Chapter 9
Interpreting Soil and Tissue Tests

CONTENTS

9 Interpreting soil and tissue tests

9.1 Introduction

The interpretation of results from soil and plant tissue tests help farmers and service providers to make more informed, cost-effective fertiliser decisions. Many field experiments have been used to verify soil and plant testing laboratory results.

Soil tests are a valuable tool for identifying the macronutrient status of paddocks on the farm. They also provide information for soil amendments to address such issues as sodicity and acidity. Although providing very important information, soil and plant tissue tests are only one piece of the jigsaw to determine the final fertiliser recommendations.

Plant tissue tests are the preferred method for diagnosing the level of micronutrient (trace element) toxicities, deficiencies and nutrient imbalances for plants. Occasionally plants can exhibit a nutrient deficiency which is not detected by a soil analysis. Research has also shown that using soil tests to indicate trace-element deficiencies can be very inaccurate; especially on acid soils.

Soil biological properties are also important to plant growth. A description of the biological properties of soils and how to measure these is discussed in Chapter 5.

Learning outcomes
This chapter will provide information about soil and plant tissue testing, allowing the reader to accurately interpret soil tests and to use the results to assist in making fertiliser decisions.

9.2 Interpreting soil tests

9.2.1 Soil chemical analyses

Many field experiments have been carried out in Australia to calibrate the results of laboratory soil testing with yield responses for specific crops and pastures grown on similar soil types.

A standard soil test report provides information on the following:

- Soil texture
- Organic carbon
- Soil pH
- Available phosphorus (P)
- Phosphorus buffering index (PBI)
- Available potassium (K)
- Available sulphur (S)
- Nitrogen (N)
- Cation exchange capacity (CEC)
- Exchangeable cations (Ca, Mg, K, Na and Al)
- Calcium/Magnesium Ratio
- Sodium level (Na% or Exchangeable Sodium Percent - ESP)
- Aluminium level (Al% or Al_{ex})
- Soil salinity (Electrical Conductivity - EC)
- Comments on the test results
- Recommendations for fertiliser application (if requested)

Refer to the example soil test, recommendations, and comments in Figures 9.1a to 9.1c.

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Nutrient Advantage Advice® Recommendation Report

Report Print Date: 10/04/2013
Agent/Dealer:
Advisor/Contact:
Phone:
Purchase Order No:

Grower Name:
Sample No:
Paddock Name:
Sample Name:
Sample Depth (cm) 0 **To** 10

Nearest Town:
Test Code: A31
Sample Type: Soil
Sampling Date:

Analyte / Assay	Unit	Value	Very Low / Marginal / Optimum / High / Excess	Optimal
pH (1:5 Water)		5.60	Moderately Acidic	5.8 - 7.0
pH (1:5 CaCl2)		5.10		
Electrical Conductivity	dS/m	0.24	No salinity issues	0.2 - 0.4
Chloride	mg/kg	150.00		< 300
Organic Carbon (OC)	%	4.60		2.3 - 5.3
Nitrate Nitrogen (NO3)	mg/kg	45.00	No standards for pastures	
Phosphorus (Olsen)	mg/kg	22.10		20 - 30
Phosphorus (Colwell)	mg/kg	91.00		
Phosphorus Buffer Index (PBI-Col)		190.00	Moderate	
Sulphate Sulphur (KCl40)	mg/kg	15.00		> 13
Cation Exchange Capacity	cmol(+)/kg	12.70	Low risk of nutrient leaching	
Calcium (Amm-acet.)	cmol(+)/kg	8.50		> 5.0
Calcium (Amm-acet.)	%	67.00	Good for soil structure	60 - 85 %
Magnesium (Amm-acet.)	cmol(+)/kg	2.80		> 1.8
Magnesium (Amm-acet.)	%	22.00	Minimal impact on structure	6 - 25 %
Sodium (Amm-acet.)	cmol(+)/kg	0.48		0.1 - 0.6
Sodium % of Cations (ESP)	%	3.80	No sodicity issues	< 6 %
Potassium (Amm-acet.)	cmol(+)/kg	0.80	Satisfactory for pastures	> 0.5
Potassium (Amm-acet.)	%	6.30		3 - 8 %
Available Potassium	mg/kg	310.00		180 - 250
Aluminium Saturation	%	0.79	Harmless to pasture growth	< 5 %
Aluminium (KCl)	mg/kg	<9.00		< 50
Aluminium (KCl)	cmol(+)/kg	0.10		< 0.6
Calcium/Magnesium Ratio		3.00	No soil structure issues	2.0 - 10.0

