

UNDERSTANDING YOUR

Soil Test

STEP BY STEP

Cath Botta





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ACKNOWLEDGEMENTS

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Disclaimer: this book does not seek to advise on or promote fertiliser application. It contains material to help the reader understand their soil-test results, but results should always be checked with your local government natural resources department or agronomist.

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YOUR SOIL TEST: QUICK REFERENCE GUIDE

	Test	Units	Comments
Cation exchange capacity (CEC)		cmol(+)/kg	Level determined by soil type generally: a CEC >12 is considered moderate and soil has good nutrient-holding capacity. Sand/sandy: < 10 Clay: 10–15 Organic matter: 200–400 Sandy soils may be prone to leaching. Consider splitting fertiliser applications on such soils.
pH	CaCl ₂ /water		Ideal: > 4.8(CaCl ₂)/5.5(water) Lower than ideal considered highly acidic with increased risk of aluminium toxicity. For productive improved pastures, consider liming (type of lime depends on test results). pH(CaCl ₂) is typically 0.8 units lower than pH(water) for soils with low salt levels.
Organic matter (OM)	Walkley Black	%	Pastures (> 400 mm rainfall): Low: < 5 Normal: 5–8 High: > 8 Required for nutrient cycling, biological activity; provides protection for soil surface; improves soil structure. Soils with low OM likely to slake/have poor structure. Organic carbon x 1.7 = OM%
Phosphorus (P)	Olsen	mg/kg (ppm)	Native pastures: < 12 Introduced pasture species and systems aiming for 80–90% potential pasture yield (lower stocking rate): 12–14 Introduced pasture species and systems aiming for 90–95% potential pasture yield (higher stocking rate): 15–18

	Test	Units	Comments										
Phosphorus (P) CONTINUED	Colwell/ Phosphorus Buffering Index (PBI)	mg/kg (ppm)	Systems aiming for 80–90% potential pasture yield (lower stocking rate): <table border="1"> <thead> <tr> <th>PBI</th> <th>Target Colwell P</th> </tr> </thead> <tbody> <tr> <td>Low (71–140)</td> <td>27–35</td> </tr> <tr> <td>Moderate (141–280)</td> <td>32–42</td> </tr> <tr> <td>High (280–840)</td> <td>44–58</td> </tr> </tbody> </table>	PBI	Target Colwell P	Low (71–140)	27–35	Moderate (141–280)	32–42	High (280–840)	44–58		
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Potassium (K)	Colwell K	mg/kg (ppm)	Systems aiming for 80–90% potential pasture yield (lower stocking rate): <table border="1"> <thead> <tr> <th>Soil texture</th> <th>Target Colwell K</th> </tr> </thead> <tbody> <tr> <td>Sands</td> <td>60–100</td> </tr> <tr> <td>Sandy loams</td> <td>70–110</td> </tr> <tr> <td>Clay loams</td> <td>70–120</td> </tr> <tr> <td>Clays</td> <td>80–130</td> </tr> </tbody> </table>	Soil texture	Target Colwell K	Sands	60–100	Sandy loams	70–110	Clay loams	70–120	Clays	80–130
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	Test	Units	Comments						
Potassium (K) CONTINUED	Exchangeable K	cmol/kg	<table border="1"> <tr> <td>Systems aiming for:</td> <td>Loam soil types</td> </tr> <tr> <td>80–90% potential pasture yield</td> <td>0.28–0.44</td> </tr> <tr> <td>90–95% potential pasture yield</td> <td>0.38–0.54</td> </tr> </table>	Systems aiming for:	Loam soil types	80–90% potential pasture yield	0.28–0.44	90–95% potential pasture yield	0.38–0.54
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			90–95% potential pasture yield	0.38–0.54					
Target levels for sandy soil types are lower; higher for clay soil types. Target level as % of CEC: 3–8%									
Sulphur	KCl-40	mg/kg (ppm)	<table border="1"> <tr> <td>Systems aiming for:</td> <td></td> </tr> <tr> <td>80–90% potential pasture yield</td> <td>6–7.5</td> </tr> <tr> <td>90–95% potential pasture yield</td> <td>7.5–12</td> </tr> </table>	Systems aiming for:		80–90% potential pasture yield	6–7.5	90–95% potential pasture yield	7.5–12
			Systems aiming for:						
			80–90% potential pasture yield	6–7.5					
90–95% potential pasture yield	7.5–12								
Exchangeable aluminium		% (of CEC)	<p>< 5% (< 3% for most clover species; < 1% for sensitive plants, e.g. lucerne). Becomes toxic to plants if $< 4.8(\text{CaCl}_2)/5.5(\text{water})$. Consider liming, particularly if resowing.</p>						
	CaCl	mg/kg (ppm)	Ideal: < 2						
	KCl	mg/kg (ppm)	Ideal: < 50						
Exchangeable cations		% (of CEC)	<p>Ideal: Calcium: 65–80 Magnesium: 15–18 Potassium: 3–8 Sodium: < 3</p>						
		%	<p>Soil structure Ca:Mg ratio > 2:1 = well-structured soil ESP < 6 = well-structured soil Soils with Ca:Mg < 2 and ESP > 6 are more likely to be dispersive/poorly structured. Use gypsum/organic matter to improve.</p>						
EC (salinity)	1:5	dS/m	Ideal: < 0.50 dS/m						
ECe		dS/m	Ideal: < 1.8. If > 2, more sensitive plants (e.g. lucerne) affected. Saline if > 4.						

INTRODUCTION

This booklet has been written for the dryland grazing zones of the Goulburn Broken Catchment of Victoria. The same principles will apply, however, to other dryland grazing zones in Victoria. It aims to assist land managers in understanding and interpreting soil test data. The guidelines are not intended to provide specific recommendations but general information for consideration when making soil nutrient decisions in conjunction with professional agronomic advice.

Soil is a critical resource in a productive agricultural system. Whether you are growing crops or pastures, soil tests are an important tool in your routine farm management program. Understanding and monitoring the 'health' of your soil provides the foundation for key farm decisions for sustainable productivity.

A program of soil testing can give you a broad understanding of your soil's overall fertility. Conducted over time from the same paddock, it can provide you with a snapshot of your soil's fertility, allowing you to monitor changes, make more informed and confident fertiliser decisions, and reduce the risk of unnecessary inputs and unintended off- and on-site environmental impacts.

Healthy, productive soils are friable, provide water and nutrients, and are biologically active. There are many factors that influence soil health and soil productivity. Assessment of soil *chemical* properties using soil tests is focusing on only one set of these factors. Other factors include the management of

the *physical* and *biological* properties of the soil to enable and support the soil functions vital for plant growth. Land managers are encouraged to consider all three of these factors in their management strategies, not just soil chemical properties.

Soil chemical properties ensure the supply of adequate nutrients for plant growth and indirectly animal health. The major mineral nutrients (which are used in greatest quantity by plants and usually become deficient first) that are important for crop and pasture production are nitrogen, phosphorus, potassium, sulphur, calcium and magnesium. The micro-nutrients (trace elements) required in smaller amounts to support plant growth are boron, copper, iron, molybdenum and zinc. Other trace elements, such as selenium, are particularly important for animal health. Soil pH and soil cation exchange capacity are also key soil chemical properties that influence nutrient availability. These are discussed in greater detail later.

Soil physical properties provide the framework in which plant roots and organisms live. Soil particles are held together in natural clumps or crumbs (referred to as soil peds or aggregates). These consist of the soil particles of sand, silt and clay, combined with the soil organic matter. A well-structured soil allows good water and air movement, penetration by plant roots and adequate water retention. Soil *structure* refers to the number, size and arrangement of the soil aggregates and the spaces between

them (the pores). This can be determined in the field by examining the soil profile and the soil aggregates, as well as the penetration of the plant root system into the soil profile.

The relative proportions of the soil particles (sand, silt and clay) give the soil its *texture* (this is discussed in greater detail on p. 8).



A poorly structured soil (left) and well-structured soil (right) (source: Dr Richard Doyle, Senior Lecturer in Soil Science, Tasmanian Institute of Agriculture, School of Land and Food, University of Tasmania)

Soil biological properties are essential to healthy soils and sustaining agricultural production. Active soil biota ensure vital processes in the soil are maintained, such as organic matter breakdown, nitrogen fixation, nutrient cycling, and the formation and maintenance of soil aggregates. They also play a role in suppression of disease-causing organisms and the degradation of pollutants.

Soil organic matter is paramount for maintaining large numbers of diverse soil biota. Soil organic matter consists

of living and decaying plant residues and roots, living and decaying soil biota, and soil humus (the stable end product of decomposed organic matter). Organic matter plays a critical role in improving the physical, chemical and biological properties of soils, so good grazing management (i.e. rotational grazing to allow adequate ground cover and growth and senescence of roots) is critical for the retention of organic matter in the soil. Soil pH and good soil structure are also paramount for maintaining a diverse, active soil biota population.

How soils form

Soils are formed from the gradual breakdown of rocks, minerals and organic materials via weathering (through physical, chemical and biological processes).

Soil formation is also influenced by the accumulation of materials through the action of water, wind and gravity.

There are five main interacting factors that affect the formation of a large variety of soils:

1. parent material (i.e. the rocks and minerals present in the geology form the basis of the soil);
2. living organisms (which can provide and decompose organic matter and mineralise important plant nutrients);
3. climate (which affects the rate of weathering and organic decomposition);

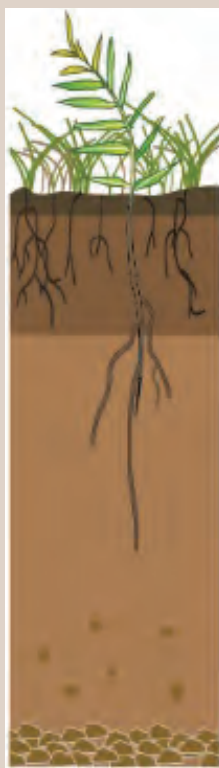
- topography (i.e. the grade of slope can affect drainage, erosion and deposition); and
- time (soil-forming processes are slow – it can take millions of years to produce soil).

The type of parent material and the degree of weathering will influence the type of soil, including the clay minerals present and their chemical reactivity. In the cation exchange capacity section (see p. 10), you will learn more about how this works.

Soils commonly have three main horizons (or distinct zones):

- A horizon** – the topsoil has higher levels of biological activity, nutrients and organic matter. This horizon is usually darker in colour than the others due to the presence of organic materials.
- B horizon** – the subsoil has higher levels of clay and usually holds more moisture than the A horizon, but is often less fertile. It is generally less biologically active, heavier in texture (i.e. more clay) and lighter in colour than the A horizon.
- C horizon** – the underlying weathered rock from which the A and B horizons form. The relative thickness of the A and B horizons will vary, depending on the soil type and the location in the landscape.

Some soils also exhibit an **O horizon**, which consists mainly of plant litter that has accumulated on the soil's surface.



(Source: www.qld.gov.au)

How to take a soil sample

Remember that a soil test is only as good as the care taken in sampling.

Sampling time Grazing pastures should be tested every three to five years (highly productive farming systems that export greater nutrient will require more frequent testing, and less productive farming systems will require less frequent testing).

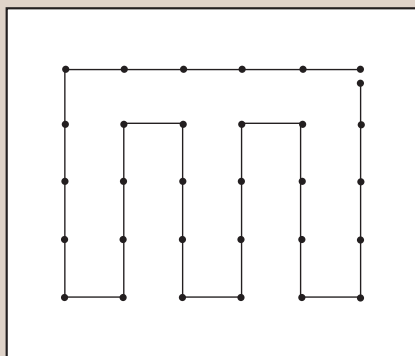
It is best to sample at the same period each year. Late winter to early spring is usually the recommended sampling time (but avoid very wet conditions). During the drier months of summer and autumn, it is often difficult to obtain a good soil sample at the standard depth of 10 cm.

Note: paddocks should not be sampled for at least six to eight weeks after the last fertiliser application. If practical, also leave sampling until a couple of weeks after removal of stock from a paddock.

Sampling depth It is important that the standard sampling depths are used. Soils are generally sampled to a depth of 10 cm by using a sampling tube or soil corer to extract the soil core. Corers are generally available from your agronomist, local Landcare group or CMA office.

Deeper cores may need to be taken to check for subsoil acidity, salinity or other issues, depending on the crops or pasture being considered (please contact your advisor for this advice).

Sampling pattern There are a number of common sampling systems: the zigzag, line transect or grid. For optimal coverage of the paddock, a grid sampling pattern can be used; the transect sampling pattern, however, is often considered the best for monitoring changes over time.



