil. Most added biomass is degraded is released to the atmosphere within one to years of being added to the soil.



As discussed in Section 2, it has been conservatively estimated that it requires addition of, on average, at least 30-60 tonnes per hectare of biomass per year to build and maintain SOC at 2% (or around 4% SOM) in the upper 30cm of soil. This is equivalent to at least 3.0-6.0 kg of biomass per square metre year. Plant roots can provide roughly matching amounts of biomass carbon to the soil as above ground biomass, and promoting deeper root growth is a good way to get organic matter down the soil profile. This means that around 1.5-3.0 kg of dry plant biomass per square metre needs to be added to the soil each year to maintain 25 SOC in the upper 30cm of soil. Adding this much biomass per hectare per year is easier to achieve under annual pasture and in high-yielding crops, but is more difficult in cropping and grazing in lower rainfall areas or on significantly constrained soils.

Cropping can deplete SOC because it typically does not add as much biomass as pasture and often has few growing plants on land over summer, Cropping also depletes SOC because tillage and fertiliser application promotes more rapid degradation of organic matter.

Traditionally, cropping rotations included pasture and ley fallow periods to rest land and allow accumulation of SOM and nutrients for following crops. Under more intensive cropping systems, SOM can be maintained through promoting deeper root growth, including high biomass plants in the rotations (e.g. cereals and fodder hay crops harvested to leave more biomass in the paddock), including deeper rooted species in rotations, and retaining stubbles. When seasonal conditions allow, 'green manure' and 'cover crops' can be grown to boost SOM. Manure and composts can be used to building and maintain SOM, and can also provide nutrients and soil-conditioning organic compounds. Excess nitrogen fertilisation can 'burn off' SOM, so efficient use of slower release forms of nitrogen and inclusion of legume crops in rotations can help to retain SOM.

Destocking and supplementary feeding

A strategy for managing soil health is to maintain ground cover and healthy plant and root growth by managing grazing pressure on land during summer and winter feed gap periods. Ideally, stock numbers will be managed so that some areas can be locked up through spring for hay cutting so that hay can be used during feed gaps. Feeding out hay and grain can reduce grazing pressure during feed gap periods and also cycles nutrients on the farm, but can also create the risk of over-grazing if pasture heights are not monitored and stock are removed from areas where average plant height is less than 4-5cm. If stocking rates make it hard to maintain this minimum pasture height across the farm during winter and summer feed gaps, then destocking to reduce grazing pressures during these periods is advisable.

Strategies for increasing biomass additions to soil include:

1. Improving soil nutrition and overcoming other key soil constraints (pH, compaction) to increase plant and root biomass. This includes addressing sub-soil constraints to deeper root growth.
2. Retaining biomass from crop residues. This also protects the soil surface from erosion and baking summer heat and helps to retain soil moisture. Biomass left on the surface will can blow or wash away, and it is best to lightly integrate into the surface soil. Livestock trampling and manuring and the action of earthworms and dung beetles can also help to get biomass into soil.
3. Avoiding overgrazing and managing grazing to increase root depth and retain more biomass from pastures (see Boxed discussion).
4. Avoiding periods where there are no living or dormant plants growing. This can be difficult to avoid in drier areas and years, and particularly under cropping systems, but periods without living roots in the soil disrupt soil ecosystems and can result in carbon and nutrient losses when soil is rewetted and bacterial populations rapidly degrade dead organic matter.
5. Improving soil porosity and water infiltration so that rainfall is retained by soil and can sustain growing or dormant plant cover for longer.
6. When seasonal conditions allow, growing biomass 'green manure' or 'cover' crops. This can involve sowing plants that will boost organic matter and soil nitrogen, or just letting plants grow without grazing and terminating and integrating the biomass into soil.
7. Sowing plants that have naturally deeper and hardier 'clay breaking; roots. Multispecies pasture mixes can be used to provide a variety of root types.
8. Adding manures and slower -degrading compost products to build and maintain desired SOC levels and repair soils after extended drought. Repeated applications of 10-30 t/ha of manure and compost every few years have been found to maintain higher levels of SOM over time.

A key strategy for retaining more SOM is to reduce disruptions and drying of soil and soil eco-systems. The soil fungi, bacteria, earthworms and other organisms that hold and cycle SOM can be damaged by tillage, drying and some farm chemical use. Once disrupted they can take months to recover and much of their dead organic matter will be decomposed by bacteria that don't retain as much SOM in soil. Tillage also breaks soil aggregates and exposes SOM to more rapid biodegradation.

Reducing the frequency, depth and intensity of tillage helps to retain soil organic matter. However, many of the heavier and shallow clay soils in central Victoria may benefit from tillage to integrate soil amendments and organic matter into to soil and often need surface tillage to prepare seed beds for sowing. Improved soil health and porosity should reduce the need for more intensive tillage, reducing fuel, labour and equipment costs. Management of vehicle and livestock traffic to minimise compaction will also help maintain better structured soils.

8

ASSESSING YOUR SOIL

The first stage of the soil health planning process is to assess soils to identify soils constraints across the farm.

There are a number of excellent resources available that outline methods for doing this, and the following discussion and Further Information and Tools section of this documents provide relevant links to these.

The following stages are suggested:

Mapping differences in soil, terrain, land use and productivity

Generate a map to be used to start adding details about differences in soils across properties and individual paddocks. This can be done with pen and paper or on computer. Free online mapping resources can be used to obtain aerial images of most properties in Victoria. Mapshare (http://mapshare.vic.gov.au/MapShareVic/) is a Victorian government resource that allows access to topographical, water way and aerial imagery mapping of properties. Images can be downloaded and used to create a farm map.

Other mapping resources are available. Visualising Australasia's Soils and Victorian Resources Online provide free soil map data that will provide some indication of broad soil types in your area. These are not precise enough to show specific details on you farm and are not a substitute for physically assessing your soil. Often aerial imagery will show differences in surface soil and vegetation colour and help to map possible differences across the farm. Google Earth provides recent aerial images and can be useful to checking differences in plant 'greenness' and surface soil cover and colour at different times of the year.

It is suggested you first identify and draw in:

- Different paddocks, and known variations within these – for example, you may already know that some sections of the farm have different colour, texture type (sand, loam, clay, gravel) and depth topsoils. You may have previous soil test results for different areas You may even know your subsoils from post-hole digging, other excavation or deep soil testing. You might also note whether paddocks are rocky or mostly clear or clear of rocks, and, if you know, what types of rock are present (e.g. basalt, sandstone, mudstone, granite). Differences in types and the abundance of surface rocks can indicate differences in soil types.
- Land use and history. The map should include notes about which areas are cropped and grazed and the history of management, including typical crop rotations and pasture re-sowing, yields of crops including cut hay, typical stocking rates and livestock productivity, and application of fertilisers, lime, gypsum and other soil amendments. This can help to identify paddocks that have higher/lower yields, have been used more/less intensively, and have had more/less inputs applied. It is also worth noting higher traffic areas from vehicles and livestock (e.g. near gates, stock 'camping' areas, and watering and feeding points) as these areas may have greater soil compaction and nutrition. This information is useful for identifying areas to test soil and for nutrient budget planning.

- Differences in terrain, water flow and ponding/waterlogging. Soils often differ from the top and bottom of hills and along creeks and flood prone areas. Hills and creek lines can sometimes mark stark differences in underlying geology/pedology and soil type.
- Observed differences in plant growth and productivity. Most farmers know which paddocks and which parts of paddocks perform better or worse than the average across the paddock. If you know these, draw them onto the map. The under-performing areas will be a good place to undertake soil assessments, and the best performing areas might be an indicator of what can be achieved across the farm with improved soil management.
- Observed difference in vegetation types. Differences in types of pasture species growing in paddocks can indicate differences in soil types and depths. Mapping treed areas (which should be obvious on aerial images) might be useful in assessing on-farm biodiversity and what undisturbed soils look like on your farm.

Choose the areas of the farm where you plan to assess soils and mark these on the map. It is suggested that you identify areas that you believe are representative of different landscapes and soils on your farm and areas that you know to be under-performing. These will the areas to focus on first, but it is suggested you start carrying a spade and 'poker' on the tray of your farm vehicle and every so often have a dig and poke across the whole farm.

