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:

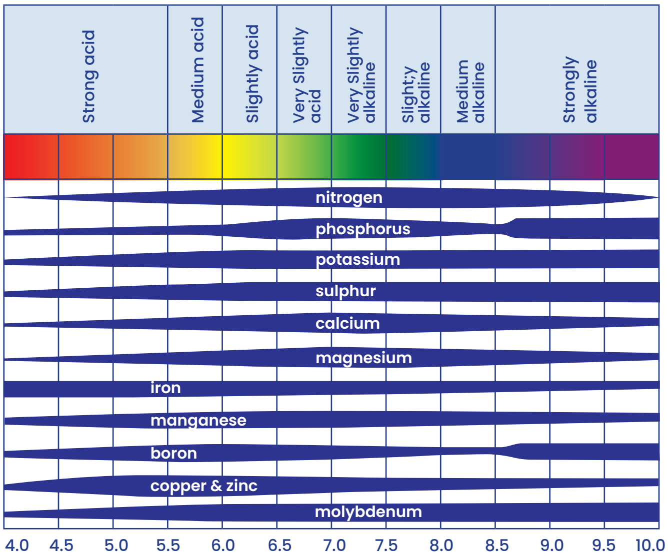
1. **Mineral nutrient deficiencies.** Most soils in central Victoria are inherently deficient in Phosphorous, and many sandier and lighter coloured soils are often low in one of more other macro-nutrients (i.e. those required in higher concentrations for healthy plant growth) such as Potassium, Sulphur 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.

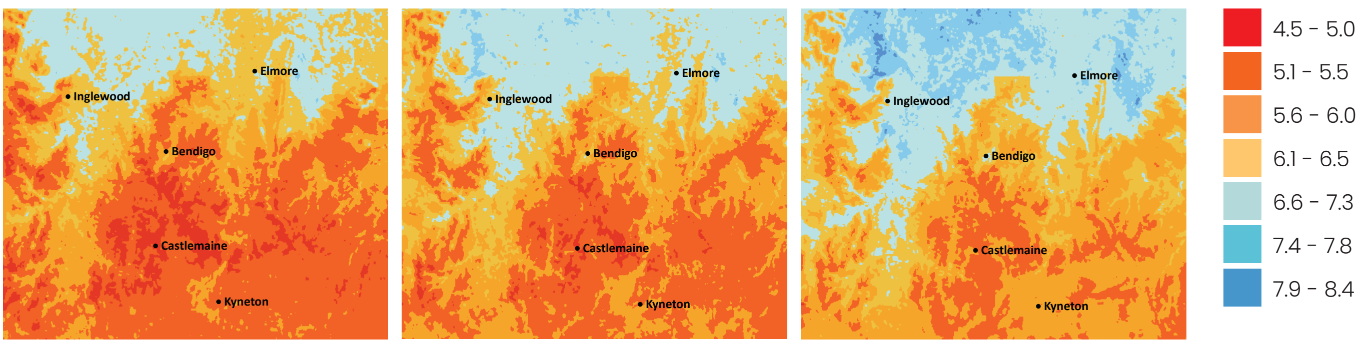
Figure 3.1: The effect of soil pH (Calcium Chloride) on the solubility and plant availability of different nutrients and potential 'toxic' elements



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:

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.

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

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

Common soil constraints	Causes	Management options
Poor soil structure and aeration		
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. **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.	• 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)	• 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.
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.	• Naturally high levels of sodium and lower than optimal levels of calcium • Rising salt from water table in lower lying areas after wet periods	• Addition of sources of calcium such as gypsum and, on acidic soils, lime. • Increased organic matter.

<table>
<tr><th>Common soil constraints</th><th>Causes</th><th>Management options</th></tr>
<tr><td colspan="3">Poor nutrient availability</td></tr>
<tr><td>Low mineral nutrient</td><td rowspan="2">• 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.</td><td rowspan="2">• 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.</td></tr>
<tr><td>Low soluble and plant available nutrients</td></tr>
<tr><td>Poor nutrient holding capacity</td><td>• Lower clay content
• Low cation exchange capacity of clays
• Low organic matter content</td><td>• 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.</td></tr>
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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.