Paddock grid sampling pattern

Be alert to changes in soil type in the sampling area. Submit a separate soil sample from each soil type (e.g. clay, loam or sandy) and from

How to take a soil sample (CONTINUED)

paddocks that have been managed differently, because these factors affect fertiliser needs. Record where samples were taken on a map (using GPS, if possible) for a more accurate comparison each testing. It is recommended that around 25–30 soil cores are taken to make up an individual soil sample.

Note: be careful not to take soil core samples from dung pads, stock camps, gateways, fence lines and around troughs.

Sample handling and packaging

Place no less than 300 g of the (well-mixed) sample into a clean bag and seal it. Clearly write on the bag the paddock or section name and your name. Once the samples have been collected, they should be sent as soon as possible to the laboratory for analysis. If there is any delay, keep the samples cool before posting them to the laboratory.

Selecting a laboratory There are many soil-testing laboratories offering a range of soil tests, so it is important to clarify which test(s)

you want carried out. It is also crucial to ask when choosing a laboratory whether it is a member of the Australian Soil Plant Analysis Council (ASPAC) and if this accreditation applies to all the tests it offers. ASPAC-accredited laboratories meet accuracy standards for one or more of the tests carried out in their laboratory. Equally important is asking whether the laboratory has accreditation with the National Association of Testing Authorities (NATA). NATA is an association that sets and maintains the high quality control standards for the various analytical methods. It is important to understand that accreditation is only provided for specific tests, so it is unlikely that all tests on the price list will be accredited. Therefore, it is recommended that you check if the laboratory is accredited for the tests you want.

(Source: adapted from www.depi.vic.gov.au/agriculture-and-food/farm-management/business-management/ems-in-victorian-agriculture/environmental-monitoring-tools/soil-fertility)

Plant nutrients and chemical symbols

Plants take up nutrients that are in the soil water (solution) via their roots. Nutrients exist in the soil water as ions (either cations or anions). Cations are ions with a positive charge (+) and anions are ions with a negative charge (-).

Table 1 Chemical names, their symbols and ion form in soil

Chemical name	Chemical symbol	Ion form most commonly found in soil or most important for nutrient uptake by plants
Phosphorus	P	H_2PO_4^- (also exists in other forms)
Nitrogen	N	NO_3^- , NH_4^+ (also exists in other forms)
Potassium	K	K^+
Calcium	Ca	Ca^{2+}
Magnesium	Mg	Mg^{2+}
Aluminium	Al	Al^{3+} (also exists in other forms)
Zinc	Zn	Zn^{2+}
Sulphur	S	SO_4^{2-}
Hydrogen	H	H^+
Iron	Fe	Fe^{2+} (also exists in other forms)
Molybdenum	Mo	MoO_4^{2-}
Copper	Cu	Cu^{2+}
Boron	Bo	H_2BO_3^- , HBO_3^{2-} (and other forms)
Manganese	Mn	Mn^{2+}
Chlorine	Cl	Cl^-
Hydroxyl	OH	OH^-
Sodium	Na	Na^+

Units of measurement and conversions

Soil laboratories use a range of units to measure nutrient levels. Use this information should you need to convert them.

Units of measurement

$\mu\text{g/g}$ = micro-grams per gram

mg/L = milligrams per litre

$\text{meq}/100\text{g}$ = milli-equivalent per 100 gram of soil

meq \% = milli-equivalent percent

cmol/kg = centimole per kilogram; also written as $\text{cmol}(+)\text{kg}^{-1}$

ppm = parts per million

$\mu\text{S}/\text{cm}$ = microSiemens per centimetre

mS/cm = milliSiemens per centimetre

dS/m = deciSiemens per meter

ha = hectares

t = tonnes

Conversions

$1 \text{ mg}/\text{kg} = 1 \text{ ppm} = 1 \mu\text{g}/\text{g}$

$1 \text{ meq}/100\text{g} = 1 \text{ meq \%} = 1 \text{ cmol}/\text{kg} = 1 \text{ ppm}$

$1 \text{ ha} = 2.5 \text{ acres}$

$1 \text{ t} = 1000 \text{ kilograms}$

Electrical conductivity ($\text{EC}_{1:5}$)

$1000 \mu\text{S}/\text{cm} = 1 \text{ deciSiemen}/\text{metre} (\text{dS}/\text{m})$

$1000 \mu\text{S}/\text{cm} = 1 \text{ milliSiemen}/\text{centimetre} (\text{mS}/\text{cm})$

$1000 \mu\text{S}/\text{cm} = 1 \text{ EC unit}$

FURTHER READING

www.aspac-australasia.com

www.nata.asn.au (follow links: Find a Lab, Chemical Testing, Soils, Environmental/Chemical Tests)

video on soil sampling: www.agriculture.vic.gov.au/agriculture/farm-management/pastures

SOIL TEXTURE AND COLOUR

Texture

Soil texture is determined by relative proportions of the different soil particles present, namely sand, silt and clay. Soil texture will vary due to the differences in the type and mineral composition of the parent rock material, the soil's position in the landscape, and the physical and chemical weathering processes involved in soil formation.

The particles in soil are divided into four groups, depending on the particle size:

Rock and gravel	> 2 mm in diameter
Coarse sand	0.2–2 mm
Fine sand	0.02–0.2 mm
Silt	0.002–0.02 mm
Clay	< 0.002 mm

Key soil physical and chemical properties important for plant growth are influenced strongly by soil texture, such as water storage capacity and nutrient supply (e.g. soils with a high clay content retain more water due to small pores and have the capacity to hold a greater amount of nutrients). Soil texture also affects the movement of air and water in a soil (e.g. the large pores of sandier soils allow greater infiltration rates and better internal drainage than the more clay-textured soils).

A simple field measure of soil texture is to observe the way the moist soil feels


when manipulated in your hand, and the length of soil ribbon that is created. A laboratory determination of soil texture gives a more detailed and reliable measure of the relative amounts of sand, silt and clay particles in a soil. Generally the loams (ranging from soil textures of fine, sandy loams to silty clay loams) will have more plant-available water than the sandier-textured soils or the straight clay-textured soils, and so can maintain plant growth for longer periods after rain.

Soils with sandier textures (and low organic content) can be more easily eroded, hold less water and less nutrients. These soils will need the protection of good vegetative cover (over summer, in particular). Soils with a sandier texture should have nutrients applied in smaller quantities and more frequently, as they are prone to leaching, particularly for more mobile nutrients, such as potassium, nitrogen and sulphur.

Clay-textured soils can hold more nutrients but can be more difficult to manage, because they are dense and coarsely structured. This can mean they are more prone to waterlogging and poor soil structure. Building organic matter levels in the clay-textured and the sandier textured soils will reduce the impact of these limitations (see *Organic Matter*, p. 18).

Colour

Soil colour is usually described in terms of common colours such as red, yellow, brown, black or grey (soil colour charts,









such as Munsell Colour Company [1975], are used for more scientific or objective assessments of soil colour).

The colour of a soil is related to the minerals present, organic matter, and the drainage characteristics of the soil. Iron is a common mineral that influences colour in soils. In an aerobic (well-drained) environment, iron has a red colour (e.g. red-coloured subsoil usually indicates the presence of iron oxides). Yellow colours commonly result from iron in less well-drained situations and grey colours in waterlogged (i.e. anaerobic) conditions. Many types of subsoil are mottled with two or three colours, indicating periodical waterlogging.

Surface soils often have a darker coloured zone at the very surface. This is

often due to the accumulation of organic matter in the surface top soils. Some soil profiles can have very pale coloured zones between the surface soil and the subsoil horizons. This can indicate that strong leaching of nutrients, iron and other minerals has occurred.

Table 2 A guide to common soil colours

Water status of the soil	Soil colour	Colour
Well drained	Red	
	Brown	
	Yellow	
Periodically waterlogged	Mottled yellow/red/grey	
Mostly waterlogged	Grey	
	Green grey	

FURTHER READING

www.agriculture.vic.gov.au (follow links: agriculture/farm-management/soil-and-water/soils/understanding-soil-tests-pasture)

CATION EXCHANGE CAPACITY (CEC)

The cation exchange could be considered as the engine room of soil chemistry, as it drives much of what happens underground. If you grasp this concept, it will help you understand some of the science that is pivotal to how soils work.

Plant nutrients exist as either cations or anions in the soil. The word 'ion' means 'a charged particle'. Cations have a *positive* charge and anions have a *negative* charge and it is important to understand their mobility in the soil.

Remember: a positive charge is attracted to a negative charge and vice-versa.

There are two types of cations:

- acid-forming (or acidic) cations, e.g. hydrogen (H^+) and aluminium (Al^{3+}). These *are not plant nutrients* and a soil with high levels of either is an acid soil with a low pH; and
- alkaline-forming (or base) cations, e.g. calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and sodium (Na^+).

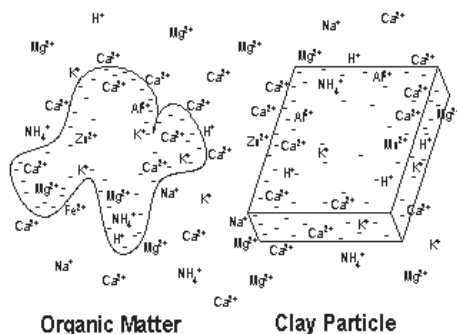
Cations (both types) are adsorbed (chemically bound) onto the negatively charged surfaces of clay or soil organic matter. Cations removed by plants from the soil solution can be replaced by those exchangeable cations held on the surfaces of soil components.

Interestingly, soil organic matter has both negative and positive charges,


so will adsorb both anions and cations.

Clay particles tend to have a negative charge. How much negative charge they have depends on the particular clay minerals present in your soil. Also, the smaller the clay particles, the larger the surface area and the more negative charges they will hold.

The **cation exchange capacity (CEC)** shown on your soil test is an indication of the amount of negative charges on your soil (and thus its ability by electrostatic force to hold/*adsorb* and release the positively charged cations into the soil solution where plants can access these nutrients). This gives you a general idea of the fertility of your soil: a sandy soil, for example, will generally have a low CEC (i.e. low fertility); that of clay soils will be higher, and soils with good levels of



Cations (positively charged ions, such as calcium and potassium) are attracted to (negatively charged) soil clay particles and organic matter in the soil. Anions (negatively charged ions, such as nitrate) are repelled (source: University of Minnesota Extension).



organic matter have the highest (in each case due to the particle surface area).

CEC is usually measured as centimoles of positive charge per kilogram of soil (cmol/kg). This is numerically equal to the older unit of measurement milliequivalents per 100 grams (meq/100 g).

In most soil laboratories, CEC is estimated by summing the exchangeable base cations (calcium, magnesium, potassium and sodium) to give an adequate measure of CEC ('CEC by bases'). As soils become more acidic, however, the acidic cations (hydrogen, aluminium and manganese) become the predominant portion of the CEC. **Effective CEC (ECEC)** on a soil test refers to the sum of both base *and* acidic cations and this gives a more accurate indication of your CEC.

The CEC of clay minerals may commonly range from 10–150 cmol(+)/kg, while that of organic matter may be in the range of 200–400 cmol(+)/kg. Conversely, the CEC of sand and sandy soils is often below 10 cmol(+)/kg. This means that the more organic matter content and the amount of clay and type of clay minerals present in your soil greatly influences its capacity to retain nutrients.

Generally speaking, however, a CEC above 12 cmol(+)/kg would be considered moderate and means that a soil has a good capacity to retain nutrients for plant growth.

Management considerations


Soils with higher CEC capacity are generally considered more fertile, able to support higher production levels and can retain larger amounts of nutrients against losses via leaching through the soil profile. This has important implications for developing a whole-farm plan and farming to the capacity of your soil.

If your CEC is low, consider increasing inputs of organic matter, either through additional inputs of organic materials or careful grazing management (e.g. maintaining good ground cover).

Environmental considerations

Being negatively charged, nutrients that exist as anions (e.g. nitrogen and sulphur) are not attracted to the negatively charged clay surfaces and are therefore more susceptible to leaching and nutrient runoff when added as soluble fertilisers (resulting in environmental concerns and economic loss), particularly in soils with a low CEC. Care must be taken when applying them, as large applications of a negatively charged element followed by heavy rainfall can move the nutrient quickly through the soil before adequate access by plants is possible.

This can also happen on sandier textured



soils (with a low CEC) where there are not enough negative charges on the soil particles to hold positively charged cations, such as potassium. This has important implications when planning a fertiliser program. In such soils, consider splitting applications of fertilisers to avoid potential losses via leaching through the soil profile.