Having a poke and dig

A focus of the Healthy Soil project is to look at both upper soils and sub-soils to a depth of at least 60 cm. In many parts of Central Victoria, the upper 10-30 cm of upper soil is a lighter clay-loam, loam or sandier soil overlying heavy clays, gravelly clays or even bedrock. Often these deeper subsoils have poor water infiltration or chemical characteristics that prevent deeper and healthier root growth, and this can only be determined by digging or taking cores of deeper soils.

When soil moisture is sufficient down the soil profile, a spade or shovel may be enough to dig a 60 cm hole, but often an auger, crow bar, pick or post-hole digger may be needed. If such tools are needed, this is usually an indication that there are sub-soil constraints to healthy plant growth.

Table 1 provides a worksheet for assessing and scoring surface appearance, and upper soil/ topsoil and subsoil layers. This can be printed off or photocopied or to allow you to keep a record of changes observed throughout the year. Not every test needs to be undertaken every time, but it provides a tool for recording information and rating how soils are performing at different assessment points. Many of the tests allow performance to be scored on a 0 to 5 scale, and this helps to quickly identify where soils are under-performing and monitor future changes. A valuable guide to use during this process is the North Central Catchment Management Authority's Soil Health Guide which provides more details about some of the tests. This is an excellent reference, and it is strongly recommended that it is used as a guide when undertaking soil assessments.

A suggested method for assessing soils is to:

1. Randomly select where to dig. Avoid areas that might be atypically compacted or fertile due to stock movement such as near water troughs, feeders, gates and stock traffic lines, 'camp' areas, and manure patches, etc and come in at least 20-30m off fence lines. Choose the area you want to sample and throw a stick 2-3 metres from where you are standing. Dig where it lands. This stops you picking a spot to sample based on solely on appearances.
2. Assess the appearance of the soil surface noting type and extent of groundcover, organic matter cover, the types of plants growing, surface cracking, sealing or crusting, and evidence of burrowing animals (earthworms, insects, arachnids).
3. Check how easily the soil can be penetrated with a spade – first pushing with your foot gently and then with more force. Can it get all the way down without full force? Can it get down with full force? Note the depths at which digging gets harder or the blade will not go any further. Unless you have hit a rock, these depths tell you where your soil becomes more compacted. Ideally you should be able to get to a full spade head or moist soil without full force. You can also use a poker or 'penetrometer' made of high tensile wire or metal rod. These are useful for quickly testing differences across and area and are particularly useful on stony soil. See the Soil Health Guide for details. The levels of soil moisture will influence how easily soils can be penetrated, so it is suggested this test is undertaken throughout the year to see how hard-setting soil layers are when they are dry and how quickly soils dry out down the profile. Penetrometer testing can be useful to detect compaction 'hardpans' from historic or current tillage, stock and vehicle traffic management – sometimes pushing through a hardpan occurring at 20-30cm depth will reveal less resistant soil below this level, indicating that working to break up the hardpan could give roots access to deeper soil nutrient and moisture.
4. To undertake the dig tests, spread a groundsheet (e.g. a small tarp) and then quickly cut out an upper sod that is a spade head wide and long

(usually around 15cm X 15cm) and to a depth of the spade head, or around 25-30 cm (or as far as the spade it will go in), and dig put the sod and place it on the groundsheet so the soil surface is near the top edge of the sheet. The reason to dig the 25-30cm sod quickly is to capture earthworms which may move away from the digging if you are slow.

5. Dig the next layer or layers to a depth of 60cm, noting the depths at which it becomes difficult to dig and any changes in texture (sand, clay, gravel, silt), colour, moisture content and root depth. As you dig out the soil, place each depth below the original sod on the groundsheet to get an indication of changes in the soil the profile. Often you'll need to expand the depth and width of the hole to get to the soil further down the profile, and if you do, place these layers next to the original excavation to avoiding mixing the layers. Looking and measuring depths inside the hole is also a good way to assess changes in the soil profile and the depth of root growth.
6. If the soil still has some moisture (usually between April/May and September/October in the north central Victoria, but potentially all year around in the southern part of the region), it is suggested you undertake an earthworm count noting the depth at which they are found and the number and size of earthworms. Also look at the extent to which earthworm activity has aerated soil through burrows and 'ped' (small 'ball') formation. These are good indicators of soil health. You should see at least 2-4 large earthworms per 15cm X 15cm X 30cm spade head cut sod. The presence of large 'adult' earthworms immediately following the Autumn break indicates that they were able to 'hibernate' over summer by digging down to soil with enough soil moisture to sustain them, and this is an indicator of a healthier

Earthworms

Earthworms play a major role in aerating soil and converting organic matter into plant available nutrients. Healthy earthworm populations can 'turn over' and 'manure' many tonnes of upper soil per hectare per year and are useful for moving organic matter from the surface soil to lower layers. Earthworms are also a great indicator of soil health. A healthy soil will have an average of at least 2-4 adult earthworms in each spade sod dug to 25-30cm when soil has sufficient moisture (generally between June and October). Ideally populations will be even higher. Sometimes you will not find earthworms but will see evidence of their burrows and friable spherical 'casts'/droppings. To thrive, earthworms need organic matter; a healthy population of soil bacteria and fungi to feed on; soil moisture; and aerated and uncompacted soil. Drought, tillage and chemical use that disrupts soil biology and their food chain will reduce earthworm activity. Most earthworms are slow to reproduce, and it can take more than a year for populations to. Adult earthworms can hibernate in clay subsoils during dry periods for up to 3-4 months, but otherwise rely on the survival of their eggs in soil over dry periods. Finding adult earthworms in the weeks after the autumn break tells you that adults are surviving over summer, which is a good sign of healthy soil. If few adults are surviving over summer, then juvenile hatchlings will be less able to work and manure soil before the onset of dry conditions.

and deeper soil. If only juvenile earthworms are found during the first few months following the autumn break, this suggests few if any adults survived over summer and means the population is sustained by eggs. This reduces the time over which earthworms get to breed before late spring and summer and can result in smaller populations and less benefit from earthworm activity. Low earthworm counts between May-September usually indicate low soil organic matter and other chemical and physical constraints to earthworms and other soil biology. See the section in earthworms for further details.

7. Look at how soil changes down the soil profile. Conduct assessments and tests for aggregate strength and size, texture/clay content, colour, pH, slaking and dispersal and root depth. The Soil Health Guide provides methods assessing these factors.
8. To make up a soil sample to be sent for laboratory testing, take and mix sub-samples at least 5-10 points across an area, keeping the upper soil and sub-soil samples in separate buckets. This is for the purposes of assessing soil profile characteristics. If you are testing in to decide fertiliser application rates, it is recommended you take at least 10-30 sub-samples from the upper 10-20cm to get a more accurate sample. Soil testing laboratories will provide details of how much soil they need and how samples should be stored and sent for sampling.

You can also use the dig to assess water infiltration at various depths. This can be done by digging a shallow hole (10cm), medium depth hole (20-30cm) and deep hole (50-60cm), gently filling each hole with around 10cm of water (fill it initially, and then top it up to 10cm after 5 minutes) and then noticing how quickly (or not) the water drains away. Ideally a depth of 10 cm of water should drain from within 1 hour, and the more rapidly it drains the better. A more advanced infiltration testing using a section of pipe or tubing can also be conducted – see: SoilsforLife - Infiltration. This test tells you how porous the soil is, and how easily rainfall will be absorbed down the soil profile when the soil is dry or wet. Water infiltration will often vary depending whether soils are wet or dry. Dry clay soils that have deep cracking and good aggregate formation can have good water infiltration and this indicates that summer and initial autumn rainfall will be more readily absorbed. However, many clays in central Victoria swell and can become less permeable when they are wet. Where such soils have poor aggregation and porosity, growing season rainfall can be lost as runoff and increase soil erosion and loss of surface organic matter. In some area, subsoil clays become heavy and impermeable, and this can result in waterlogging. Some sandy and fine textured silt and clay soils can develop water-repellency when very dry.

It is suggested basic 'dig test' soil assessments are taken throughout the year, but particularly during the months following the autumn break (when soils and plants first respond to rewetting), in mid spring (when soils and plants should be at their prime, but may be drying), and in February (when conditions are dry, and the drought resilience of soil and plants can be assessed).

