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>

Nutrient deficiency	Symptoms/signs in grasses and cereals	Symptoms in clovers, medics and other legumes	Made worse by	Improved by
Micronutrients/trace elements				
Copper (Cu)	• New/young leaves are curled inwards and are pale. • Leaf margins may be irregular/serrated. • Poor grain-set.	• Stunted pale young leaves and poor growth. • Poor seed set. • Reduced root nodulation.	• Highly acid or alkaline pH • Removal of crops, hay and animal products	• 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
Zinc (Zn). Commonly deficient on many central Victorian soils, and depleted by cropping.	• Stunted and pale growth, particularly of younger leaves • Younger leaves may become 'mottled' and have dead patches. • Older leaves may yellow	• 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.	• Overly alkaline pH • Removal of crops, hay and animal products	
Boron (B). Sometimes deficient and can limit legume (clover, sub-clover) growth and reproduction in particular. Depleted by cropping.	• Slow growing and twisted or dead tips on newer leaves.	• Stunted and malformed younger leaves, with red and yellow tints and imperfect/dead edges. • Older stem may look 'swollen'/thick.	• Highly acidic or alkaline 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.
Magnesium (Mg). Not commonly deficient on central Victorian soils.	• Weak growth. • Yellowing of older leaves and yellowing between veins • Leaves may have red or bronze colour • Leaf curl inwards	• Weak growth. • Older leaves become yellow/red-bronze and die.	• Acidic soils • Removal of crops, hay and animal products	• 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.

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.

<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>Aluminium (Al) toxicity. Occurs on highly acidic soils (ph <4.5). Common on many central Victorian soils.</td><td colspan="2">• Similar symptoms to P deficiency
• Roots are stubby and with thickened and brown root tips and no/few root hairs.
• Poor nodulation in legumes</td><td>• Occurs on highly acidic soils with pH < 4.5</td><td>• Neutralising pH with lime
• Maintaining pH 'buffering' organic matter and healthy soil ecosystems.</td></tr>
<tr><td>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</td><td colspan="2">• 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.</td><td>• Occurs on acidic soils with pH <5.0
Low organic matter and poor porosity will further reduce water availability to roots.</td><td>• Neutralising pH with lime
• Increasing soil organic matter and soil porosity.</td></tr>
</table>

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.

Fertility management practice	What it involves	Factors to consider
Selection of pasture and crop plants	• 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.	• 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.
Strategic rotational grazing management	• 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)	• 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'
Biomass 'crops'	• 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.	• 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.

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.