Phosphorus is the odd anion. It is not mobile in the soil, despite having a negative charge, because it is not highly soluble and chemically binds with clay minerals, aluminium, and iron oxide minerals. It will still move through the soil, however, attached to the soil minerals. Minimising runoff with good ground cover will help ameliorate this.

FURTHER READING

www.depi.vic.gov.au/agriculture-and-food/farm-management/soil-and-water/soils/understanding-soil-tests-pastures

Cation exchange capacity fact sheet: [www.soilquality.org.au/factsheets/Cation Exchange Capacity](http://www.soilquality.org.au/factsheets/Cation%20Exchange%20Capacity)

Glendinning, JS (ed.), 2000, *Australian Soil Fertility Manual* (rev. edn), Fertiliser Industry Federation of Australia Inc. & CSIRO Publishing, Melbourne

SOIL pH

Soil pH is a measure of the concentration of hydrogen (H^+) ions in the soil solution (i.e. the greater the number of hydrogen ions, the greater your soil's acidity).

This measure of soil acidity or alkalinity is based on a logarithmic scale from 1 to 14, with 7 being neutral. So, the lower the pH reading, the greater the acidity of your soil. The logarithmic scale means that each unit change in soil pH translates to a tenfold change in the acidity or alkalinity of the soil. For example, a soil pH of 4 is ten times more acidic than a soil pH of 5 and 100 times more acidic than a soil pH of 6.

Two laboratory methods are used to measure soil pH:

- the water method (in a ratio of one part of soil to five parts of water). Results are reported as pH(water) or pH 1:5(water); and
- the $CaCl_2$ method (in a ratio of one part of soil to five parts of calcium chloride solution). Results are reported as pH($CaCl_2$) or pH 1:5($CaCl_2$). *The value given in this test is (on average) 0.8 units lower than the pH(water) value.*

Note, however, that pH measured in water is more affected by seasonal variations than pH measured in $CaCl_2$ solution (so, from a soil monitoring point of view, it's best to use the results from the $CaCl_2$ test).

Throughout the Goulburn Broken Catchment, soils are generally acidic. In

the higher rainfall areas (above 600 mm), it is common to find soils with a pH less than 4.8($CaCl_2$) or 5.5(water).

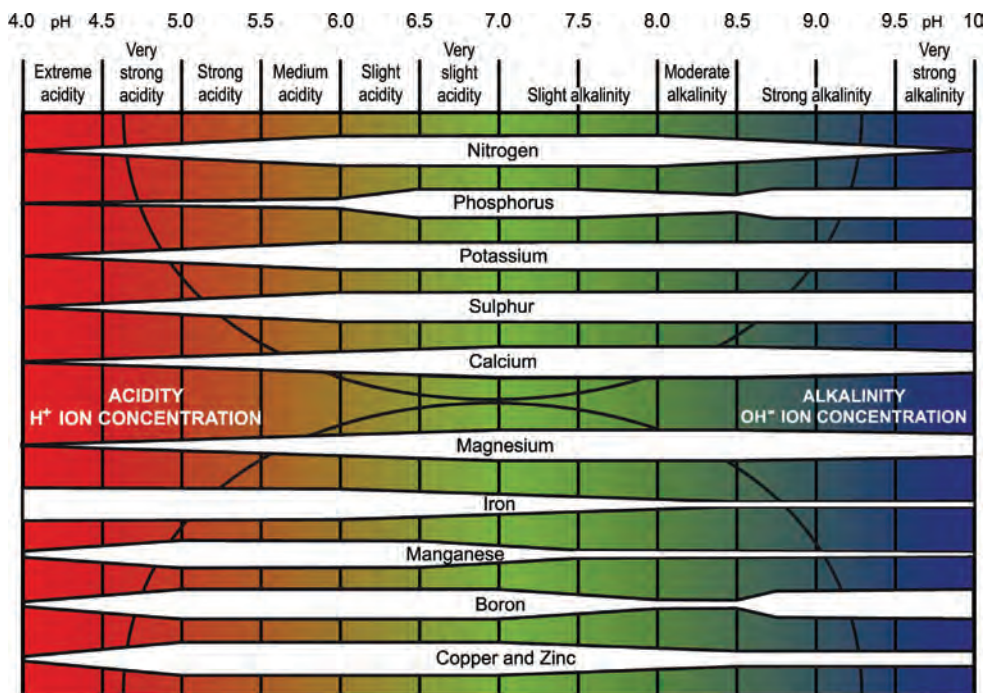
Soil pH is important because it:

- influences most soil chemical processes that can affect nutrient availability (e.g. the availability of phosphorus and nitrogen);
- dictates the availability of elements that are toxic to plants (e.g. aluminium); and
- affects microbial activity, particularly biological processes affecting decomposition rates of organic matter, which in turn affect nutrient availability and plant growth.

All of the above conspire to restrict root growth and limit access to water and nutrients, which often results in poor germination and establishment of crops and pastures.

In acid soils – less than pH 4.8 ($CaCl_2$) or 5.5(water) – the major plant nutrients (nitrogen, phosphorus, potassium, sulphur, calcium and manganese) and the trace element molybdenum may have restricted availability to plants (see diagram, p. 14).

Acid soils also affect the element aluminium, which becomes more soluble and, in high levels, can be toxic to sensitive plants, limiting root growth and restricting access to water and nutrients (see graph, p. 15). Plant species range in their tolerance of available aluminium in



redrawn by PDA from Troug, E. (1946)

The influence of pH on nutrient availability is complex, but this graph provides a basic guide to the general trends: the wider the white band, the more favourable the conditions of supply. Note: figures refer to pH(water) (source: Potash Development Association UK, adapted from Emil Truog, 1946)

soils. High manganese levels are often associated with waterlogged soils in addition to soil acidity and this can also be toxic to plants.

In acid soils, microbial populations and their activity can be reduced. Rhizobia

bacteria are particularly affected by acidic soil conditions, thereby decreasing legume nodulation (and symbiotic nitrogen fixation and availability). Pasture legumes may fail to persist due to failing legume nodulation and reduced functioning of the symbiosis.

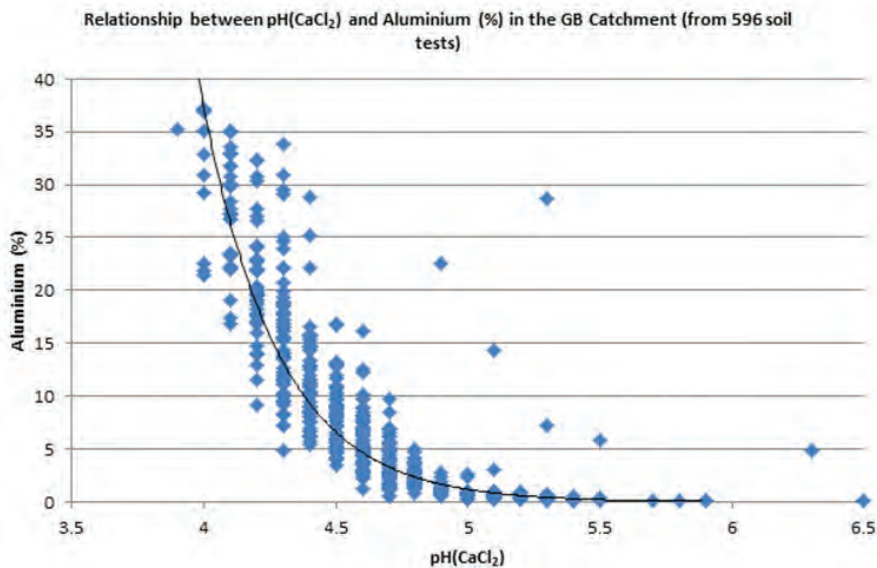
Management considerations

The ideal target for topsoil is above a pH of 4.8(CaCl₂) or 5.5(water). In pastures grown on soils with a pH below the target range, overall pasture production may be reduced and some legume species may fail to persist.

If the topsoil pH is below these target pH levels, liming is often recommended, particularly if resowing a pasture. While

indicating the need for lime, your soil pH reading is not a reliable guide to how much lime is needed. It is important that you consider other factors in conjunction with your soil pH:

- the soil type (i.e. soils with a high cation exchange capacity – those with high organic matter and clay content – will be more resistant to changes in pH and will generally require more lime than soils with a low cation exchange capacity);



Generally, as soil pH(CaCl₂) declines below 4.8(CaCl₂) or 5.5(water), exchangeable aluminium increases (data from Strathbogie, Ruffy, Tarcombe, Naring, Warrenbayne, Boho, Benalla region, Goornabab, Alexandra, Yea, Broadford, Mansfield, Nagambie, and Miepoll) (source: Goulburn Broken CMA, 2014).

- lime quality (ask your agronomist about a lime's neutralising value);
- your farming system (e.g. whether it has a low- or high-stocking density and is a low- or high-input system); and
- rainfall (i.e. the higher your rainfall, the higher the probability of acidic soils).

From an economic point of view, liming should only be considered for your most productive land (i.e. avoid areas subject to waterlogging, weeds, rocks, and native grasses, or which have access issues).

Plants differ in their tolerance of acid soil conditions. The use of tolerant pasture or crop species/varieties can reduce the impact of soil acidity.

Why do soils acidify?

The acidification of soil is a natural process that occurs over thousands of years. Under agriculture, however, the process can be accelerated, affecting either the surface soil only or the subsoil as well. Surface acidity can be relatively simple to treat with the application of lime (calcium carbonate) but, if untreated, can become a problem in subsurface soils, which are more difficult and costly to correct.

Research has demonstrated that the biggest contributors to acidification of Australian soils under agriculture are:

- nitrate leaching – nitrate in the soil solution (both natural and applied) is highly mobile and, if not used by plants (e.g. annual pasture species, which don't have the larger root systems of perennials to capture

it), can leach away from the root zone, leaving behind hydrogen and aluminium ions, and thereby increasing soil acidity; and

- the export of alkalinity in produce, such as milk, wool, grain and hay. As nutrient cations (such as calcium, magnesium and potassium) are taken up from the soil by plants and then removed by harvesting crops or hay, in particular, the more acidic cations (hydrogen and aluminium) make up a larger proportion of the soil cation exchange. The nutrient cations can also be lost by leaching (usually in association with nitrate leaching), again resulting in the more acidic cations making up a larger proportion of the soil cation exchange. Both of these processes will steadily lower the soil pH over time.

Environmental considerations

Soil acidity is a major environmental and economic concern. A number of management practices can maintain your pH levels (attained through a liming program) or reduce the rate of further soil acidification, including:

- reducing the risk of nitrate leaching in high rainfall areas by using the correct type and rate of nitrogen fertiliser at the right time (avoid applying before high rainfall events);
- utilising perennial pastures, which better capture nitrate before it leaches; and

- feeding hay back on to paddocks from which it was cut, thereby reducing the acidifying effect of product export from paddocks.

Pasture production on highly acidic soils will most likely be reduced and consideration of the potential off-site impacts must be made. Off-site impacts mainly resulting from reduced plant growth include an increased risk of salinity, as deep-rooted pasture species required to increase water usage may not thrive. There is also an increased risk of runoff and subsequent erosion that can have impacts on streams and water quality. Increased risks of nutrient leaching may pollute ground water.

FURTHER READING

www.dpi.nsw.gov.au: Primefact 34 (February 2006), Pasture Responses to Lime

Animation on soil acidification: http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_acidification

Glendinning, JS (ed.), 2000, *Australian Soil Fertility Manual* (rev. edn), Fertiliser Industry Federation of Australia Inc. & CSIRO Publishing, Melbourne

www.publish.csiro.au/?paper=SR9950277: Slattery W, Morrison G & Coventry D, 1995, 'Liming effects on soil exchangeable and soil solution cations of four soil types in North-eastern Victoria', *Australian Journal of Soil Research*, vol. 33, pp. 277–95

ORGANIC MATTER

Soil organic matter probably plays the most important role in the health and productivity of your soil. It comprises a diverse collection of living components (e.g. fungi, bacteria, actinomycetes and earthworms) and non-living components (decaying and decomposing plant and animal material).

Typically the top 20 cm of soil has higher numbers of soil organisms and higher levels of biological activity than soil lower in the profile, so your management practices can have a great impact on them. Most of them rely upon organic matter as their energy source and, during the decomposition process in aerobic conditions, release a large reservoir of plant-available nutrients (i.e. nitrogen, phosphorus, potassium,

sulphur, calcium, magnesium and trace elements). Because organic matter has a huge surface area and both negative and positive charges, it can hold great quantities of these (positively charged) nutrients or cations (*see also* Cation Exchange Capacity, p. 10). The glues and slimes that the soil organisms produce during the decomposition process help bind the soil mineral particles into aggregates. This improved soil structure equates to improved water-holding capacity, aeration, drainage and root penetration, and less risk of erosion and leaching of nutrients.