You don't have to do all the tests at every sample point every time you test, but the intent is you keep copies of the assessment sheet in farm vehicles and periodically test areas when you are in the paddock and have time. It is suggested samples are sent to laboratories for testing from at least some testing areas initially, and re-tested at least every few years if the area is cropped, cut for hay, or is grazed intensively. Lower intensity grazing properties can lab test soils less frequently. All farms can use the assessment sheets to see whether soil health and function is improving, remaining the same, or getting worse over time.

Summary

- Map difference on your farm and pick areas to assess based on observed under-performance
- Assess plant growth and soil conditions at the surface in areas you assess. Look for weak or patchiness of growth and symptoms of deficiencies, lack of surface ground cover, and surface crusting, cracking and friability.
- Dig holes to 50-60cm depth, making particular observations about:
    - The depth at which the soil becomes hard to dig
    - The depth and strength of root growth
    - Changes in soil texture and colour and the depths at which these occur
    - The friability/porosity of soil at different depths
    - The presence or absence of earthworms and visible organic matter
    - pH at different depths
    - water infiltration
    - stability, dispersion and slaking of aggregates
- Take samples for laboratory testing and use the results to assess likely nutrient deficiencies, soil organic matter levels, pH, nutrient/cation exchange, calcium-to-sodium and magnesium levels, and potential toxicities.

Laboratory testing of soil samples

Initial and periodic laboratory testing of soil samples helps to identify or confirm soil constraints more accurately than field assessments. There are many commercial soil testing services and laboratories available. It is recommended that an independent NATA (National Association of Testing Authorities) certified laboratory is used, as these use standardised and accurate testing methods and are not promoting use of particular products or services. Most laboratories can provide a report summarising the results and indicating deficiencies or other constraints associated with tested parameters. The table below is suggested as guide to interpreting results for key soil testing parameters. It is suggested initial soil testing includes most of these to identify likely constraints, and later testing focuses on these constraints. Most laboratories will provide analysis of results for an additional fee. Section 9 of this Guide provides a table for recording the status of the nutrients you decide to test for.

Table 8.1: Soil assessment tool – this provides a guide for assessing soil health in the paddock. Sending soil samples for laboratory analysis is also useful for identifying possible nutrient deficiencies and imbalances that impact on plant health and soil structure and performance.

Sample area (paddock and location)	
Time of year	
Recent conditions (e.g. dry, wet, paddock history)	
Other observations re: area/paddock	

Soil health factor	What to look for / How to measure	Observations/notes	Score of condition (0=very poor, 5=very good) 0	1	2	3	4	5
Surface assessment								
% cover	Pace across the paddock/ area and every 10-20 paces stop and look at the roughly 30cm X 30cm area in front of your leading foot. Look what % of the surface is uncovered soil, and what proportion of the cover is dead organic matter, or dormant or growing plant matter. The % cover = 100% minus any uncovered area. Score: 0 = <10% cover; 1 = 10-20%; 2= 20-40%; 3 = 40-60%; 4 = 60-80%; 5 = 80-100%.							
Plant vigour and type	Note dominant and other plant species present and how well they are growing for the time of the year. Look for any signs of possible nutrient deficiency. Note plant types and any signs of possible nutrient deficiencies (see Figure 3 and Table 3). Score according to vigour from 0 = very weak/poor to 5 = very strong and healthy.							
Soil surface appearance	Look for friability/'crumbliness', crusting, cracking, mosses, bio-crusting, and salt residues where surface soil is exposed. Score from 0 = smooth, hard and sealed/crusted through to 5 = very crumbly and friable.							
Evidence of soil fauna (animal) activity	Look for insect, spider and worm burrows ('macro pores') in soil. In pasture, look for dung beetles and worms in and under dung piles. Score from 0 = no evidence to animal activity through to 5 = very high level of observable soil fauna activity.							

Soil health factor	What to look for / How to measure	Observations/notes	Score of condition (0=very poor, 5=very good)					
			0	1	2	3	4	5
Soil depth penetration test	Use poker/penetrometer to see how easy it is to penetrate the soil and gauge compaction at depth. Score: 0 = <5cm; 1 =5-10cm; 2=10-15cm; 3 =15-20cm; 4 =20-30cm; 5 = >30cm							
Soil water infiltration (optional when soil is wet/ moist – the penetration test and assessment of porosity (below) will usually, but not always, provide an indication of infiltration)	Assess how quickly water soaks into the soil. This involves pushing a piece of open tubing or pipe vertically into the soil, gently compacting the soil on the outside of the pipe to form a seal and then filling the pipe with water to a depth of 10 cm and measuring how quickly this infiltrates the soil. Score from 0 = no/very little (<1 cm) infiltration after 30 minutes, to 5 = free draining = 10cm of water infiltrated into soil within 10 minutes. Different depths of the soil can be assessed by digging holes to different depths and filling them to 10cm and noting how quickly they drain. Sections of piping or tubing driven into the soil can be used to stop infiltration out the sides.							
Presence and strength of organic layer (in upper soil only)	Note whether there is a darker surface organic layer and the depth of this layer.	Score from 0 = no organic layer; 1= <0.5cm weak layer; 2 = 0.5-1cm layer; 3 = 1-2cm; 4 = 2-4cm; 5 = >4cm-						
Depth of upper soil (indicated by strong roots and more friable texture)	Score from 0 =<5cm, 1 = 5-10cm; 2 = 10-20cm; 3 = 20-30cm; 4 = 30-40cm; 5 = >40cm	Friable soil depth: ______cm Strong root depth until ______cm Depth where there are no longer visible roots: _____cm						

Soil health factor	What to look for / How to measure	Observations/notes	Score of condition (0=very poor, 5=very good) 0	1	2	3	4	5
Noted depths of changes in texture, density and/or colour	Note depth at which changes occur and the nature of these changes. Add the depth and circle the texture and colour at different levels. In most soils in Central Victoria the upper 'friable' soil and sub-soil will be observable within the upper 40-60cm – sometime this difference will be very stark (e.g. strongly different texture and colour), but sometimes it will be more subtle (e.g. a clay soil becomes slightly heavier/more dense down the profile, but otherwise colour remains similar, with the main difference being root depth and earthworm activity making the upper soil more porous and friable). Some soils will only show one change in 'layers' down the profile over 60cm, others will have three or four distinct layers – e,g, sand-loam upper soil, friable brown clay-loam upper subsoil over red clay-gravel over heavy mottled clay.	Upper/top soil = 0 - ____cm Texture: Sand, Loam, Clay-loam, Clay, Heavy clay Colour: White/pale, light yellow, light grey, grey, red, brown, black						
		Upper sub soil = ____ - ____cm Texture: Sand, Loam, Clay-loam, Clay, Heavy clay Colour: White/pale, light yellow, light grey, grey, red, brown, black						
		Deeper subsoil = ____ - ____cm Texture: Sand, Loam, Clay-loam, Clay, Heavy clay Colour: White/pale, light yellow, light grey, grey, red, brown, black						
		Deeper subsoil = > ____ cm Texture: Sand, Loam, Clay-loam, Clay, Heavy clay Colour: White/pale, light yellow, light grey, grey, red, brown, black						
Presence, depth and colour of mottling	Note red/orange, blue/grey and black mottling and the depth at which this occurs. Mottling typically indicates that anaerobic waterlogged conditions have occurred, and can also indicate pH changes in the soil.	Mottling present – Yes / No Depth at which mottling observed _______cm						

Soil health factor	What to look for / How to measure	Observations/notes	Score of condition (0=very poor, 5=very good)					
			0	1	2	3	4	5
pH	Use pH test kit or accurate meter. Have pH tested when soils are sent to laboratories. Note pH and score 0 = <4. or >9.0; 1 = 4-4.5 or 8.5-9.0; 2 = 4.4-5.0 or 8.0-8.5; 3 = 5.0-5.5 or 7.5-8.0; 4 = 5.5-6.0 and 7.0-7.5; 5= between 6.0-7.0 (both 4 & 5 are good pH levels)	Upper/top soil 0 to ___ cm pH = _______						
		Upper sub soil ___ to ___cm pH = ______						
		Deeper subsoil ___ to ___ cm pH= _____						
Structure, strength and porosity in layers	Use pull test and drop test to assess friability and aggregation, and observation to assess porosity and structure. Score from 0 = no/low structure and porosity to 5 = highly friable and porous.	Upper/top soil 0 to ___cm						
		Upper sub soil ___ to ___cm						
		Deeper subsoil ___ to ___ cm						
Dispersion and slaking test.	Use dispersion and slaking test to score from 0= highly dispersive to 5 = highly stable aggregates.	Upper/top soil						
		Upper sub soil						
		Deeper subsoil						
Visible organic matter and roots	Look for obvious living and dead roots and other organic matter and where this occurs. Score from 0 = no roots or organic matter at the depth through to 5 = strong root growth and obvious organic matter at depth	Upper/top soil						
		Upper sub soil						
		Deeper subsoil						
Earthworm numbers and evidence of activity	Pull apart a 15cm X 15xm X 30cm deep sod and count large mature earthworms. Look for evidence of pores and 'balls' from burrowing and note any smaller earthworms. Record number of earthworms and score 0 = none and no evidence of activity; 1 = none, but evidence of some earthworm activity; 2= 1 mature earthworm; 3 = 2-3 mature earthworms; 4 = 4-6 mature earthworms; 5 = >6 mature earthworms							

Table 8.2: Key soil testing parameters and what to look for when reading laboratory results.