Analyses conducted by **Nutrient Advantage Laboratory Services**

ASPAC

NATA Accreditation No: 11958
Certificate of Analysis is available upon request.

8 South Road, Werribee VIC 3030
Tel: 1800 803 453
Email: lab.feedback@incitecpivot.com.au

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Figure 9.1a Example soil test report

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Nutrient Advantage®

Nutrient Advantage Advice® Recommendation Report

Grower Name:		**Nearest Town:**	
Sample No:		**Test Code:**	A31
Paddock Name:		**Sample Type:**	Soil
Sample Name:		**Sampling Date:**	
Sample Depth (cm)	0 **To** 10		

Sample Details:

Enterprise (Crop):	DAIRY DRYLD	**Activity (enterprise):**	Dairy
Pasture:	Existing	**Lucerne:**	
Proposed Sowing Method:		**Time of Sowing:**	
Dairy Stocking Rate (cows/ha):	1.70	**Beef/sheep Stocking Rate (dse/ha):**	
Other Stock Type:		**Other Stocking Rate (dse/ha):**	
Cuts per year:		**Yield per Cut (t/ha) :**	
Seed Production Type:		**Fodder Crop Type:**	
Sample Depth (cm) From:	0	**To:**	10

Recommendations

Product Recommendation	**Application Rate (kg/ha) (Unless Stated)**	**Timing**	**Application Method**	**N kg/ha**	**P kg/ha**	**K kg/ha**	**S kg/ha**
Pasture Extra	200.00	Autumn before the break	Spread but not within 6 days of forecast heavy rain	0.0	25.0	0.0	24.7
GREEN UREA 14	100.00	Early Winter dependant on feed availability	Spread when soil moisture adequate	46.0	0.0	0.0	0.0
GrassBoosta	125.00	Late Winter dependant on feed availability	Spread when soil moisture adequate	37.3	0.0	0.0	18.8
Total Nutrient Applied				**83.3**	**25.0**	**0.0**	**43.5**

This Recommendation has been done by:

Other Elements in recommendation	Ca kg/ha	Mg kg/ha	Cu kg/ha	Zn kg/ha	Mo gm/ha	Co gm/ha	B kg/ha	Fe kg/ha	Mn kg/ha	Si kg/ha
Pasture Extra	31.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GREEN UREA 14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GrassBoosta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Nutrient Applied	31.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Legend:
N : Nitrogen; P : Phosphorus; K : Potassium; S : Sulphur; Ca : Calcium
Mg : Magnesium; Cu : Copper; Zn : Zinc; Mo : Molybdenum; Co : Cobalt
B : Boron; Fe : Iron; Mn : Manganese; Si : Silicon

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Figure 9.1b Recommendations based on example soil test report

Nutrient Advantage®

Nutrient Advantage Advice® Recommendation Report

Grower Name:		**Nearest Town:**	
Sample No:		**Test Code:**	A31
Paddock Name:		**Sample Type:**	Soil
Sample Name:		**Sampling Date:**	
Sample Depth (cm)	0 **To** 10		

Comments

Best practice fertiliser application to pastures can minimise nutrient loss and reduce any impact on the environment. Current best practices for phosphorus fertiliser application are:

- Avoid applying fertiliser when ground cover is less than 70%, or land is overgrazed or affected by drought/fire.
- Prevent fertiliser entering waterways and water storages during application.
- Do not apply fertiliser if heavy rain is forecast within four days.
- Avoid applying fertiliser to waterlogged soils or soils likely to flood soon after application.
- Locate fertiliser storage areas away from potential run-off areas.