Humus is the relatively stable end product of decomposed organic matter. This means it is more resistant to further decomposition by soil organisms and so



Organic matter additions to soil can lead to an increase in the numbers of beneficial soil organisms, such as earthworms (pictured), bacteria, fungi, and other soil fauna (source: Judy Brookes).

tends to decay more slowly (over decades to centuries). Due to its large surface area and being the most chemically reactive component of organic matter (having both positively and negatively charged sites), humus plays a pivotal role in all key soil functions.

Total carbon in your soil test refers to both the organic forms (as described above) and the inorganic forms of carbon (usually carbonates and bicarbonates).

The terms **total organic carbon**, **soil organic carbon** and **organic carbon**

Nutrient potential in soil organic matter

The ratio of carbon:nitrogen:sulphur:phosphorus in organic matter is roughly 100:10:1.5:1.5.

In other words, a hectare of soil 10 cm deep with a bulk density of 1 tonne/m³ weighs 1 000 000 kg. Therefore, soil with a carbon matter content of 3% would contain 3000 kg of organic nitrogen, and 450 kg each of organic phosphorus and sulphur per hectare.

Not all of the organic forms of nutrients are mineralised (converted to plant-available forms) by soil organisms each year, however, but what is (slowly) converted still represents a potentially significant pool of nutrient for plant production.

are the same and refer specifically to the carbon derived from the organic materials in soil.

In the testing process, soil laboratories typically use either a wet or dry oxidation process to convert all forms of carbon in the soil to carbon dioxide. An example of a wet oxidation process used by laboratories is the Walkley-Black method. The LECO test is an example of the dry oxidation process used.

The target range for your particular area will depend on the climate (particularly the rainfall and temperature), soil type and your management. Drier, hotter areas will generally have lower soil carbon values (except where irrigation is used) compared to wetter and colder areas. Cropped soils will generally have lower soil carbon values compared to soils under permanent pasture.

Table 3 Organic carbon percentages (%) for dryland pastures. These values can be multiplied by the conversion factor of 1.7 for the equivalent organic matter percentages.

Organic carbon levels	Pastures – low rainfall (< 400 mm)	Pastures – high rainfall (> 400 mm)
Low	< 1.8	< 3
Normal	1.8–2.7	3–5.0
High	> 2.7	> 5.0

(Source: adapted from www.depi.vic.gov.au/agriculture-and-food/farm-management/soil-and-water/soils/understanding-soil-tests-pastures)

Management considerations

Organic matter is the jewel in the crown: it plays such a critical role in improving and maintaining the physical, chemical and biological properties of soils. So, it's important to monitor and manage your soil to maintain the organic carbon levels at the highest possible level (keeping economical and seasonal constraints in mind) to sustain your soil's health and overall productivity. Organic carbon levels can dramatically decrease due to erosion, cultivation, cropping, and burning of crop stubble. If your soil organic carbon levels are low, options to improve them include:

- increasing inputs of organic matter. Large organic additions (such as manures, biosolids, composts and biochar) can increase the organic carbon percentage in a soil temporarily, but unless the additions are continued, the soil will revert to its steady state of equilibrium of organic carbon. Consideration of economic return should be an important factor in your decision-making when using these options; and
- growing more biomass. This can increase organic additions in the soil via decomposition of increased root mass and leaf litter. Options include:
 - green manure crops, particularly legume crops or mixes (e.g. vetch or peas with oats) that are grown and then slashed and/or turned into the soil before seed set;

Building organic matter is a slow process

A hectare of soil 10 cm deep with an average bulk density of 1 tonne/m³ weighs 1000 tonnes. Therefore, increasing soil organic matter by 1% will result in a 10-tonne change.

But you cannot simply add 10 tonnes of manure or residue, as only 10–20% of this material becomes part of the soil organic matter. The rest is converted over several years into carbon dioxide via soil biological decomposition processes.

- including (in particular, perennial) grasses in your pasture mix, as these tend to have a higher root-to-shoot ratio and can increase organic additions to the soil via the roots;
- rotational grazing, which encourages extensive pasture root growth and maximises pasture recovery time between grazing events (hence producing more organic matter for decomposition); and
- ensuring adequate supply of nutrients (fertiliser) to pastures to encourage greater plant root and general pasture growth.



Environmental considerations

In pasture situations, it is crucial to manage your grazing to ensure there is optimum ground cover (i.e. the soil surface is covered by living and dead plant material), particularly in summer.

This reduces the potential for organic matter losses and soil losses by wind and water erosion (plus the opportunity for weed invasion). As a general rule, maintenance of more than 70% ground cover is required to prevent such losses. More ground cover is required on steeper country.

FURTHER READING

Chan, KY, Oates A, Liu DL, Li GD, Prangnell R, Polie G & Conyers MK, 2010, *A Farmer's Guide to Increasing Soil Organic Carbon Under Pastures*, Industry & Investment NSW, Wagga Wagga (www.dpi.nsw.gov.au/agriculture/resources/soils/soil-carbon/increasing-soil-organic-carbon-farmers-guide)

www.dpi.nsw.gov.au/agriculture/resources/soils/soil-carbon/increasing-soil-organic-carbon-of-agricultural-land

Animation: http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_organic_carbon-cycle

PHOSPHORUS (P)

Phosphorus (P) is an essential element for both plant and animal growth (about 80% of P is found in the bones and teeth of animals). In plants, it is important for energy storage and transfer, early shoot and root growth (i.e. vital for seedlings and young plants), and legume nodulation processes.

Most Australian agricultural soils are highly weathered with very low levels of P in their natural state, so introduced crops and grasses need P applied for productive yields.

Especially when the soil pH is less than 4.8(CaCl₂) or 5.5(water), P reacts quickly with the soil, chemically bonding with clay minerals, aluminium and iron minerals. These reactions result in less P available to plants, and only a small portion of P applied as fertiliser is taken up by the plant in the year of application.

There are various chemical tests used to estimate the amount of plant-available P in the soil, so it is important to use one that is suitable for your region and situation. Soil-test results are most meaningful where there has been field research conducted to establish yield-response curves for that particular soil-test method, soil type and plant species combination. This gives some confidence to interpreting how much P might be needed to achieve a certain plant response. A national research program has provided well-established, pasture-yield response curves for the **Olsen P** test, in which soil is shaken in a bicarbonate solution for 30 minutes

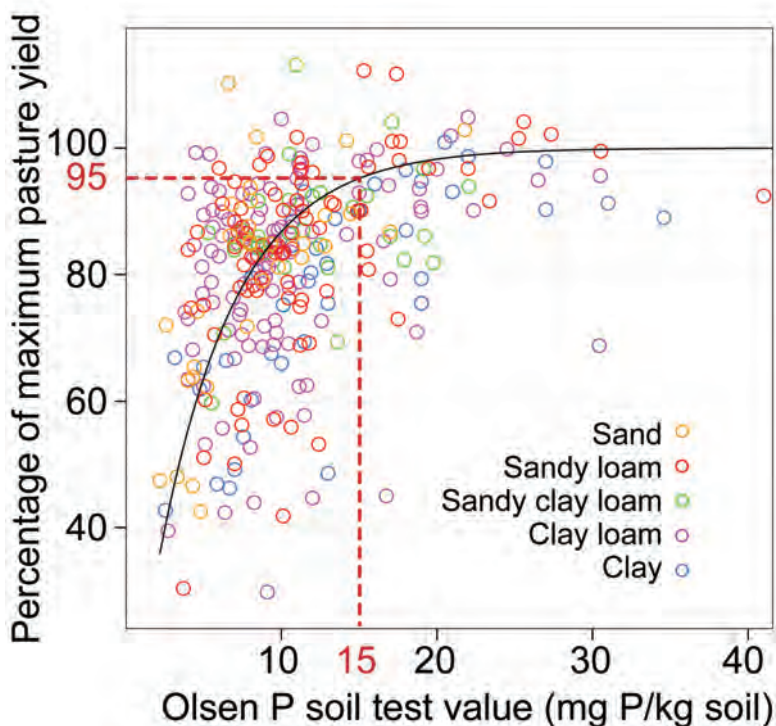
to measure plant-available P in the soil solution.

The Colwell P test is similar to the Olsen P test, but uses a different dilution ratio and is shaken for 16 hours before measuring the amount of P in the solution. Because of this, it is thought that the Colwell P test not only gives a measure of the plant-available P, but also some of the less available soil-adsorbed (chemically bound) P in the soil. This is why the Colwell P test produces higher test values than the Olsen P test.

The Phosphorus Buffering Index (PBI) provides a measure of your soil's tendency to chemically adsorb (chemically bind) P. The PBI should be used in conjunction with the Colwell P test. The target Colwell values will increase with increasing PBI values. Additionally, PBI provides a more accurate estimate of the amount of P needed to increase plant-available P levels in your soils. Low PBI soils adsorb only small amounts of P, leaving more of the fertiliser-applied P available for plant uptake. High PBI soils, however, more strongly bind P, making more of it unavailable for plant use. So, high PBI soils require greater applications of P over time to raise plant-available P levels.

There are a couple of other soil tests you may see on your soil test for P, such as the Bray test and the DGT-phosphorus.

The **Bray** test is more commonly used in NSW, particularly for the temperate areas on acid soils. The **DGT-P** is a relatively



A national assessment of soil-test levels and yield responses to fertiliser found that 95% of the maximum pasture yield can be achieved by targeting an Olsen P test value of 15 mg P/kg of soil. Higher or lower soil P test targets may be appropriate, depending on the value of pasture utilised and the profitability of the grazing enterprise (source: Gourley et al, 2007).

new P test, which is being developed primarily for crops (as yet, no calibration has been made with pasture species, nor is the test ASPAC-certified).

Responses to P based on soil-test results can vary widely and consultation with local advisors is recommended. Estimating critical values or target ranges for P requires local knowledge

of soils, climatic conditions and an understanding of pasture type and management goals. Table 4 (p. 24) provides target ranges for P (Olsen P, Colwell P and PBI). Targeting the higher levels of these ranges will be necessary for pasture systems that are aiming for 90–95% potential pasture yield and using higher stocking rates.

Table 4 Target ranges for P (Olsen P, Colwell P and Phosphorus Buffering Index)

Olsen P	Target range (mg/kg or ppm)
Native pasture species	< 12
Introduced pasture species – pasture system aiming for 80–90% potential pasture yield (lower stocking rate)	12–14
Introduced pasture species – pasture system aiming for 90–95% potential pasture yield (higher stocking rate)	15–18
Colwell P	Target range (mg/kg or ppm) for pasture system aiming for 80–90% potential pasture yield (lower stocking rate)
PBI range	
0–35 (very low sandy soils)	18–26
35–70 (very low sandy/silty loams)	23–30
71–140 (low)	27–35
141–280 (moderate)	32–42
281–840 (high)	44–58
> 840 (very high)	> 70
Colwell P	Target range (mg/kg or ppm) for pasture systems aiming for 90 - 95% potential pasture yield (higher stocking rate)
PBI range	
0–35 (very low sandy soils)	23–34
35–70(very low sandy/silty loams)	30–39
71–140 (low)	35–45
141–280 (moderate)	42–54
281–840 (high)	58–75
> 840 (very high)	> 80

Note: There is too much variation to be able to convert Olsen P to Colwell P (and vice versa). (Source: www.depi.vic.gov.au/agriculture-and-food/farm-management/soil-and-water/soils/understanding-soil-tests-pastures)

Management considerations

Phosphorus is a key driver of pasture growth. If your farm management goals are more directed towards achieving environmental outcomes (i.e. lower stocking rates), then your target range for P will be in the lower end of the target range. If your goals are more directed towards achieving high production levels, then your target range will be higher. Monitoring your soil P levels over time will provide you with more confidence in interpreting your P production targets.

Also monitor your soil pH and apply lime if pH is low and aluminium levels are high (causing the P to be tied up). If using P fertiliser, target your best pastures (i.e. paddocks with good clover content, low weed content, good pH levels and low risk of waterlogging). This will give you a greater chance of obtaining an economic return on your investment in P.

It is important to maintain organic matter levels in your soil as a reserve

of soil P. Soil biological processes can mineralise this P over time.

Rotational grazing helps achieve a more even spread of P across the paddock, avoiding hotspots of high P concentration in stock camps.