Testing parameter	Significance /importance	What to look for
pH	High. Soil acidity is common in much of the Health Soils Initiative area, and overly-acidic conditions effects the availability of nutrients and the health of soil biology. pH is measured using either a water (H_2O) or calcium chloride (CaCls) test, and these produce slightly different numeric results. Water based pH testing can be more variable and reflect seasonal conditions. Field pH kits can provide a good level of accuracy.	Ideally, pH will be in the range of 5.5 -7.0 (H_2O) or 5.0-7.0 ($CaCl_2$), and more serious problems occur at pH levels less than 5.0 (H_2O) or 4.5 ($CaCl_2$) or greater than 8.0 on either scale.
Phosphorous (P) – total and available	Very high. P is essential to plant health and yield and is commonly deficient in centra Victoria. Some acidic clay soils with high Al and Fe ions can make P less available.	Olsen P >15-20 mg/kg On acid soils refer to Bray 2 test - Levels of total P > 60 mg/kg On neutral to alkaline soils refer to Colwell test – levels of P > 50-60 mg/kg may be needed in central Vic due to moderate high PBI (see below) Levels of soluble P > 10 mg/kg
Phosphorous buffering index (PBI)	Moderate – PBI indicates how available any added sources of P may be, and whether there are likely to be 'stocks' of P that might be made more available by correcting soil pH and promoting active soil biology. Phosphorous is typically less plant available on acidic soils with high Al and Fe levels, and this is common in central Victoria.	The PBI will indicate how much P is likely to be available and should be looked at with reference to the Colwell test results. For low PBI, then lower Cowell results (<40 mg/kg) should be adequate, but the higher the PBI than the higher the Colwell result will need to be.
Nitrogen (N) – total	Very high – it is essential to healthy plant growth and pasture and crop yield and quality. Total N tells you how much N is present in organic matter, or as ammonia and nitrate (see below).	Ideally total N levels will be higher than 25-50 mg N/kg of dry soil and higher in clay soils. Other than fertiliser, most N in soil comes from decaying organic matter and increasing organic matter returned to the soil will make more N available to plants.
Nitrogen as nitrate	High – this is a measure of how much plant-available and soluble N is at the time of soil testing.	Ideally levels will be higher than 10-15 mg/kg of dry soil
Potassium (K)	High for cropping in particular – some central Victorian soils are prone to K and S deficiency under cropping and hay cutting	Colwell K of > 160 mg/kg
Sulphur (S)		Soluble S of > 8 mg/kg
Calcium (Ca)	Moderate for pasture. Many central Victorian soils have adequate but low levels of Ca, and the quality of fodder can be reduced if high N:P:K produces vigorous growth. High Ca levels can reduce the availability of P.	Soluble Ca levels of >700-750 mg/kg Exchangeable Ca of 1-3 cmol+/kg and 65-80% of total exchangeable cations.

Testing parameter	Significance /importance	What to look for
Exchangeable cations and Cation Exchange Capacity (CEC)	Provides information about how readily soils hold nutrients and make these available to plants. Can also indicate lower soil fertility and the capacity of soils to retain organic carbon. Information about exchangeable Ca, Na and Mg levels can indicate potential sodicity, aggregate dispersion, porosity and risk of compaction.	>14 cmol+/kg is preferred on clay-loams and clay soils. Lower levels on sands are to be expected. Low levels on clay and clay-loams can indicate a very weathered and leached clay with low inherent fertility. High Na and Mg relative to Ca can indicate heavy and sodic/dispersive clays prone to compaction and poor porosity.
Magnesium (Mg)	Moderate – not commonly deficient in central Victoria	Exchangeable Mg of 1-3 cmol+/kg and 10-20% of total exchangeable cations. Many central Victorian soils have high Mg relative to Ca, which is indicative a heavy magnesic clay that can become impermeable and dense when wet, but will typically crack when dry unless it is also sodic (see below).
Sodium (Na)	Na is mainly of concern do to soil sodicity, but can also be an indicator of soil salinity with high Cl and/or high EC readings Subsoil clays commonly have high Na levels in central Victoria and many soils are moderately to strongly sodic.	Exchangeable Na of <0.7 cmol+/kg and < 1% of total exchangeable cations. If levels are >6% then the soil is sodic. Many central Victorian clay soils have high Na to Ca and are commonly sodic and dispersive, with poor soil structure and compaction. EC <3.8 dS/M.
Aluminium (Al)	Mainly of concern due to potential toxicity and making P less available on acidic soils. High Al is common on many central Victorian soils.	Exchangeable Al of <0.5 cmol/kg and <1% of total exchangeable cations is preferred Greater than 10% in an acidic soil indicates a need to neutralise pH with lime (which will also add Ca) or other soil ameliorant.
Manganese (Mn)	Not commonly deficient on most of central Victoria. Usually only potentially deficient on alkaline soils. Higher levels can pose toxicity risk on acidic soils.	Between 5-20 mg/kg is adequate on acidic soils.
Copper (Cu) **Zinc (Zn)**	Commonly low and potentially deficient in central Victoria. Low levels can affect pasture/fodder nutrition and reduce plant vigour.	>5mg/kg is preferred on clays.
Molybdenum (Mo)	Commonly low and potentially deficient on acidic soils in central Victoria. Can reduce root and plant growth vigour and reduce nitrifying nodulation of legumes.	>1.0 mg/kg should be sufficient on acidic clays for pasture, but higher levels may be need to sustain availability in cropping.
Boron (B)	Potentially low and deficient. Can reduce plant and root growth vigour.	>1.5-2.0 mg/kg preferred on acidic clays.

Other nutrients (note: looking for visual signs of deficiencies in plants and plant tissue testing are often the best method for assessing whether such deficiencies are impacting on plant growth and fodder quality. Test strips of additives containing the elements can also help determine whether plants will have a yield response)

Testing parameter	Significance /importance	What to look for
Iron (Fe)	Rarely deficient in central Victoria, but often very high in clay soils and subsoils and can result in toxic effect and low P availability of acidic soils. High Fe clays can also strongly hold water making it less available to plants.	Look for high levels of Fe and low pH.
Other trace elements (e.g. Selenium, Cobalt, Silicates)	These nutrients are required in low levels and are typically less significant than those listed above. They are rarely critically low, but plants can respond to their addition in fertilisers. Co and Se are more likely to be expressed as a deficiency in grazing livestock than plants, and are more likely to be deficient on granitic sands and clays. Silicates play a role in water uptake and cell strength and although most soils have high silicon levels, weathered and leached soils can develop low plant-available silicate under cropping systems.	

Key messages

- Assessing soil health requires a combination of in-field observations and laboratory analysis of soil samples.
- Soils vary down their profile. Digging to at least 50-60cm is a good way to identify physical, biological and pH constraints to root and plant growth.
- Common nutrient deficiencies in central Victoria include phosphorous, zinc, copper, molybdenum and sometimes potassium, sulphur, and other trace elements. Nitrogen levels can be low due to poor nitrogen-fixing nodulation of legumes and low organic matter.
- Many clays in central Victoria have high levels of aluminium and iron that can create toxic effects and lower phosphorous availability on acidic soils,
- pH correction through the addition of lime or other soil ameliorants can often improve the availability of nutrients, reduce toxicities, and add calcium to address soil sodicity and magnesium imbalances that make soils more susceptible to compaction.
- Plant tissue tests can be used to assess whether nutrient deficiencies are affecting plant and grazing livestock health.
- Once nutrient deficiencies and pH constraints have been amended, nutrient budgeting and periodic re-testing of known deficiencies can be used to maintain and monitor good soil nutrition.
- Visual assessment of the health of plant and root growth remains a key strategy of assessing soil health and likely nutrient deficiencies.
- Keeping a spade on the back of farm vehicles and stopping to dig and assess areas where growth is sluggish is a good way to understand and monitor soil health across your farm.