Guideline Consideration for Nitrogen Use on Pastures

1. Grazing Management (mature pasture) is critical in maintaining a good grass density - graze to a minimum of 1200kgDM/ha (or 5cm in height) - over grazing will cause ryegrass decline, lax grazing will cause shading, tiller death, lower feed quality and density decline. The optimal time for nitrogen application is immediately following a grazing. Ryegrass should be grazed at 2.5-3 leaf stage (spring graze at 2.5 leaf stage) which corresponds with optimal white clover grazing. Phalaris grazing is set at 4-5 leaf stage.
Following a nitrogen application stock should be excluded from the paddock for a 3 week period to avoid nitrate poisoning.
2. Pasture Composition plays a part in determining nitrogen responses - generally pastures with a high composition of improved grasses ie.ryegrass and low to moderate composition of clover (up to 30%) will provide the better pasture response, as will pastures with minimal weeds, disease and insect pest activity.
3. Paddock fertility is very important in supporting a healthy pasture - ensure major nutrients, trace elements and soil ameliorates are addressed to improve dry matter responses to nitrogen applications.
4. Moisture is probably the major limiting factor to nitrogen responses - ensure the soil has adequate soil moisture to sustain production and following a broadcast nitrogen application at least 5mm (light soil) or 10mm (heavy soil) rainfall event or irrigation follows within 2 days of application. Green Urea can be consider if volatilisation is considered to be an issue.
5. Application Rates should be in a range of 30-50kgN/ha.
6. Time of year (season) causes variation in responses to nitrogen. Responses to perennial ryegrass can be as low as 5 kgDM/ha/kgN in the winter and up to 25 kgDM/ha/kgN in the spring. Italian type ryegrasses tend to be more responsive to nitrogen than perennials. Forward thinking in predicting future gaps will allow nitrogen applications to be used to maximum efficiency ie. Aug 15 calving herd should have nitrogen applied on 1st July assuming leaf emergence every 15 days.
Don't apply nitrogen if soil temperatures are below 5oC as ryegrass has stopped growing.
7. Cost of Dry Matter is the key consideration in determining whether nitrogen should be applied or not. Estimates on expected dry matter responses and ultilisation coupled with the cost of nitrogen will provide a dry matter cost, this can then be compared to other feed alternative to see the value (or not) in using nitrogen. These costs will vary during the year with winter feed the most expensive.
8. Environment can be negatively impacted by poor nitrogen management. Don't apply close to waterways, or to paddocks that are waterlogged and grasses are not growing.
9. Utilisation - If the additional pasture Dry Matter grown as a result of applying Nitrogen can not be utilised, do not apply Nitrogen.
Follow the points listed above for best practice in nitrogen management.

The Phosphorus Buffering Index (PBI) measures the soils capacity to hold phosphorus (P), and how tightly the phosphorus is held by the soil. PBI values can range from a very low value of less than 35 to an extremely high value of greater than 840. The PBI result determined for your soil will impact on the availability of phosphorus. It may also indicate whether your soil is prone to the leaching of phosphorus or the phosphorus being tied up in forms unavailable to the plant. The PBI values will also influence how much phosphorus you will need to apply to build up soil reserves of P.

While potassium levels are adequate for grazing, consider including with nitrogen if hay or silage is to be cut in the spring.

Molybdenum (Mo): Not Tested - Mo is important in the fixation of nitrogen by rhizobium bacteria. Where soil pH(w) < 6.0, Mo may be applied to the soil at 50 to 60 g/ha Mo once every 5 - 8 years. Molybdenum (Mo) and copper (Cu) should be applied with top dressing fertiliser. Use plant tissue test is best used to determine the need for the Cu & Mo.