Environmental considerations

Even though P is not highly mobile in the soil, it is now recognised that the loss of P in surface run-off during heavy rain events amounts to a major loss of P to pastures and contributes considerably to the pollution of waterways. Your ground cover is critical: avoid applying P when it is less than 70%; less-than-ideal ground cover may be due to overgrazing, the impact of drought conditions, or fire.

Consider maintaining a fertiliser-free buffer zone around water bodies and riparian zones (ideally fencing them off from stock).

A minimum distance of 10 m around dams, and a minimum of 40 m from waterways will reduce the risk of P polluting your water bodies (and you losing P).

FURTHER READING

Animation on phosphorus: <http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil-phosphorus-animation-grazing-system>

www.makingmorefromsheep.com.au/grow-more-pasture/tool_7.3.htm

www.agriculture.vic.gov.au/agriculture/farm-management/pastures/informed-decisions-on-phosphorus

Glendinning, JS (ed.), 2000, *Australian Soil Fertility Manual* (rev. edn), Fertiliser Industry Federation of Australia Inc. & CSIRO Publishing, Melbourne

Gourley, CJP, Melland, AM, Waller, RA, Awty, IM, Smith, AP, Peverill, KI, & Hannah, MC, 2007, *Making Better Fertiliser Decisions for Grazed Pastures in Australia*, Victorian Government Department of Primary Industries (download: www.asris.csiro.au/downloads/BFD/Making-Better-Fertiliser-Decisions-for-Grazed-Pastures-in-Australia)

NITROGEN (N)


Nitrogen (N) is essential for all plant growth processes and plants need it in large quantities. In plants, it is a key element in amino acids, proteins, enzymes and chlorophyll. In simple terms, N produces bigger leaves and bigger plants, with dark green growth. In a mixed pasture situation, N directly affects the grass component of the pasture and the protein content within those grasses. In pasture systems where N fertilisers are not applied, such as in extensive sheep and cattle enterprises,

the clover component of pastures is the main supplier of N.

Your soil test may offer up to three measurements for N. When considering these, however, it is important to note that N levels in soils fluctuate widely, depending on seasonal conditions and rainfall. Levels greatly depend on biological activity, and the nitrate-N form is highly mobile and easily leached. This means its concentration in the soil can vary considerably over a short time, even



A host-specific strain of soil bacteria (rhizobia) infects the roots of legumes, such as clover, to form a nodule, which converts atmospheric nitrogen to ammonia. The legume uses this nitrogen and the bacteria uses carbohydrates made by the plant. When pink (as above), the nodules are healthy and functioning (source: Ninjatacoshell, Wikimedia Commons)



in the same paddock, and it is therefore difficult to interpret the results.

As it suggests, **total nitrogen** measures the total amount of N in the soil. Over 98% of this N, however, is contained in organic matter (plant residue, insects, fungi, bacteria, etc.) and is unavailable to plants. This bank of organic N is mineralised (decomposed by microbes) to produce ammonium-N (NH_4^+) and nitrate-N (NO_3^-). Mineralisation occurs throughout the growing season, providing a steady supply of N to pasture (however, in high-production situations, such as haymaking, this is unlikely to meet N requirements of that crop). Nitrogen mineralisation processes are negatively influenced by low pH and waterlogging.

Nitrate-N (NO_3^-) is a negatively charged anion and is therefore not held by the soil but remains highly mobile in the soil solution. This mobility means that nitrate-N is readily available for plant uptake, but (in high rainfall events and free-draining soils) is more easily leached out of reach of the plant root system.

Unlike nitrate-N, **ammonium-N (NH_4^+)** is a positively charged cation and can be chemically bonded onto the (negatively charged) surfaces of clays and organic matter. Agronomists use levels of ammonium-N on soil tests to indicate how much N is likely to become available.

Ammonium-N can be measured in the laboratory using a chemical extractant,

such as potassium chloride. Nitrate-N is often measured in the laboratory using the 1:5 soil:water solution, using a similar procedure to that used for measuring pH.

Total nitrogen can be measured in the laboratory using the Kjeldahl (chemical) digestion process. The other common method is the Dumas (or LECO) combustion method.

Estimating a target range for N requires local knowledge and some experience with the local soils and climate. There are no real target levels, but agronomists generally prefer a level of 10 mg/kg or more in pasture soils (for both nitrate and ammonium). Nitrogen recommendations are better based on regional fertiliser trials conducted over a number of years, rather than on soil-test levels.

N is also supplied to the soil through the symbiotic relationship that legumes form with a host-specific strain of bacteria known as rhizobia. These infect the root to form a nodule. In introduced pasture situations, the most common legume is clover. The legume nodules on the root have an iron atom containing a protein called leghaemoglobin, which is able to convert atmospheric N to ammonia. The ammonia is used by the plant and the plant carbohydrates are used by the bacteria. There is growing evidence that shows some free-living bacteria also provide a significant amount of N to soils through non-symbiotic processes.

Management considerations

When pastures and crops are cut for hay, significant amounts of N are exported. Applying N fertiliser in these situations should be considered.

It is important to maintain organic matter levels in soil as a reserve of soil N, which soil biological processes can mineralise over time.

Maintaining the legume component in pastures maximises symbiotic N fixation (as a general rule, undergrazing or the absence of grazing will favour grass growth and reduce legume content).

Rotational grazing helps achieve a more even spread of N across the paddock, avoiding hotspots of high-N concentration in stock camps.

Monitor your soil pH and use lime, if needed, as biological N-fixation processes are restricted at low pH levels.

If resowing, inoculate clover seed with the correct host-specific strain of rhizobia.

Environmental considerations

When applying N as fertiliser, there is the risk that excess nitrates are either lost as runoff (into waterways) or accumulate in the soil (to be leached into the groundwater). So, for environmental (and economic) reasons, use the right rate and right type of N fertiliser at the right time, avoiding periods of high rainfall.

Importantly, high fertiliser N application can limit biological N fixation processes.

FURTHER READING

Animation on nitrogen cycle: http://vro.depi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_nitrogen-cycle
www.soilquality.org.au/factsheets/mineral-nitrogen

Glendinning, JS (ed.), 2000, *Australian Soil Fertility Manual* (rev. edn), Fertiliser Industry Federation of Australia Inc. & CSIRO Publishing, Melbourne

POTASSIUM (K)

Potassium (K) is one of the three major (macro-) nutrients (with phosphorus and nitrogen) for plants and is important for regulating water and nutrient uptake, flowering and seed set, and plant resistance to environmental stresses and disease.

K is one of the most abundant elements in soil, but its availability to plants is controlled by soil chemistry and mineralogy. It is taken up by plant roots as the positively charged cation K^+ from the soil solution or as an exchangeable cation (see Exchangeable Cations, p. 32) held by the negative surface of clay minerals and organic matter. It is also found 'fixed' between clay layers and within particular clay minerals (Illite). Fixed K is not readily available to plants and is only released slowly into the soil solution as minerals are weathered.

Some plant species, such as lucerne, have higher demands for K, and there are differences in pasture species in their efficiency of K uptake – those with broader rooting patterns and greater rooting depth are able to access the K found in soil profiles with clay at depth.

Most clay-textured soils in the Goulburn Broken Catchment contain adequate amounts of K in the soil for optimum crop and pasture growth. Sandy-textured soils (with a low cation exchange capacity) in higher rainfall areas have limited ability to store K and are, therefore, more prone to K deficiency. So, interpreting soil K results and predicting plant responses to applied K fertiliser is dependent on soil texture and soil type (see Table 6, p. 30).

Generally crop and pasture responses to applied K fertiliser have been rare in south-east Australia (including the Goulburn Broken Catchment) on clay soils.

When plants are growing quickly in response to warm, moist spring conditions, for example, the K taken up by the plant roots from the soil solution may not be replaced quickly enough by natural soil processes to avoid a temporary deficiency in pasture. Therefore, many agronomists will advise the application of a K-based fertiliser, particularly on pastures or crops targeted for hay production/silage or grown on sandier textured soils. Because these lighter soils have limited ability to store K (due to a low cation exchange capacity, see p. 10), large applications of fertiliser on such soils are likely to be used inefficiently by plants and lost by leaching – small and frequent applications are commonly more appropriate.

Soil tests measure either extractable K or exchangeable K.

The **Colwell K** method measures extractable K in the soil solution, estimating the readily available and potentially available K in your soil (see Table 5, p. 30).

The **Exchangeable K** test, however, is only a measure of readily available K (see Table 6, p. 30).

The **Skene K** is an older test but, in practice, gives an equivalent level of K to the Colwell K method.

Table 5 Target ranges for extractable K (mg/kg) – Colwell K method

	Sands	Sandy loams	Clay loams	Clays
System aiming for 80–90% potential pasture yield (lower stocking rate)	60–100	70–110	70–120	80–130
System aiming for 90–95% potential pasture yield (higher stocking rate)	90–130	100–150	110–160	120–180

Table 6 Target ranges for exchangeable K (cmol/kg) according to soil type

	Sands	Sandy or silty loams	Sandy or silty clay loams	Clays loams and clays
System aiming for 80–90% potential pasture yield (lower stocking rate)	0.25–0.36	0.28–0.38	0.31–0.44	0.31–0.44
System aiming for 90–95% potential pasture yield (higher stocking rate)	0.33–0.44	0.38–0.49	0.30–0.54	0.41–0.56

FURTHER READING

www.depi.vic.gov.au/agriculture-and-food/farm-management/soil-and-water/soils/understanding-soil-tests-pastures

Potassium fact sheet: www.soilquality.org.au/factsheets/potassium

Glendinning, JS (ed.), 2000, *Australian Soil Fertility Manual* (rev. edn), Fertiliser Industry Federation of Australia Inc. & CSIRO Publishing, Melbourne

Gourley, CJP, Melland, AM, Waller, RA, Awty, IM, Smith, AP, Peverill, KI, & Hannah, MC, 2007, *Making Better Fertiliser Decisions for Grazed Pastures in Australia*, Victorian Government Department of Primary Industries (download: www.asris.csiro.au/downloads/BFD/Making-Better-Fertiliser-Decisions-for-Grazed-Pastures-in-Australia)

SULPHUR (S)

Sulphur (S) is an essential element for growing plants as it aids in nitrogen fixation by legumes and is involved in the formation of several important amino acids, proteins and vitamins. It also has a key role in the synthesis of chlorophyll. Sulphur is vital in animal health as well (for instance, in the formation of proteins that make up skin, hair and wool).

More than 95% of the S in the soil is contained in the organic matter. Through biological processes similar to those of nitrogen, S is mineralised by soil organisms to plant-available sulphate ions. These biological processes are negatively influenced by a low pH and waterlogging.

The sulphate ion has a negative charge, so is not held by the (negatively charged) clay surfaces but remains in the soil solution, making it highly mobile (nor does it form strong bonds with iron and aluminium minerals, as is the case with phosphorus). Its mobility means that it can be more readily leached out of reach of the plant root system, particularly in sandy, free-draining soils in high rainfall zones.

FURTHER READING

www.depi.vic.gov.au/agriculture-and-food/farm-management/soil-and-water/soils/understanding-soil-tests-pastures

Sulphur fact sheet: www.soilquality.org.au/factsheets/Sulphur

Glendinning, JS (ed.), 2000, *Australian Soil Fertility Manual* (rev. edn), Fertiliser Industry Federation of Australia Inc. & CSIRO Publishing, Melbourne

Gourley, CJP, Melland, AM, Waller, RA, Awty, IM, Smith, AP, Peverill, KI, & Hannah, MC, 2007, *Making Better Fertiliser Decisions for Grazed Pastures in Australia*, Victorian Government Department of Primary Industries (download: www.asris.csiro.au/downloads/BFD/Making-Better-Fertiliser-Decisions-for-Grazed-Pastures-in-Australia)

The main test used for S is the **Potassium Chloride-40 (KCl-40)** (or **Blair**) test. It is generally thought that the KCl-40 test picks up most of the S already in the (plant-available) sulphate ion form, as well as some of the organic (tied-up) S.

Table 7 The ideal target for S (mg/kg)

	Target S (KCl-40) mg/kg
Pasture system aiming for 80–90% potential pasture yield (lower stocking rate)	6–7.5
Pasture system aiming for 90–95% potential pasture yield (higher stocking rate)	7.5–12

Management considerations

Maintaining good organic matter levels in your soil as a reserve of soil S is good practice. Soil biological processes can mineralise this S over time.

If you are using fertilisers, consider rotating high-analysis fertilisers (containing little or no S) with low-analysis fertilisers (containing appreciable amounts of S).