9

DEVELOPING A MANAGEMENT PLAN

Developing a soil health, nutrition and organic matter management plan.

This section provides a worksheet for developing a soil health, nutrition and organic management plan based on soil assessments, laboratory test results, and your farming objectives. It allows you to consider and choose management options you plan to adopt or trial, as well as set a timetable for implementing and monitoring the outcomes of different soil health management practices. A series of worksheets are provided to identify the most significant soil constraints on your farm and choose appropriate management options on a paddock by paddock or area basis.

It is suggested you store this guide as well as farm maps, soil assessments, soil laboratory test results, notes, completed planning worksheets, farm input and yield records, and other useful information (e.g. rainfall, notes about the season, etc) in a physical binder or, if you prefer, an electronic file.

Your farming situation and objectives

Every farm is different and there is no single 'right way' to manage soil health, just what is right for your farming objectives, system, soils and climate. The Healthy Soil Initiative suggests you are pragmatic and adaptable in the approach you take, and trial approaches on a small scale when you can to work out what is the most cost-effective way to improve and maintain soil health.

The Soil Health Initiative suggests the overall objectives of a Soil Health plan can be summarised as having a farm management system that achieves and maintains:

- Sufficient plant-available nutrients and water to produce the levels of yield you want to achieve.
- Soil structure that allows easy water infiltration, air flow and strong root growth to a depth of preferably at least 30-40 cm.
- Soil chemistry (nutrient availability, pH, sodicity/salinity, toxicities) that is beneficial and not hostile to root growth.
- A healthy and beneficial soil ecosystem that contributes to improved nutrient cycling, soil fertility, soil structure , disease suppression and deeper and healthier root growth.
- Management that uses favourable seasons to deepen soil and increase biomass returned to the soil.
- Management to protect soil health from extreme disruptions such as dry summers, drought and heavy tillage, and to repair soil after such disruptions.

The ways to achieve these conditions will vary depending on your farming situation. Generally, it is easier to build and maintain soil health under less intensive and disruptive production systems such as grazing and in areas with higher rainfall and milder climates. Continuous cropping systems in hotter and drier areas will often require strategic and deliberate interventions to maintain soil health.

Describing paddocks and areas

The worksheet shown in Table 9.1 is designed to quickly summarise the outcomes of the soil health assessment process outlined in Section 8. It is suggested separate worksheets are used for specific paddocks or similar areas on the farm. Tick boxes are provided to identify and give priority to different soil characteristics and constraints. Completing this form for all assessed and tested paddocks or similar areas allows priority to given to the critical soil constraints to be addressed in different areas. It is suggested the worksheet is also used to record periodic ;fid test' field observations and assessments of soil attributes (not including the soil laboratory testing). The need for, and frequency of, follow-up soil laboratory testing will depend on the intensity of production, yields and nutrient management practices. In low intensity farming systems, it may be sufficient to periodically apply some form of fertiliser to replace nutrients know to be naturally deficient in soil based on how much yield is removed and the appearance and productivity of pastures. In higher intensity systems, such as cropping, frequent soil laboratory testing can be used to ensure more efficient application of nutrient to replace those removed by yields.

Identifying options and actions

Table 9.2 is designed to consider management options detail the actions you intend to implement to address constraints. Suggested options can be selected and details of when they will be implemented recorded in the last column. Spaces are provided for other actions to be included. The Healthy Soils Initiative promotes a holistic management approach where initial actions will address the most significant constraint, but then on-going pasture and crop management practices to drive the Healthy Plant ⇆ Healthy Soil cycle that will maintain deeper and healthier soils and root systems.

Completing this worksheet for each paddock helps to address the critical soil constraints and keep records of what has been done and when. It also helps to identify possible soil constraints that may worsen over time if not monitored and managed, such as low to moderate nutrient deficiencies, soil acidification and low organic matter. Note that a common management option is the trial practices in test strips of limited areas to see whether there is enough of a productivity benefit to implement the practice more widely across the farm. Similarly, with any more widely adopted new practice, it is often good to leave a small untreated area to see what differences are achieved by the new practice. This can inform decisions about applying the practice to other parts of the farm and provide knowledge for other farmers.

Some soil health management practices such as pH correction and application of nutrients can have immediate productivity benefits and will cover their costs within one or two years. Other practices, such as application of gypsum, compost or other soil conditioners or sowing and maintaining a green manure crop may take longer to repay the investment. More costly practices such as strategic tillage with deep soil amendment placement to alter the soil profile can take even longer to recoup costs. Appendix B provides a guide for deciding whether an investment in soil health is likely to produce an adequate return on investment over a 5-to-10 year period.

Printable versions of the worksheets are provided at: www.masg.org.au

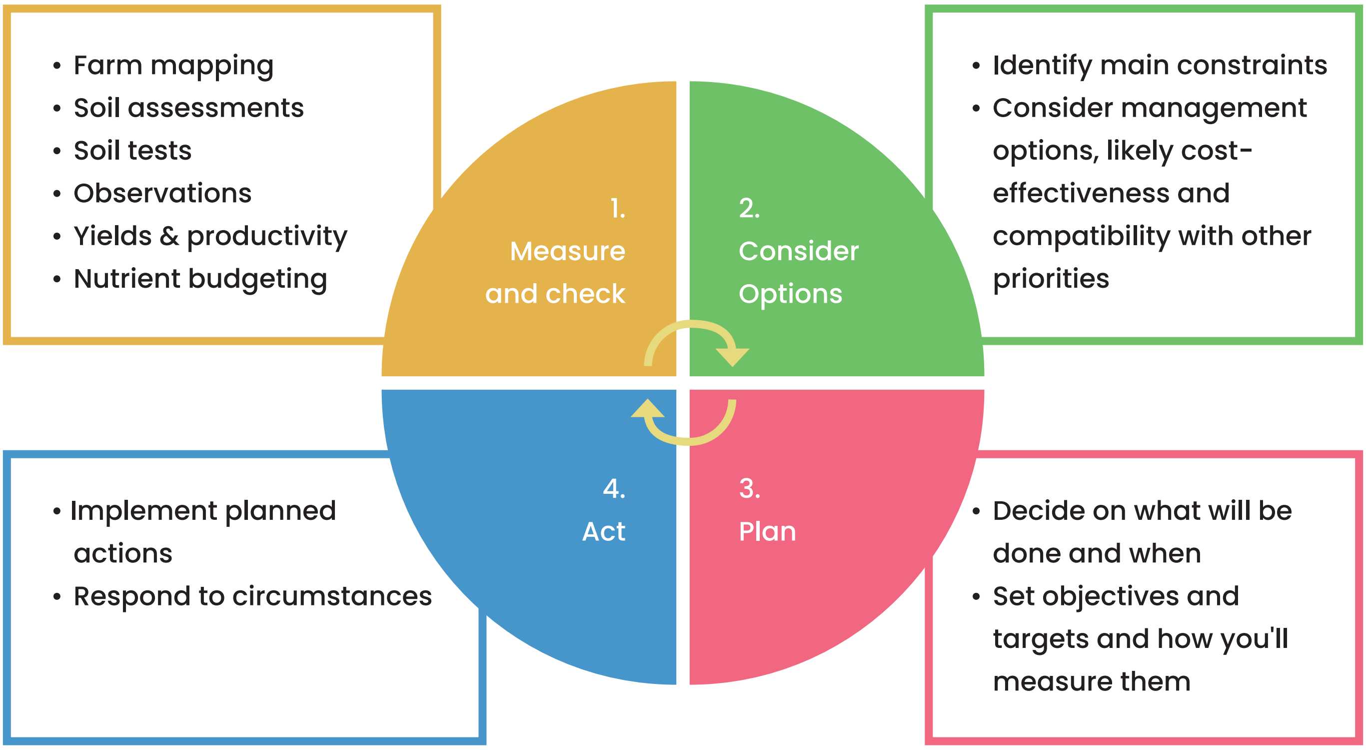
Monitoring and continual improvement

Building and maintaining soil health is an on-going process. The Healthy Soils Initiative promotes a 'Continual Improvement' approach as shown in Figure 9.1. This shows the stages:

1. Measure and check – this involves the soil assessment and testing undertaken using this guide, as well as on-going observations, monitoring of yields, productivity and nutrient management.
2. Consider options – this involves using the worksheets provided to identify the main soil constraints and options for managing these.
3. Plan – this involves using the worksheets provided to decide on which actions you will adopt and when you will implement them. The plan also considered how and when progress will be monitored and assessed.
4. Act – this is the implementation of the plan. In reality, changes in circumstance might change what is done when, and the plan can be modified to reflect this. The main value of the documented plan is to keep records of what soil assessments and tests have told you about the farm, the management options that have been considered and trailed or implemented, and what the outcomes of this process has been in terms of farm productivity and observed soil, plant and animal health.