Liming could be considered for soils with this pH range, however applying lime would be best left until pastures are renovated so it can be incorporated with cultivation. Avoid the application of lime and molybdenum on the same paddock in the same year. Lime, by increasing the soil pH, can increase the availability of molybdenum which may pose a risk to stock health.

Discuss the results of these tests with your Area Sales Manager or agent. Where NPK blends are being used to boost winter or spring production, adjustment to these recommendations will be necessary.

Disclaimer: Laboratory analyses and fertiliser recommendations are made in good faith, based on the best technical information available as at the date of this report. Incitec Pivot Limited, its officers, employees, consultants, Agents and Dealers do not accept any liability whatsoever arising from or in connection with the analytical results, interpretations and recommendations provided, and the client takes the analytical results, interpretations and recommendations on these terms. In respect of liability which cannot be excluded by law, Incitec Pivot's liability is restricted to the re-supply of the laboratory analysis or the cost of having the analysis re-supplied.

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Figure 9.1c Comments based on example soil test report

Other soil analyses which are available from a range of laboratories are as follows:

- Soil physical properties (including colour, texture, slaking and dispersion)
- Boron (HWS) e.g. mg/kg
- Buffer pH
- Carbonate
- Chloride (Cl)
- Exchangeable cations with soluble salt wash (Ca, K, Mg, Na)
- Gypsum
- Total Soil Nitrogen (includes all sources of soil N, including organic matter)
- Total Phosphorus (includes all sources of soil P, including organic matter)
- Potassium (K) Skene, Nitric K
- Silicon (BSES, $CaCl_2$)
- Sulphur (S) (MCP, CPC)
- Total Soluble Salts
- Trace elements DTPA (Copper (Cu), Iron (Fe), Manganese (Mn), Zinc (Zn), Zn (HCl)

Soil test results for nutrients are usually expressed as mg/kg (milligrams per kilogram). Cation Exchange Capacity (CEC) is now reported as cmol (+)/kg (centimoles per kilogram) and also reported on a percentage (%) basis.

9.2.2 Soil Physical Properties

Standard soil physical properties measured include:

- Soil colour
- Soil texture

Soil colour and texture are taken into account when interpreting some of the other soil chemical analyses and preparing fertiliser recommendations. Other soil physical tests are available to gauge soil structural stability and to diagnose specific problems related to soil management. They are also used to assess a soil's ability to handle a management activity such as mole drainage, cultivation, compaction and irrigation. These tests include:

- Slaking
- Dispersion

9.2.2.1 Soil Colour

Soil colour has little direct influence on its chemical, physical or biological attributes but, when considered with other observations, can be very useful. Often soils of darker colour are higher in organic matter than lighter coloured soils. Red colour can be related to *un-hydrated* iron oxides present in well drained soils, whereas yellow or mottled coloured soils may be related to *hydrated* iron oxides which may occur where soils are saturated for long periods and/or poorly drained. The Munsell Soil Colour Charts are internationally accepted as being the standard guide to discern soil colour classification - See Victorian Resources Online.

9.2.2.2 Soil texture description

The texture of a soil is an indication of soil type and its properties, and is always taken into account when interpreting the other results and preparing fertiliser recommendations - See Chapter 4 for more on soil properties. Soil texture is measured separately for Mineral Soils and for Organic Soils (e.g. Peat).

Soil texture shows how we should apply mobile nutrients, such as K, N and to a lesser extent, S. For example, soils with a light texture and low CEC are more susceptible to leaching and should be managed by applying smaller quantities of nutrients more frequently.