EXCHANGEABLE CATIONS AND PERCENTAGES

If you are unfamiliar with the concept of cations and their exchange in the soil, you will find a comprehensive explanation on p. 10.

In short, the major cations present in soil are calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na). In acid soils, aluminium (Al), hydrogen (H) and manganese (Mn) also occur in higher amounts.

Generally, your soil test will report levels of the major cations in two ways:

- as cmol/kg of soil (or meq/100g), and
- as a percentage of the total exchangeable cations (most likely towards the bottom of your soil test).

The proportion (or *percentage*) of the cation exchange capacity that is occupied by the base exchangeable cations (i.e. calcium, magnesium, potassium and sodium) is known as the **base saturation percentage**. There is considerable evidence that the relative proportions (percentages) of cations are more relevant to soil performance than

Table 8 Desirable percentage range of exchangeable cations for soils

Cation	Range (%)
Calcium	65–80
Magnesium	10–20
Potassium	3–8
Sodium	< 6
Aluminium	< 5

(Source: www.depi.vic.gov.au/agriculture-and-food/farm-management/soil-and-water/soils/understanding-soil-tests-pastures)

the actual levels (those given in cmol/kg). However, most soil tests will also report the desirable percentage range of each cation, as in Table 8 below.

Calcium (Ca)

Calcium (Ca) is essential for many plant functions, including cell division, root and shoot growth, cell wall development and strength, legume nodulation and nitrogen fixation processes, enzyme activity, and seed set in clover.


A component of many common minerals found in the soil, Ca is released into the soil as these minerals undergo weathering processes. As a (positively charged) cation (Ca^{2+}) in the soil solution, Ca is adsorbed (chemically bonded) onto the negatively charged surfaces of soil organic matter and clay particles. Even in acidic soils, Ca is often the most dominant cation in the soil, and can occupy 70% or more of the soil's cation exchange sites (see also calcium:magnesium ratio, p. 35).

Deficiencies of calcium are not common.

Magnesium (Mg)

Magnesium (Mg) is a key element of the chlorophyll molecule and so plays a vital role in plant photosynthesis. It is also involved in the transport of phosphorus in the plant, and has an important part in enzyme activity, protein and sugar synthesis and other functions.

Magnesium is available to plants in the soil solution as a (positively charged)



cation (Mg^{2+}) and, as such, is adsorbed onto the negatively charged soil surfaces associated with the CEC. Soils often contain less exchangeable Mg than Ca. It is a component of several minerals in the soil and is released into the soil during weathering processes.

Magnesium is usually present in sufficient quantities to satisfy plant requirements (see Table 8). An important measure, however, in your soil test is the calcium:magnesium ratio (see p. 35).

Potassium (K)

Potassium (K) is the only macro-nutrient that is also exchangeable (i.e. nitrogen and phosphorus are not), hence its inclusion in this section as well. It is important for regulating water and nutrient uptake, flowering and seed set and plant resistance to stresses.

K is one of the most abundant elements in soil. It is taken up by plant roots as a positively charged cation (K^+) from the soil solution. K ions are also found between clay layers within specific minerals, and this type of K is only released slowly into the soil solution.

Note: in your test results, you may find Exchangeable K as well as Colwell K. These are not the same. Exchangeable K is a measure of readily available K and Colwell K indicates readily available and potentially available K.

Sodium (Na)

Sodium (Na) is a component of some minerals in soil and a common

component of salts in soil (see also Salinity, Electrical Conductivity and Chloride, p. 37). As a cation, Na is adsorbed onto the negatively charged soil surfaces associated with the cation exchange capacity. It is not considered to be an essential nutrient for plants. However, if the proportion of the exchange sites occupied by Na is 6% or greater, the soil is considered to be sodic (adversely affecting soil structure). Also, if the amount of exchangeable Na is large, then less of the essential cations (such as Ca, K and Mg) are available.

To counteract high Na, gypsum (calcium sulphate) can be added to the soil. The aim is to replace some of the Na with calcium on the soil's exchange sites.

Hydrogen (H)

Hydrogen (H) is not a plant nutrient but a component of many minerals, oxides and clay minerals in the soil. The measure of exchangeable H^+ ions in the soil solution indicates your soil's pH (see also pH, p. 13), i.e. the more H^+ ions in the soil solution, the lower the pH and the more acidic your soil. In acid soils, H and aluminium ions make up a larger proportion of the exchangeable cations, reducing the proportion of essential nutrients held by the soil, e.g. calcium, magnesium and potassium. This can be especially significant in high rainfall environments (greater than 600 mm) due to the potential leaching of the basic cations (calcium, magnesium and potassium).

When reading your soil test, if the percentages of each exchangeable base cation are low and that of H is high, then you are likely to have an acidic soil.

Aluminium (Al)

Like hydrogen, aluminium (Al) is not a plant nutrient but is a major component of soils, particularly clay minerals.

In most cases, exchangeable Al is only measured if the soil's pH level is less than 4.8(CaCl₂) or 5.5(water). In some cases, Al levels are measured using



Nil aluminium

2 ppm aluminium

High aluminium levels in acidic soils limit root growth in sensitive pasture species, such as phalaris.

either the CaCl₂ (calcium chloride) or KCl (potassium chloride) methods, which are reported in milligrams per kilogram (mg/kg) or parts per million (ppm).

In acidic soils, Al is adsorbed (chemically bonded) onto the negatively charged soil surfaces associated with the soil's cation exchange capacity, taking up a greater proportion of the surfaces than the exchangeable cations considered as essential nutrients for plants (for example, calcium, magnesium and potassium). In acidic soils, the solubility of Al increases and, in excess, is *an important growth-limiting factor for plants*, and restricts access to water and nutrients. Plant species range in their tolerance of available Al in soils.

Al is often expressed in soil test results as a percentage of the soil's cation exchange capacity. If your test results indicate your soil is highly acidic, it is helpful to check the percentage of exchangeable Al: exchangeable Al should be the lowest of all cations and it is ideal that it remains less than 5% (see Table 8, p. 32). For Al levels measured using the CaCl₂ (calcium chloride) method, less than 2 mg/kg (or ppm) is ideal. For Al levels measured using the KCl (potassium chloride) method, less than 50 mg/kg (or ppm) is ideal.

Note: when applying lime (generally calcium carbonate), the carbonate reacts with the hydrogen ions in the soil and precipitates the available Al into an unavailable form, thus eliminating its toxicity.

Cation ratios

Cation ratios examine the relative proportions of cations as well as the percentage of the total cation exchange capacity that is attributed to that particular cation. There are a number of important ratios detailed below.

calcium:magnesium

Soil structural problems (such as dispersion) may occur in some soils if the ratio of calcium:magnesium is less than 2. Well-structured soils generally have a calcium:magnesium ratio greater than 2 (in other words, the amount of exchangeable calcium cations is more than two times greater than the amount of exchangeable magnesium cations). This ratio needs to be considered in combination with the exchangeable sodium percentage (ESP) (*see below*).

Exchangeable sodium percentage (ESP)

Exchangeable sodium percentage (ESP) is used to indicate if soils have sodic properties. Sodic soils are often dispersive with poor structural characteristics. These soils tend to have poor drainage and aeration and can be more vulnerable to erosion.

The exchangeable sodium percentage is calculated by dividing the exchangeable sodium amount by the sum of cations (or CEC) and multiplying it by 100.

An ESP of less than 6% is considered non-sodic; an ESP of 6–15% is considered sodic; and an ESP of greater than 15%

is considered strongly sodic (*see also Salinity*, p. 37).

Exchangeable aluminium percentage


Exchangeable aluminium should comprise the lowest percentage of the cations. The ideal amount is less than 5% for most pasture species, but less than 1% is required for more sensitive species, such as lucerne.

Exchangeable aluminium is used to ascertain the requirement for lime where aluminium-sensitive species, such as white clovers, lucerne and, to a lesser extent, subclovers, are involved. Elevated aluminium levels can be toxic to plants, but aluminium generally drops to harmless levels once the pH(CaCl₂) is greater than 4.8 or 5.5(water).

Management considerations

The application of gypsum (calcium sulphate) could be considered where pasture or crops are to be sown on soils with a calcium:magnesium ratio of less than 2 and/or an exchangeable sodium percentage of more than 6%. Gypsum provides a source of calcium and can promote improved soil structure of sodic (dispersive) soils.

If the topsoil exchangeable aluminium percentage is more than 5% and pH is below a pH of 4.8(CaCl₂) or 5.5(water), liming is often recommended, particularly if resowing a pasture. The amount of lime required will depend on the soil pH profile, lime quality, soil



type, farming system and rainfall. When making a decision to lime a paddock, consideration also needs to be given to other factors that may limit an economic return from liming, such as marginal areas and access issues.

Lime application on low pH soils adds calcium to the soil and corrects low pH and high aluminium issues. Care should be taken when selecting liming materials, however. Both agricultural lime (calcium carbonate) and dolomitic lime are good sources of calcium, but dolomitic lime also contains appreciable quantities of magnesium. Adding magnesium to soils already high in magnesium or with soil structure issues can exacerbate poor soil structure (so it is important to check your calcium:magnesium ratio). *Caution:* there is also a risk of inducing animal health risks and creating nutrient imbalances between the key nutrient cations of calcium, magnesium, and potassium, particularly in soils with a low cation exchange capacity. If

exchangeable magnesium is more than 20% of the cations present, it can result in a potassium deficiency in plants and animals. Conversely, a magnesium deficiency can be induced if the Ca:Mg ratio becomes too high or if the potassium level is high.

In pasture situations, sodic soils with a calcium:magnesium ratio of less than 2 and/or an ESP of 6% or more, it is critical to manage grazing to ensure the soil is covered, particularly on sloping country, as these soils are more vulnerable to erosion. As a general rule, maintenance of more than 70% ground cover is required to prevent soil losses by wind and water erosion. More ground cover is required on steeper country.

Rotational grazing that encourages pasture root growth and maximises pasture recovery time in between grazing events can help build and maintain soil organic matter levels to promote improved soil structure of dispersive soils.

FURTHER READING

www.depi.vic.gov.au/agriculture-and-food/farm-management/soil-and-water/soils/understanding-soil-tests-pastures

Glendinning, JS (ed.), 2000, *Australian Soil Fertility Manual* (rev. edn), Fertiliser Industry Federation of Australia Inc. & CSIRO Publishing, Melbourne

SALINITY, ELECTRICAL CONDUCTIVITY (EC) AND CHLORIDE

Increasing dryland salinity is one of the main natural resource management concerns facing the central parts of the Goulburn Broken Catchment and threatens important assets within the Catchment, such as water quality, productive land, urban infrastructure and biodiversity.

Soil salinity is a measure of the naturally occurring water-soluble salts in the soil solution. In sufficient quantities, these salts can adversely affect the growth of most plants. The subsequent poor growth often leads to an increased risk of soil erosion.

Sodium chloride (NaCl), common salt, is the most common salt in soils, but others can occur, including potassium, calcium and magnesium salts. The presence of salts in soils originates from the geology of the underlying rock type of the soil, wind-blown salts from sea spray, and historical inland sea levels over parts of Australia. Salts become more mobile in the soil due to changes in the regional and local groundwater levels. In the case of dryland salinity, this can happen with clearance of native forest vegetation for shallow-rooting agricultural plants. In the case of irrigation salinity, this can occur with inefficient irrigation practice (e.g. overwatering) or with the use of saline irrigation water.

Dryland soils develop salinity via interactions with groundwater. If groundwater rises to within 2 metres of the soil surface, water can rise by capillary action to the surface. In this process, salt is brought into the root

zone and when the water evaporates at the soil surface, concentrated salts are left behind.

Salinity negatively affects plant growth by making it more difficult for plants to extract water from the soil; some salts may be toxic to plants; and high levels of salt may also affect the availability of other ions (e.g. an excess of chloride reduces the uptake of nitrogen and an excess of potassium limits the uptake of calcium).

Overall, the impact of salinity is a reduction in plant growth. Germination/seedling emergence and early growth are the most sensitive stages. Mature plants may appear wilted and show leaf burn; leaves are often smaller and darker. The more tolerant species will dominate pasture; generally this means less clover and more salt-tolerant grasses, such as barley grass.

The point at which the growth of different plants is adversely affected varies. Some species are very sensitive to salt, while others, such as *Phalaris aquatica* and River Red Gum (*Eucalyptus camaldulensis*), are salt tolerant.