The continual improvement process is a cycle, with a return to the Measure and Check stage to monitor how well the Soil Health plan is working, and then through the other stages to modify and improve the plan as needed. For example, test strip trials of lime, zinc or copper might show good results, so the plan can be modified to spread these across all areas where soils are overly-acidic or deficient in zinc and copper.

Figure 9.1: A continual improvement approach to soil health management



Conclusion

This guide has outlined a process for assessing soil and plant health to identify significant soil health constraints and provided information about how to manage these.

The guide has focused on the importance of the Healthy Plant ⇆ Healthy Soil cycle and the need to address the physical, chemical, biological and climatic constraints to deeper and healthier root growth. This has recognised that all farms are different and presents a range of possibly management options.

It is strongly suggested that you seek further information and advice as needed as you develop and implement your soil health management plan. Some suggested sources of information, tools and local sustainability groups are detailed in Appendix C. Mount Alexander Sustainability Group continues to support the Healthy Soils Initiative and Mount Alexander Regenerative Agriculture Group. For further information, email: info@masg.org.au or call 0407 882 070.

Area of farm: Date of assessment:

Field observations	
Upper soil	Subsoil to 60cm
Surface cover ☐ High ☐ Medium ☐ Low **Signs of nutrient deficiency in plants** ☐ N ☐ P ☐ K ☐ S ☐ Ca ☐ Zn ☐ Cu ☐ Mo ☐ B ☐ Others ____________________ **Surface sealing or cracking** ☐ Smooth/sealed, little cracking. ☐ Some cracking ☐ Friable/crumbly **Upper soil depth** = ________cm **Colour** ☐ Dark ☐ Brown ☐ Red ☐ Yellow ☐ Grey ☐ Pale grey/yellow/brown	Note depth of changes in colour and texture. **Colour** ☐ Dark ☐ Brown ☐ Red ☐ Yellow ☐ Grey ☐ Pale grey/yellow/brown **Texture** ☐ Fine sand/silt ☐ Coarse sand ☐ Sandy loam ☐ Loam ☐ Clay loam ☐ Cracking/structured clay ☐ Dense unstructured clay **Structure/porosity** ☐ Good ☐ Heavy ☐ Very dense/poor
Texture ☐ Fine sand/silt ☐ Coarse sand ☐ Sandy loam ☐ Loam ☐ Clay loam ☐ Cracking/structured clay ☐ Dense unstructured clay **Structure/porosity** ☐ Good ☐ Heavy ☐ Very dense/poor **Water infiltration** ☐ Low ☐ Moderate ☐ High	**Water infiltration** ☐ Low ☐ Moderate ☐ High **Slaking and dispersion test** ☐ Stable aggregates ☐ Slaking, but no/low dispersion ☐ Mildly dispersive ☐ Strongly dispersive **pH (if measured)** Root growth/health ☐ Strong ☐ Moderate ☐ Weak
Slaking and dispersion test ☐ Stable aggregates ☐ Slaking, but no/low dispersion ☐ Mildly dispersive ☐ Strongly dispersive **pH (if measured)** __________ Root growth/health ☐ Strong ☐ Moderate Weak **Earthworm numbers or evidence of activity** ☐ High ☐ Medium ☐ Low	**Earthworm numbers or evidence of activity** ☐ High ☐ Medium ☐ Low
Other (list)	**Other (list)**

Area of farm: Date of assessment:

Laboratory testing		Main constraints (list)
Upper soil	Sub soil to 60cm	
Likely/possible nutrient deficiencies **Signs of nutrient deficiency in plants** ☐ N ☐ P ☐ K ☐ S ☐ Ca ☐ Zn ☐ Cu ☐ Mo ☐ B ☐ Others ____________________ **pH** ☐ Too acidic (<5.5) ☐ Acidic /potentially acidifying (5.5-6.0) ☐ 'Neutral' (within 6.0-8.0) ☐ Overly alkaline (>8.0)	**Likely/possible nutrient deficiencies** **Signs of nutrient deficiency in plants** ☐ N ☐ P ☐ K ☐ S ☐ Ca ☐ Zn ☐ Cu ☐ Mo ☐ B ☐ Others ____________________ **pH** ☐ Too acidic (<5.5) ☐ Acidic /potentially acidifying (5.5-6.0) ☐ 'Neutral' (within 6.0-8.0) ☐ Overly alkaline (>8.0)	
Cation exchange capacity ☐ Low ☐ Medium ☐ High **Organic matter/carbon levels** ☐ Low ☐ Medium ☐ High **Exchangeable ions** ☐ Low exchangeable Ca to Na ration (sodic) ☐ Low exchangeable Ca to Mg ratio (magnesic) ☐ High Al ☐ High Fe	**Cation exchange capacity** ☐ Low ☐ Medium ☐ High **Organic matter/carbon levels** ☐ Low ☐ Medium ☐ High **Exchangeable ions** ☐ Low exchangeable Ca to Na ration (sodic) ☐ Low exchangeable Ca to Mg ratio (magnesic) ☐ High Al ☐ High Fe	
Other (list)	**Other (list)**	

Table 9.2: Planner

Area Main constraints	Actions	Details and Timing (write when and. if it is something that needs to be repeated or monitored. how often this will be undertaken)
Upper soil compaction/ poor structure	☐ Assess and monitor levels of upper soil compaction at different times of the year ☐ Manage vehicle and livestock traffic to minimise compaction. ☐ Use low intensity strategic tillage to loosen soil to allow more root growth and to integrate organic matter and soil amendments into the soil. ☐ If soils are sodic and dispersive, or strongly magnesic, use gypsum or lime (on acidic soils) to provide Ca ☐ Retain more crop and pasture biomass to increase soil organic matter to promote better aggregate formation. ☐ Grow plants with 'clay breaking' roots and manage these (e.g. through strategic rotational grazing) to allow plants to grown and maintain deeper roots. ☐ Apply compost or other humic materials to promote better soil aggregation and structure ☐ Other (add details)	
Shallow subsoil compaction/poor structure	☐ Assess and monitor levels of sub soil compaction at different times of the year ☐ If soils are sodic and dispersive, or strongly magnesic, use gypsum or lime (on acidic soils) to provide Ca ☐ Use strategic deeper tillage to break up hardpans, incorporate soil amendments, and loosen sub-soil to promote deeper root growth. ☐ Grow plants with 'clay breaking; deep roots and manage these to so they can grow and maintain deeper roots. ☐ Use sub-soil amelioration to apply soil amendments such as gypsum, lime (on acidic subsoils), fertiliser, compost or organic matter to improves soil structure and promote deeper root growth. ☐ Other (add details)	

Area Main constraints	Actions	Details and Timing (write when and. if it is something that needs to be repeated or monitored. how often this will be undertaken)
Nitrogen deficiency **☐ Critically low** **☐ Low** **☐ Moderate** **☐ High/no constraint**	☐ Include legumes in pastures and cropping rotations. ☐ Correct nutrient deficiencies and pH issues that reduce legume plant and root growth and nitrogen fixation. ☐ Conduct test strips of sources of N to assess the responsiveness of crops and pasture. ☐ Apply N fertiliser at appropriate rates. ☐ Apply manures or other sources of N fertility at appropriate rates. ☐ Use strategic grazing rotations to promote legumes and nutrient cycling. ☐ Increase soil organic matter to improve nutrient cycling and holding properties of the soil. ☐ Address subsoil constraints to allow deeper root growth. ☐ Monitor how much N is being removed by yields. ☐ Monitor soil N levels through soil testing. ☐ Other (add details)	