Soil texture can be measured in two ways:

a) **Field method:** Where a small handful of moistened soil is squeezed between the thumb and forefinger to produce a ribbon. The length of the ribbon before breaking and the "feel" of the soil (sandy, silky, etc.) provide an indication of the texture - See Chapter 4.2.1. Table 9.1 describes aspects of soils which can influence soil texture interpretation. To improve consistency of results this test is usually done by experienced laboratory technicians, however the method remains subjective and the results may differ slightly between assessors. Slight variations are of no real concern to the final fertiliser recommendations.

b) **Mechanical method:** A mechanical sieving process is used to separate and quantify the percentages of sand, silt and clay in a soil. This method is more time consuming and expensive than the field method, however it is used where greater accuracy is required (e.g. research) - See Chapter 4.2.1 for more information on soil texture assessment and classification.

Table 9.1 Aspects of soils which can influence soil texture interpretation

PARAMETER	INFLUENCE ON SOIL TEXTURE INTERPRETATION
Clay Type	Clay mineralogy affects tractability. Montmorillonite is very fine and encourages ribboning when using hands to form ribbons. Kaolinite is very coarse and will inhibit ribboning
Organic matter	Cohesion of sandy textures and greasiness of clays
Oxides	Cementation (Al & Fe) masks fine textures
Carbonates	Cohesion in sands and loams, but inhibits ribboning in clays

9.2.2.3 Aggregate Slaking Test

Slaking refers to the rapid physical breakdown of the larger soil aggregates (2 – 5 mm diameter) into smaller definable soil particles (many <0.25 mm) in rainfall or distilled water (Emerson, 1967, 1991 and McGuinness, 1991). In an irrigated system, it is instructive to use the irrigation water for the Emerson dispersion test in case it has an effect on aggregate stability. See the slaking animation on the Victorian Resources Online website.

For a laboratory physical soil test, soil is air dried overnight then several aggregates, if not pulverised during transport, are placed in distilled water. The degree of slaking after two hours is recorded and categorised as either; Considerable, Partial or Water Stable.

The interpretation of structural stability depends on the degree of slaking assessed and organic matter content. In Victorian and South Australian soils, a qualitative rating system is used for the interpretation of soil slaking potential (See Table 9.2).

Table 9.2 Organic carbon and soil aggregate stability

Organic carbon rating	Low	Normal	High
Soil Aggregate Stability	Considerable slaking	Partial slaking	Water stable
Management Action	Increase organic matter	Maintain organic matter	Maintain organic matter

Source: Adapted from Emerson 1967, and Lovejoy and Pyle, (1973).

9.2.2.4 Clay dispersion test

Soil dispersion is a further breakdown of fine aggregates and clay associations. Dispersion is a measure of the potential of natural or remoulded soil aggregates to break down, followed by the small particles spreading out in distilled water (Cass et al 1996a).

The potential for dispersion of both natural and remoulded aggregates is assessed in most labs. The '*natural* soil aggregate dispersion test' provides an estimate of the current potential of soils in their present field condition. The '*remoulded* soil aggregate dispersion test' provides an assessment of the dispersion potential of soils if they are incorrectly managed, for example: soil compaction, continuous cropping, mole draining with unsuitable subsoils – See Chapter 7.2.2.

Natural aggregates of soil are air dried overnight before 3 to 5 aggregates are placed into distilled water. Other soil is dried and ground then remoulded by hand into balls of 4 – 5 mm and placed in distilled water.

The degree of dispersion/cloudiness is recorded after 2 hours and 20 hours for both natural and remoulded soil aggregates – see Figure 9.2. Also at the same 2 hour examination time, the degree of slaking, if it occurs, is also evaluated on the natural aggregates as above.