Most soil laboratories determine salinity by measuring the **electrical conductivity (EC)** of a mixture of 1 part soil to 5 parts distilled water. These are continuously mixed for one hour before testing the electrical conductivity. This test is known as the **EC 1:5** method and is measured in deciSiemens per metre (dS/m). Levels less than 0.50 dS/m are ideal.

Salinity versus sodicity

Salinity is commonly confused with sodicity, as both are associated with sodium.

In sodic soils, most of the chlorine (in the salt sodium chloride) has been leached away, leaving the sodium ions bonded to the soil's clay particles. This union is weak, and the clay particles lose their ability to stick together, readily dispersing when wet and preventing adequate drainage and water infiltration in soils. There is evidence to suggest that magnesium can also cause dispersion when the ratio of


calcium:magnesium is less than 2.

Dispersion is usually linked with the Sodosol soil type (see Appendix, p. 44). These are texture contrast soils that have an abrupt change in texture from the topsoil to the subsoil. The subsoil of Sodosols is classed as sodic. In short, a soil is classed as sodic when sodium occupies 6% or more of the cation exchange capacity (see *also* Cation Exchange Capacity, p. 10).

Soils that are classed as saline are usually sodic, but sodic soils are not always saline.



Dispersive sodic soil (causing erosion) near Faithfuls Creek, Euroa (source: Bruce Gill, Department Economic Development, Jobs, Transport and Resources)



Electrical conductivity is an indirect measure of the total soluble salt concentration in the soil solution, in which high electrical conductivities generally indicate high soluble-salt concentrations in the soil.

Determining the salt tolerance of plants is usually derived from a different method, the electrical conductivity of a saturated extract. This is called the **ECe** test and is also measured in deciSiemens per metre.

Salinity levels are satisfactory if the ECe is under 1.8 dS/m. At this level, the effects on pasture and crop species are negligible. If the ECe level is > 2 dS/m, however, some of the more sensitive species, such as lucerne, may be affected.

A soil is classed as saline when the ECe is 4 dS/m or more and many crop and pasture species are affected.

Chloride (Cl) is an essential nutrient for plants but is only required in small quantities (known as a micro-nutrient). It plays some important roles in plants, including in photosynthesis, osmotic adjustment and key plant enzymes.

Deficiency of Cl is not a common issue in Australia, but toxicity can be (and is often associated with salinity damage). Toxicity issues can result from accumulation of chloride in the leaves and this can reduce the overall crop and pasture yield on saline soils.

Cl occurs predominantly in the soil solution as a negatively charged ion (Cl⁻).

This means it does not readily adsorb (chemically bond) onto the surface of clays. Thus, Cl is very mobile in soil and largely follows the water flows through soil.

On most soil tests, chlorides are determined using the same extract for measuring the electrical conductivity (EC) – using a mixture of one part soil to five parts distilled water. The soil and water are continuously mixed for one hour before the chlorides are tested. This test is called the 1:5 soil:water method, and the unit of measure is milligrams per kilogram of soil (mg/kg).


Critical levels are:

- 120mg/kg for sands to sandy loam,
- 180mg/kg for loam to clay loam,
- 300mg/kg clays.

Above these figures, salinity damage may occur, depending on soil drainage and plant tolerance.

Management considerations

Highly saline soils can also be highly sodic (dispersive). They may not always disperse, however, due to the high amounts of soluble salts. Recognising and acting on salinity problems early is the best solution, as soil salinity can be a difficult and expensive issue to correct when well advanced. Keep an eye out for initial changes in pasture composition; critical signs include bare patches with visible salt crystals on the soil surface



and the presence of salinity indicator plants (such as Spiny Rush).

Salinity-affected areas can be managed by excluding grazing and sowing saline-tolerant perennial pasture species, such as phalaris, cocksfoot, rye and tall fescue (their deep roots help maximize

plant water use to assist in reducing ground water recharge). Tree planting on rises and the break of slope areas are also a key strategy for landholders. Consider seeking specific advice, as some strategies can be more effective in certain landscapes than others.

FURTHER READING

Animation on soil dispersion: http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_dispersion-animation

Salinity indicator plants: Hazelton, P & Murphy, B 2007, *Interpreting Soil Test Results: What do all the Numbers Mean?*, CSIRO Publishing, Melbourne

www.environment.nsw.gov.au/salinity/solutions/dryland

Glendinning, JS (ed.), 2000, *Australian Soil Fertility Manual* (rev. edn), Fertiliser Industry Federation of Australia Inc. & CSIRO Publishing, Melbourne

TRACE ELEMENTS (MICRO-NUTRIENTS)

Of the 16 essential plant nutrients, eight are trace elements (or micro-nutrients). They are so called because plants require them in only small amounts, but they are equally as important to the plant as the macro-elements (such as nitrogen, phosphorus and potassium). It is still possible, however, to have toxicities and deficiencies of trace elements that affect the growth and yield of pasture. These are generally influenced by soil pH conditions and specific soil types (soils vary in their concentrations of trace elements and, with the exception of iron and manganese, usually have lower concentrations than of the major and secondary nutrients). In addition, some of the trace element deficiencies in pastures can cause nutrient deficiencies in the stock that graze them.

The trace elements exist as cations and some as anions (see Introduction, Table 1, p. 6) and include molybdenum, manganese, iron, copper, zinc, boron, chloride, sodium, and cobalt. Selenium, while not essential for plant growth, is important for animal health and can result in such conditions as ill thrift and infertility in certain stock (it can be monitored using blood tests – confer with your local vet).

While soil tests are a valuable tool for identifying the macro-nutrient status of paddocks on the farm, research has shown that, especially on acid soils, using them to indicate micro-nutrient levels can be inaccurate and is, therefore, not generally recommended. *Plant tissue testing is the preferred method for*

Table 9 *The concentration of trace elements in the soil and the pH ranges for optimal availability*

Trace element	Symbol	Total content (ppm)	Optimum pH range
Boron	B	10–630	5.0–7.0
Cobalt	Co	1–40	5.0–5.5
Copper	Cu	1–960	5.0–6.5
Chloride	Cl	5–800	not affected
Iron	Fe	3000–100 000	4.0–6.0
Manganese	Mn	30–5000	5.0–6.5
Molybdenum	Mo	0.1–18	6.0–8.5
Zinc	Zn	2–1600	5.0–6.5

(Source: Glendinning, JS [ed.], p. 60)

diagnosing micro-nutrient toxicities and deficiencies in plants.

In addition, the difference between adequate soil levels and toxic levels of trace elements can be quite small, so interpretation of soil test results and prediction of requirements is difficult. In many cases, it is easier to address any concerns for animal health issues directly with nutrient licks and injections.

Trace element levels can change with soil depth, particularly if the pH of the soil changes with depth. For example, toxic boron levels often occur in subsoils, and this needs to be taken into account when interpreting boron results for the top 10 cm of soil.

There is little evidence of manganese deficiency occurring in pastures in Victoria, particularly in the acid soils of the Goulburn Broken Catchment. Manganese toxicity can occur in acid soils, usually in combination with waterlogging conditions.

Specific local advice should be sought for interpretation of soil test and plant tissue test results and decisions on micro-nutrient fertiliser applications.

Management considerations

Care needs to be taken if deciding to correct a micro-nutrient issue with fertiliser application, as correcting one can sometimes induce an imbalance in others. For example, iron deficiency can be induced by excess molybdenum, copper, and manganese levels in soils.

Molybdenum is generally the micro-nutrient of most concern for the Goulburn Broken Catchment, and is more likely to be deficient in acid soils. This is because the availability of molybdenum to plants is influenced by pH. The lower the pH, the lower the availability of molybdenum. In pastures, clovers are generally more sensitive to molybdenum deficiency. Liming to bring your pH above 4.8 (CaCl₂) or 5.5(water) usually fixes molybdenum deficiency in the long term, or molybdenum can be added to fertiliser, such as superphosphate, if liming is not an option (i.e. if uneconomical or in marginal country). The potential need for molybdenum should be discussed with your advisor and the frequency of application will depend on pasture species, rainfall and soil type.

FURTHER READING

Glendinning, JS (ed.), 2000, *Australian Soil Fertility Manual* (rev. edn), Fertiliser Industry Federation of Australia Inc. & CSIRO Publishing, Melbourne

Common soil types of the Goulburn Broken Catchment

Below are some of the more common soil types found throughout the dryland pasture zones of the Goulburn Broken Catchment. Others (such as Ferrosols and Dermosols) are found in localised areas in the Catchment. These soils are classified using the Australian Soil Classification System, which works in a similar fashion to plant or animal classification systems, using identification 'keys' and names with Latin or Greek roots.

The properties of the subsoil (B horizon) are a major determinant in the classification system. As you will see below, Kurosols, Chromosols and Sodosols all have a strong texture contrast between the surface horizon (topsoil) and the subsoil but are *classified differently because of key differences in characteristics in the upper part of the subsoil*.

Kurosols are soils that display a strong texture contrast between lighter loamy surface (A) horizons and clay subsoil (B) horizons. The subsoil is strongly acidic.

Kurosols occur predominantly in the higher elevations or uplands, where rainfall is higher and consequently the leaching of certain nutrients is greater. In the Goulburn Broken region, Red Kurosols occur in the uplands (such as in the Strathbogie Ranges and south-

east of Alexandra). Yellow and Brown Kurosols occur mainly in the granite areas to the south of Euroa and to the east of Seymour. There are also minor occurrences north of Seymour.

These acidic subsoils can have significant implications for management, affecting soil nutrient availability, nutrient leaching, crop and pasture establishment, and plant root growth.

Chromosols (like Kurosols) also display a strong texture contrast between surface



Kurosol profile

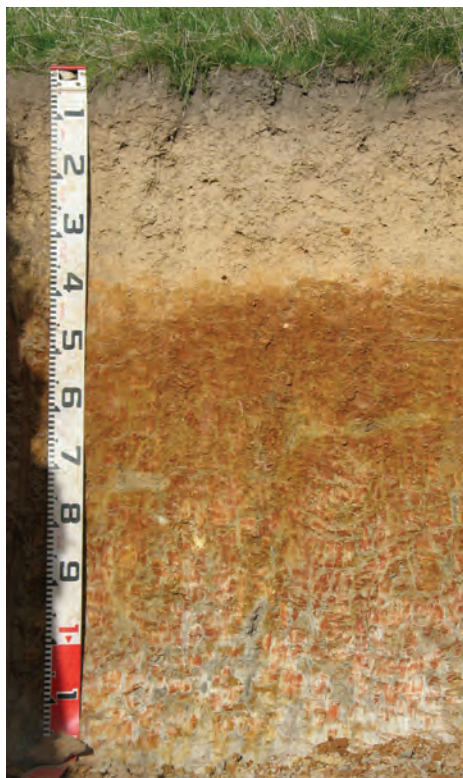
(A) horizons and subsoil (B) horizons. The subsoil is often strongly coloured, most commonly red or brown, and is not sodic (like Sodosols) or strongly acidic (like Kurosols).

Chromosols can be found on the alluvial Riverine Plains and the uplands. The dominant occurrences of this soil type are north, east and west (sporadic occurrences only) of Benalla, east of Seymour and around the Mansfield area.

The surface soil textures of these soils tend to be lighter loamy textures

and the depth of the topsoil can vary considerably. This can have significant implications for management, affecting soil workability, permeability, crop establishment, moisture availability and erodibility. The subsoil tends to be clay-textured and is often mottled in colour, indicating some restricted drainage. However, generally Chromosols are better drained than Sodosols.

Sodosols are widespread in the Goulburn Broken region. They are generally found on the extensive



Chromosol profile



Sodosol profile

Riverine Plains north of the uplands (and the Hume Highway) and the low hills and rises east of Heathcote. Sodosols have a strong texture contrast between surface (A) horizons and subsoil (B) horizons, and the subsoil horizons are classed as sodic (where high sodium levels are detrimental to the soil structure). This means the subsoils have exchangeable sodium percentages of more than 6% (see Salinity, p. 37). These soils are prone to disperse when wet and generally set hard when dry.

The dense and poorly structured Sodosols can have significant implications for management, affecting soil workability, permeability, crop establishment, moisture availability and erodibility. Root growth and water movement through the profile are commonly restricted. Sodosols can be associated with salinity and are prone to erosion and seeps. They can also contain varying amounts of buckshot gravel (ironstone nodules).

Kandosols are non-textured contrast soils (with little or only a gradual increase in clay content with depth) that have massive (i.e. weakly to non-structured) subsoils (B) horizons. These soils can vary from stony, hard-setting soils to deeper, friable soils. Some may have a bleached or very pale subsurface (A2) horizon.