Area Main constraints	Actions	Details and Timing (write when and. if it is something that needs to be repeated or monitored. how often this will be undertaken)
Other 'macro' and 'micro' nutrients: **P ☐ Critical ☐ Low** **☐ Moderate** **K ☐ Critical ☐ Low** **☐ Moderate** **S ☐ Critical ☐ Low** **☐ Moderate** **Ca ☐ Critical ☐ Low** **☐ Moderate** **Cu ☐ Critical ☐ Low** **☐ Moderate** **Zn ☐ Critical ☐ Low** **☐ Moderate** **Mo ☐ Critical ☐ Low** **☐ Moderate** **B ☐ Critical ☐ Low** **☐ Moderate** **Se ☐ Critical ☐ Low** **☐ Moderate** **Mn ☐ Critical ☐ Low** **☐ Moderate** **Other:** **☐ Critical ☐ Low** **☐ Moderate** **☐ Critical ☐ Low** **☐ Moderate** **☐ Critical ☐ Low** **☐ Moderate**	☐ Correct pH factors that may make some nutrients less available to plants. ☐ Address subsoil constraints to promote deeper root growth. ☐ Conduct test strips of different nutrient sources to see how crops and pastures respond P ☐ K ☐ S ☐ Ca ☐ Cu ☐Zn ☐Mo ☐B ☐ Se ☐Mn ☐ Others ☐ Apply appropriate fertilisers or other sources of deficient nutrients. P ☐ K ☐S ☐Ca ☐ Cu ☐Zn☐ Mo ☐ B ☐ Se ☐Mn ☐ Others ☐ Use foliar spray fertilisers is plants show signs of deficiencies P ☐ K ☐ S ☐ Ca ☐ Cu ☐ Zn ☐ Mo ☐ B ☐ Se ☐ Mn ☐ Others ☐ Use livestock feed additives or lick blocks to avoid livestock dietary deficiencies. ☐ Increase soil organic matter to improve nutrient cycling and holding properties of the soil. ☐ Monitor/estimate how much nutrient is being removed by yields. ☐ Monitor soil nutrient levels through soil testing ☐ Monitor deficiencies and imbalances through plant tissue testing. ☐ Other (add detail)	

Area Main constraints	Actions	Details and Timing (write when and. if it is something that needs to be repeated or monitored. how often this will be undertaken)
pH **☐ Strongly acidic (<5.0)** **☐ Slightly overly acidic with risk of acidification (5.0-5.5)** **☐ Acid-neutral (5.5 – 7.0)** **☐ Neutral -alkaline (7.0-8.0)** **☐ Overly alkaline (>8.0)** **Potential toxicities on acidic soils:** **☐ Al** **☐ Fe** **☐ Mn** **☐ P immobilisation**	☐ Use lime to correct overly acidic pH ☐ Use rock dust with known liming effect ☐ Manage N and other nutrients to reduce risk of acidification ☐ Improve aeration/porosity of soil to reduce the build-up of unoxidised free hydrogen ions ☐ Increase soil organic matter to buffer pH ☐ Apply compost to buffer pH ☐ Other	
Potential P buffering/draw down	☐ Neutralise pH ☐ Adjust P application rates to allow for some P buffering losses ☐ Promote active soil biology ☐ Other:	
Sodic (heavy clays with high exchangeable Na relative to Ca) or Magnesic clay (heavy clays with high exchangeable Mg relative to Ca. Note: this is more significant when combined with sodicity)	☐ Add sources of exchangeable calcium ☐ Increase soil organic matter ☐ Sow plants with hardy deep rooted 'clay breaking' roots ☐ Add compost ☐ Strategic tillage to ameliorate ☐ Where magnesic soils are self-mulching or cracking when dry apply amendments to get down these cracks ☐ Other:	
Potential salinity (high Na and EC)	☐ Identify soaks and salt scald areas ☐ Improve soil water infiltration in these areas as well as higher areas ☐ Plant deep rooted perennials on likely recharge areas above soaks/scalds ☐ Plant soaks and scalds with salt tolerant and deep-rooted plants ☐ Other:	

Area Main constraints	Actions	Details and Timing (write when and. if it is something that needs to be repeated or monitored. how often this will be undertaken)
Low organic matter	☐ Retain more of existing crop and pasture biomass/residue. ☐ Deliberately grow high biomass crops and retain more of this residue. ☐ Deliberately grow/promote deeper rooted plants in cropping and pasture rotations. ☐ Use strategic rotational grazing to promote biomass production and deeper roots growth under pasture. ☐ Monitor levels of visible organic matter at different depths in soil ☐ Conduct soil testing to determine organic matter levels ☐ Other	
Poor water infiltration	☐ Address compaction constraints (above) ☐ Slow rate of stormwater run off through contouring or tilling across rather than up and down slopes ☐ Slow rate of stormwater run-off by reducing bare ground through retention of stubble and other dead biomass ☐ Maintain organic matter at the surface to avoid crusting ☐ Other	
Poor water holding	☐ Increase organic matter levels ☐ On sandy soils, consider integration of some sub-soil clay or use of 'wetters' ☐ Other	
Poor plant water availability	☐ Increase organic matter levels ☐ Improve soil porosity and root access to water ☐ Other	
Other		

APPENDIX A: SOIL HEALTH – IS IT WORTH IT?

Many soil health management options have upfront costs that might not be fully recovered by yield and other productivity benefits in the first year. In some instances, these upfront costs can be significant and might be recovered over five or more years. For some practices, such as use of lime to neutralise acidifying soil, the benefit is also preventing yield decline rather than just increasing future yields. It can be hard to decide whether the return on investment is worth it. The following method and worksheet can be used to estimate the yield increases that would need to be achieved to cover the costs of management practices and provide an adequate return on farm investment.

Estimating the likelihood of getting an adequate return on investment

A useful exercise before trying or adopting any soil health management strategy is to estimate the average yield increase you'd need to get to make the investment worth it. A 'back of the envelope' series of calculation for doing this is shown in Table 1. Note that this method is a rough guide and doesn't directly factor in inflation, depreciation or opportunity costs, although these can be factored into some of the assumptions you make about variables. It is more useful over short periods rather than longer-term investments. The purpose of the calculations is to assess whether a soil health management initiative that has high up-front/first year costs (e.g. deep ripping, application of compost, gypsum or lime, sowing a green manure) but then improves soils and yields for a number of years afterwards is likely to be worthwhile overall.

You also need to consider whether soil health and yields will decline further without intervention and whether soil health improvements will improve land values or the value of products.

Some practices, to address soil constraints, such as deep ripping or boosting soil organic matter using a green manure or compost may not need to be repeated if the soil is well managed after the treatment. In such cases, a pay back period of 10 years is suggested.

Once you have calculated the average % yield increase required to make the soil health management practice worth considering, you need to assess whether this is realistic or likely. Where possible, it is suggested that strip or limited area trials of practices on the most constrained soils are trialled to assess whether adequate levels of return on investment are achievable in your situation.