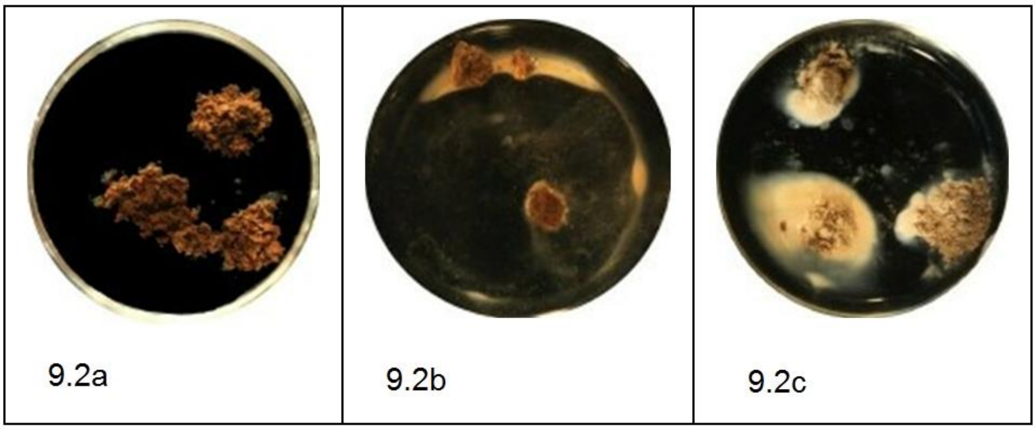

Figure 9.2 The photographs above show the results of soils placed in dishes of distilled water after a period of time. Figure 9.2a shows small clods of soil which have slaked only, Figure 9.2b shows dispersion only, and Figure 9.2c shows both slaking and dispersion (Retrieved: http://vro.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil_mgmt_slaking, Images by Stuart Boucher).

The degree of soil dispersion is evaluated and rated as shown in Table 9.3. These ratings are added to provide the Dispersion Index which is used to aid in determining the required gypsum application rates.

Table 9.3 Dispersion Index*

RATING	DISPERSION TEST RATINGS	DISPERSION INDEX			
		Dry natural soil aggregate		Remoulded soil aggregate	
		2 hr	20 hr	2 hr	20 hr
Nil	No dispersion evident	0	0	0	0
Slight	1 out of 3 (or 5) with muddy cloud around the aggregate.	1	1	1	1
Moderate	Small cloud around each aggregate, with a connection between each aggregate around the side of the vial	2	2	2	2
Strong	Observable soil aggregates, but most of the base of the vial is covered by a cloud	3	3	3	3
Complete	Aggregate not visible, total or near total suspension	4	4	4	4

* Soil aggregate dispersion ratings using the Index system developed by Loveday and Pyle (1973)

The 2 and 20 hour dispersion ratings for natural soil aggregates are added to the 2 and 20 hour dispersion ratings for the remoulded soil aggregates to provide the dispersion index. This is used to determine the gypsum requirements of dispersive soils (See Table 9.4).

Table 9.4 Interpretation of dispersion index

Clay dispersion index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Established pasture[1]	No action required – Cultivate with care									Test strip gypsum at 2.5 t/ha			Apply gypsum at 5 t/ha				
Cropping and New pasture[2]	No action required					Apply gypsum at 2.5 t/ha							Apply gypsum at 5 t/ha				

[1]Gypsum rates based on surface application with no mechanical incorporation
[2]Gypsum rates based on mechanical incorporation to 10 cm depth
Source: Adapted from the Incitec Soil Test Interpretation Manual, 1999, p112).

9.2.3 Soil Organic Carbon

Soil organic carbon (SOC) content is used to estimate of the soil organic matter content. Low organic carbon levels in a soil indicates that the soil is low in organic matter and so offers less sites for adsorption of nutrients, and less sorption back into the soil solution than a soil with a high organic carbon. Organic carbon levels will vary according to: the inherent soil type, climate, pasture or crop type; as well as farm management including stocking rate, and grazing management.

The Total Soil Organic Carbon test measures all components of C in the Soil. These can be measured also as Labile and Sequestered C which includes the SOC fractions shown in Table 9.5.