Kandosols are located in the upland areas, particularly close to the Dividing Range, as well as the western Strathbogie Ranges and the Yea to Broadford area

(where they are associated with Yellow Chromosols).

The poorly structured Kandosols can have significant implications for management, affecting soil fertility, moisture availability, erodibility and crop establishment.



Kandosol profile (source: all profile images courtesy Mark Imhof, Agricultural Research, Department of Economic Development, Jobs, Transport and Resources)

GLOSSARY

Adsorption The attraction and bonding (chemically) of a substance onto the surface of minerals, clay minerals or organic matter. In contrast, absorption is a process in which the substance is actually taken up into the structure of the mineral or clay mineral.

Aerobic Oxygen is present. This is particularly important for many biological processes that involve organisms that require oxygen, such as nitrogen fixation. Good soil structure will promote aerobic conditions by increasing the size, volume and stability of soil pores.

Anaerobic Very little or no oxygen is present. This is often the case in poorly structured and/or waterlogged soils. Anaerobic conditions can promote biological processes that produce undesirable products, such as methane and nitrous oxide.

Available That portion of the total amount of a nutrient in the soil solution that is available for plant uptake.

Available soil water That part of the soil water that can be absorbed by plant roots. This includes water held in pores between soil aggregates and within soil aggregates.

Buffering capacity The ability of the soil to resist changes in pH. Soils with higher clay levels and higher cation exchange capacity (CEC) will be able to

buffer or resist a change in the pH. In contrast, if lime is applied to a sandy soil with a low CEC, the acidic cations (aluminium and hydrogen) are removed from the soil solution (via the chemical reaction when the lime is applied). This soil has very little capacity to replenish the soil solution from the acidic cations on the CEC. Hence, there is a change to the soil pH with only a small amount of lime applied.


Cation A positively charged ion. Common soil cations include calcium (Ca^{2+}), sodium (Na^+), potassium (K^+) and magnesium (Mg^{2+}).

Chemical reaction A reaction involving changes to atoms or molecules

Chemically reactive A tendency to react with other substances

Dispersion A process that results in soil aggregates breaking down in water and in which the clay particles move apart from each other, 'dispersing' into the soil water and creating cloudy water. The water is cloudy because it contains these very small clay particles in suspension. This can then clog up the small holes (pores) in soil, causing waterlogging and erosion. When the soil dries, it will tend to set hard.

The susceptibility of a soil to dispersion is related to the relative proportions of cations on the clay surface, particularly the proportions of sodium, magnesium



and calcium ions. If a soil has sodium occupying more than 6% of the cation exchange capacity, the soil will have a tendency to disperse when wet. There is evidence to suggest that magnesium can also cause dispersion when the ratio of calcium to magnesium is less than 2.

Exchangeable cations Cations (positive ions) are attracted to the negative surfaces of the clay and organic matter particles in soils. Cations held on these negative surfaces can be replaced by other cations in the soil solution; this is why they are known as 'exchangeable'.

Extractable An agronomic soil test uses chemical extractants to chemically release a *portion* of the total amount of a nutrient in the soil. This then allows a soil laboratory to measure the amount of nutrient in the soil sample. It is used to *estimate* the amount of nutrient that is available to plants, i.e. it may over- or underestimate the amount of nutrient available.

Fixed ions Ions that are part of the crystalline structure of minerals or clay minerals. In this form, they are generally insoluble and resistant to mineralisation by micro-organisms and weathering processes. They may remain in the soil for many years unavailable to plants.

Friable When a soil breaks easily into crumbly peds and aggregates

Gypsum (calcium sulphate) Normally used as a soil ameliorant to improve soil

structure and reduce crusting in hard-setting, clayey soils. The applied calcium increases soil aggregation, which results in improved water infiltration, seed germination and root growth. Typical rates used are around 2 t/ha and up to 5 t/ha, with heavier rates being required on highly sodic soils.


Ion A charged particle

Leaching A process that results in the loss in the soil solution of the more soluble minerals, nutrients and salts by the downward movement of water into the soil profile.

Lime A naturally occurring, calcareous material used to raise the pH of acid soils and/or supply nutrient calcium for plant growth. The term normally refers to ground limestone (CaCO_3), but may also include processed forms such as hydrated lime ($\text{Ca}(\text{OH})_2$) or burnt lime (CaO). Dolomitic lime (MgCO_3) also contains appreciable quantities of magnesium.

Loam A medium-textured soil of approximate composition 10–25% clay, 25–50% silt, and less than 50% sand.

Mineralisation A biological process in which organic compounds in organic matter are decomposed by soil organisms to release nutrients in plant-available forms. Bacteria and fungi are primarily responsible for most of the mineralisation of organic matter in soils.



Nitrogen fixation The capture of free nitrogen in the air by soil organisms to produce nitrogen compounds that eventually become available to plants.

Organic carbon Derived from living plants or animals and containing carbon

Parent rocks (material) The geological material from which the soil profile develops

Peds Individual natural soil aggregates

Sodic soil A soil is considered sodic if the proportion of the exchange sites

occupied by sodium is greater than 6%. This is sufficient exchangeable sodium to adversely affect soil structural stability, plant growth and/or land use. The soil will tend to disperse.

Soil solution The critical pool of soil water from which plant roots can take up nutrients

Waterlogged The condition of a soil that is saturated with water and which has replaced most or all of the soil air in soil pores with water

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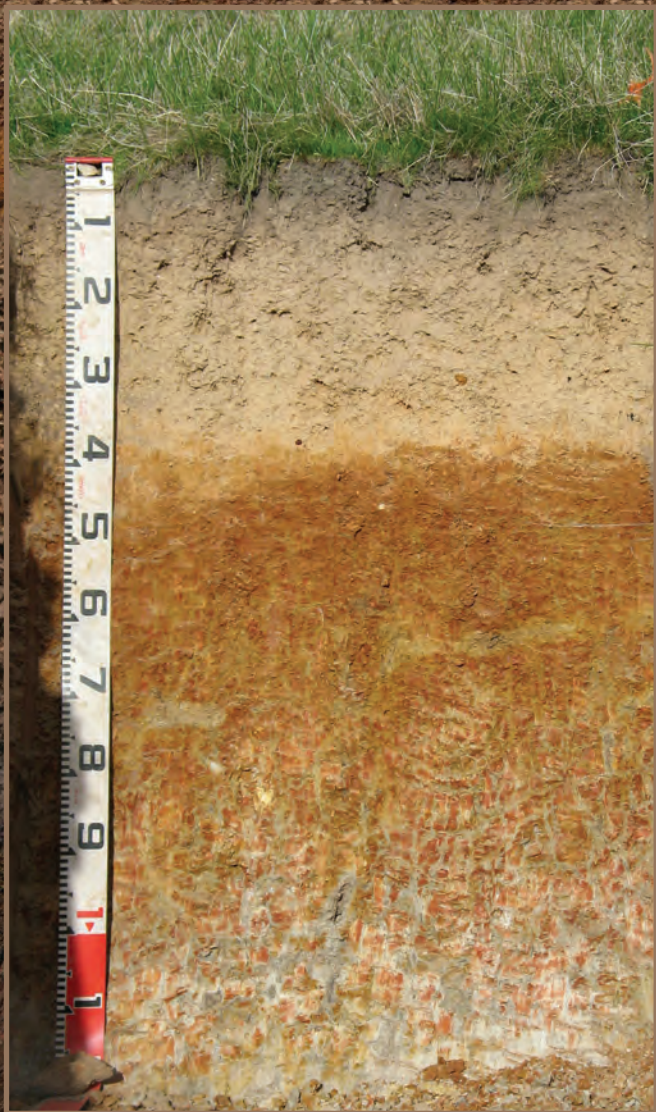
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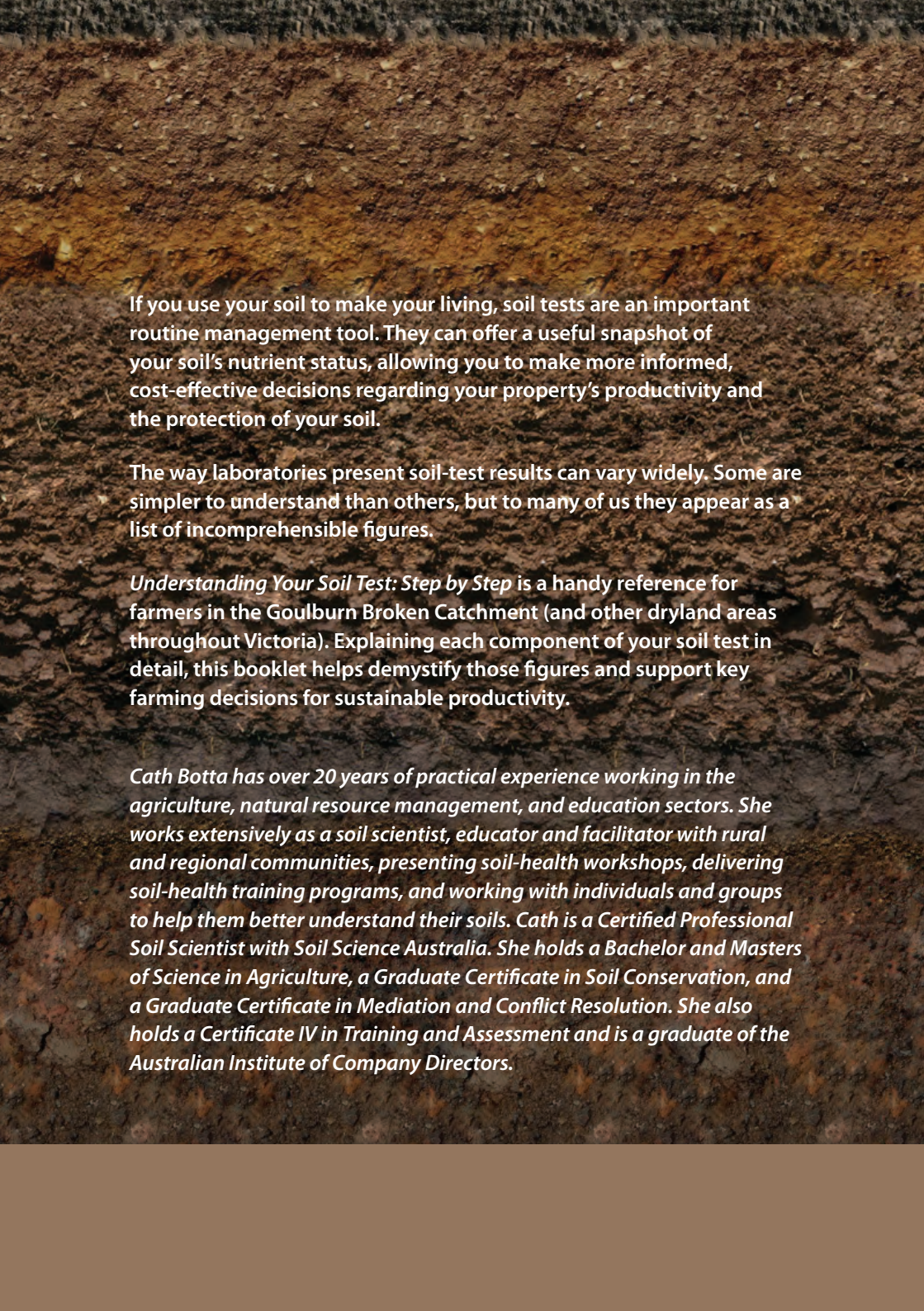
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If you use your soil to make your living, soil tests are an important routine management tool. They can offer a useful snapshot of your soil's nutrient status, allowing you to make more informed, cost-effective decisions regarding your property's productivity and the protection of your soil.

The way laboratories present soil-test results can vary widely. Some are simpler to understand than others, but to many of us they appear as a list of incomprehensible figures.

Understanding Your Soil Test: Step by Step is a handy reference for farmers in the Goulburn Broken Catchment (and other dryland areas throughout Victoria). Explaining each component of your soil test in detail, this booklet helps demystify those figures and support key farming decisions for sustainable productivity.

Cath Botta has over 20 years of practical experience working in the agriculture, natural resource management, and education sectors. She works extensively as a soil scientist, educator and facilitator with rural and regional communities, presenting soil-health workshops, delivering soil-health training programs, and working with individuals and groups to help them better understand their soils. Cath is a Certified Professional Soil Scientist with Soil Science Australia. She holds a Bachelor and Masters of Science in Agriculture, a Graduate Certificate in Soil Conservation, and a Graduate Certificate in Mediation and Conflict Resolution. She also holds a Certificate IV in Training and Assessment and is a graduate of the Australian Institute of Company Directors.