Table 1: Estimating required average annual yield increases needed to provide a return on investment in soil health

Variable		Calculated by	Enter calculated value	Comments
First year cost of practice	A	Direct value ($/ha)	$_________ /ha	Include costs of input materials, equipment, labour, etc.
Average additional cost per year after first year	B	Direct value ($/ha/year)	$______ /ha/year	Include any on-going or new input costs (including materials, equipment, labour, etc)
Average annual costs savings due to practice after first year	C	Any expected cost reductions ($/ha/year)	$______ /ha/year	If the practice will significantly reduce input costs (e.g. less fertiliser) include this.
Net annual cost/savings after first year	D	B - C	$______ /ha/year	This is the cost of the practice less and cost savings
Number of years of expected yield increases (maximum 10)	E	Direct number entry (years)	________years	
Approximate total net costs of practice	F	A + (C x (E-1))	$_________/ha	
Average annual costs of practice	G	F÷E	$_________/ha/ year	
Expected return on investment	H	Direct value (%) – e.g. 30%	__________% p.a.	Base this on your expected real rate of return (after CFI) on farm investments
Average annual income from yield increase needed to achieve Return on Investment	I	G x(1+H/100) ($/ha/year)	$_________/ha/ year	
Current average yield	J	Direct entry (units/ha)	________/____ /ha	e.g. For crops the units are tonnes per hectare. For livestock it might be head per hectare or kg of wool or litres of milk
Current net market value of yield per unit	K	Direct entry ($ unit)	$_______/_______	
Current net market value of yield per hectare	L	JxK	$ /ha	
Average annual yield increase needed to make investment in new practice worth considering	M	I/L %	%	Typically composts can be expected to result in 10-30% average yield increases on constrained soils with low SOC.
Average annual yield that would need to be achieved to provide target return on investment	N	Jx(1+M/100)	______Tonnes /ha/ year	

Table 1: Estimating required average annual yield increases needed to provide a return on investment in soil health

Variable		Calculated by	Enter calculated value	Comments
First year cost of practice	A	Direct value ($/ha)	$ 1,500 /ha	Compost applied at 25 t/ha @ costs of $60/t of compost for purchase price, transport and spreading
Average additional cost per year after first year	B	Direct value ($/ha/year)	$ 0 /ha/year	No additional costs
Average annual costs savings due to practice after first year	C	Any expected cost reductions ($/ha/year)	$ -45 /ha/year	Reductions in fertiliser costs due to improved fertility and slow release of nutrients. Assume 10% reduction on $450/ha
Net annual cost/savings after first year	D	B - C	$ -45 /ha/year	Savings of $45 per year
Number of years of expected yield increases (maximum 10)	E	Direct number entry (years)	5 years	If compost is applied every 5 years
Approximate total net costs of practice	F	A + (C x (E-1))	$ 1.320 /ha	$1,500+ (-$45 x (5-1)) = $1,500 - $180 = $ 1,320
Average annual costs of practice	G	F÷E	$ 264 /ha/year	$ 1,320/5 = $264
Expected minimum return on investment	H	Direct value (%) – e.g. 30%	30 % p.a.	Based on expected return on investment in cropping
Average annual income from yield increase needed to achieve Return on Investment	I	G x(1+H/100) ($/ha/year)	$ 343.20 /ha/year	$264 X (1+0.3) = $ 343.20
Current average yield	J	Direct entry (units/ha)	3.0 / tonnes /ha	For cereal crops. This could be compared to Seasonal Yield Gaps
Current net market value of yield per unit	K	Direct entry ($ unit)	$ 400 / tonne	Sale price less any additional harvest, transport and marketing costs per additional tonne produced
Current net market value of yield per hectare	L	JxK	$ 1,200 /ha	3.0 tonnes X $400/tonne
Average annual yield increase needed to make investment in new practice worth considering	M	I/L %	28.6 %	$ 343.20/$1,200 = 28.6%. Compost at this rate on constrained soils often achieves yield increases of at least 10-30%, so this is possible for a constrained soil. It is more likely to be achieved in areas with higher growing season rainfall and a significant yield gap.

Variable		Calculated by	Enter calculated value	Comments
Average annual yield that would need to be achieved	N	Jx(1+M/100)	3.9 Tonnes / ha/year	3.0 X (1+0.286) = 3.9 tonnes. This would mean future average yields would need to be at least 3.9 t/ha to provide the desired return on investment. A 25t/ha compost application could achieve this on a significantly constrained and low SOC soil. If seasonal yield gaps suggests high average yields are possible, then test strips of compost cost be used to assess crop response.

Soil amendments

As well as fertilisers, a range of products can help plant health and promote the Healthy Plant ⇆ Healthy Soil cycle, including:

- Gypsum adds calcium to mitigate compacted/heavy sodic and magnesic clays. It also adds sulphur for plant nutrition.
- Lime neutralises acidic soils and will add calcium that will improve sodic and magnesic clays.
- Compost can help improve soils' structure and nutrient- and water-holding characteristics. Composts tend to have greatest benefit on sandy soils and heavy leached clays with low organic matter. Compost feeds soil biology and can help build and maintain higher levels of organic carbon. Compost contains some nutrients, but it is not usually cost-effective to use compost to replace fertilisers. Compost can also have a pH 'buffering' or 'liming effect' on acidic soils and generally improves nutrient availability.
- Biochar is produced through a controlled process that heats biomass to high temperatures in a low oxygen environment so volatile gases are driven and burnt off leaving a 'char' that is further treated to enhance soil conditioning qualities. Biochar can provide some nutrients and improve soil nutrient exchange and water-holding capacity. It may also stimulate root growth. It is likely to have greatest benefits on sandier soils, but can also help improve soil porosity and improve soil fertility on heavier leached clay soils. Biochar can persist in soil for many years and is being promoted as a lasting form of soil carbon to mitigate greenhouse gas emissions.

All of these amendments typically have greater effect if they are integrated into the soil via either light cultivation or deeper strategic tillage. It is best to trial them first on small areas with the most significant soil constraints (i.e. the worst areas in the worst paddocks) to see whether there is enough of a productivity response for it to be worth doing in other areas.

APPENDIX B: USEFUL INFORMATION, RESOURCES & TOOLS

The following resources are useful for further information about assessing soil health and developing management options.

Useful guides

North Central Catchment Authority:
Soil Health Guide - https://nccma.vic.gov.au/projects/agriculture/soil-health-guide/
Sustainable Farming - https://nccma.vic.gov.au/projects/agriculture/

Corangamite Catchment Management Authority – The Brown Book
https://soilhealth.ccmaknowledgebase.vic.gov.au/brown_book/Pasture_Cropping.htm

Goulburn-Broken Catchment Management Authority - Understanding Your Soil Test - a Step by Step Guide https://www.gbcma.vic.gov.au/downloads/LandHealth/Understanding_Your_Soil_Test.pdf

Victorian Resources Online. An excellent source of information about soil types, soil assessments and soil health management https://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil-home

Dairy Australia
Soil Health- https://www.dairyaustralia.com.au/soils-and-water/soil-management-and-fertility/soil-health
Pasture management - https://www.dairyaustralia.com.au/feeding-and-farm-systems/pastures

Grain Research and Development Corporation
Crop nutrition guide - https://grdc.com.au/__data/assets/pdf_file/0028/170398/grdc_fs_soil-testing-for-crop-nutrition-s_low-res-pdf.pdf.pdf
Farming for the Future - https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2019/08/farming-for-the-future-optimising-soil-health-for-a-sustainable-future-in-australian-broadacre-cropping
Nutrition & Fertiliser - https://grdc.com.au/__data/assets/pdf_file/0029/373907/GrowNote-Wheat-South-05-Nutrition.pdf

Hort Innovations Australia – Soil Wealth https://soilwealth.com.au/

Meat and Livestock Australia
Soil health and fertility https://www.mla.com.au/extension-training-and-tools/feedbase-hub/healthy-fertile-soils/
Grazing management - Evergraze –https://www.evergraze.com.au/
Dung Beetles https://www.mla.com.au/research-and-development/Environment-sustainability/dung-beetles/

Other organisations

Local groups and advice:
Healthy Landscapes - https://www.mrsc.vic.gov.au/Live-Work/Environment/Land-Management/Healthy-Landscapes
Mount Alexander Regen Ag Group - https://www.masg.org.au/agriculture/regenerative-agriculture/
Sustainable Agriculture facilitators - https://www.agriculture.gov.au/agriculture-land/farm-food-drought/natural-resources/landcare/climate-smart/sustainable-agriculture-facilitators#victoria

General information sources:
Farmers for Climate Change https://farmersforclimateaction.org.au/
Soil CRC - https://soilcrc.com.au/fact-sheets/
Soils for Life - https://soilsforlife.org.au/
Soil Science Australia – Smart Soils for Farming https://www.soilscienceaustralia.org.au/smartsoils
National Soils Strategy - https://www.agriculture.gov.au/agriculture-land/farm-food-drought/natural-resources/soils
Soil Quality - https://www.soilquality.org.au/factsheets/bulk-density-measurement

Mapping Tools:
Google Earth - https://www.google.com.au/earth/
Mapshare - https://mapshare.vic.gov.au/mapsharevic/
Visualising Australasia's Soils - https://data.soilcrc.com.au/map