Table 9.5 Soil organic carbon tests and components

SOIL ORGANIC CARBON TEST	CARBON COMPONENTS
Total SOC	Crop or pasture residues + Particulate C + Humus + Inert C (or Recalcitrant C or Resistant OM)
Labile C	Crop/pasture residue + Particulate C
Sequestered C	Humus + Inert C

The **Walkley and Black (1947) method** of determining SOC does not measure carbon in carbonate or bicarbonate which are not part of the soil organic matter (SOM) but are present in the soil solution or as deposits of carbonate or bicarbonates.

The SOM is difficult to measure directly because of the variations in the contents of its component elements (C, H, O, N, P and S). Therefore, SOM is estimated by multiplying the total SOC (as determined by the Walkley and Black method) by a conversion factor. Conversion factors currently used range from 1.72 to 2.0, but a value of 1.72 is typically used. Since no single conversion factor is appropriate for all soils, it is be better to determine and report results in terms of SOC and not SOM values (Peverill et al.1999).

% Soil Organic Matter (SOM) = % Soil Organic Carbon (SOC) x Conversion factor

Since much attention has focussed on greenhouse gases and carbon sequestration many laboratories have begun to analyse the different forms of carbon in soil organic matter using different analytical methods. These forms include:

- Organic carbon
- Active Carbon
- Labile Carbon
- Recalcitrant Carbon

Guidelines for low, normal and high organic matter percentages (calculated from organic carbon percentages) are listed in Table 9.6. These percentages are based on data analysed using the Walkley and Black (1947) method.

Table 9.6 Organic matter percentage over a range of conditions

Organic Matter Levels	Crops Low Rainfall (less than 300 mm annually)	Pastures Low Rainfall (less than 400 mm annually)	Crops High Rainfall (400 to 600 mm annually)	Pastures High Rainfall (greater than 400 mm annually)
Low	Below 1.5	Below 3	2.5	5
'Normal'	1.5 to 2.5	3 to 4.5	2.5 to 5	5 to 10
High	Above 2.5	Above 4.5	Above 5	Above 10

Source: Department of Primary Industries Victoria - State Chemistry Laboratory, (1995).

There is currently a National Soil Carbon Research Program whereby sampling and analytical methods are being developed to analyse the different pools of organic carbon. These methods are not commercially available at this time (2013).Guidelines for low, normal, and high organic carbon percentages (using modified Walkley & Black, 1947) are listed in Table 9.7.

Table 9.7 Victorian organic carbon interpretation guidelines

Organic Carbon Rating	Crops Low Rainfall less than 475 mm per growing season)	Crops High Rainfall > 475 mm per growing season	Pastures Low Rainfall less than 475 mm	Pastures High Rainfall greater than 475 mm
Low	Below 0.8	Below 1.3	Below 1.6	2.3
'Normal'	0.8 → 1.3	1.3 → 2.6	1.6 → 2.4	2.3 → 5.3
High	Above 1.3	Above 2.6	Above 2.4	Above 5.3

Source: Department of Primary Industries Victoria - State Chemistry Laboratory, (1995).

The relationship between soil organic matter, organic carbon and soil physical properties is described in Table 9.8.

Table 9.8 The relationship of soil organic matter and organic carbon to soil physical properties

Organic matter % (g/100 g)	Organic carbon % (g/100 g)	Rating	Interpretation
<0.70	<0.40	Extremely low	Subsoils or severely eroded/degraded surface soils
0.70 – 1.00	0.40 – 0.60	Very low	Very poor structural condition, very low structural stability
1.00 – 1.70	0.60 – 1.00	Low	Poor to moderate structural condition, low to moderate structural stability
1.70 – 3.00	1.00 – 1.80	Moderate	Average structural condition, Average structural stability
3.00 – 5.15	1.80 – 3.00	High	Good structural condition, high structural stability
>5.15	>3.00	Very high	Good structural condition, high structural stability and soils probably water repellent

Source: Adapted from Hazelton and Murphy, (2007).

Refer to Chapter 5 for further information about organic matter and organic carbon.

9.2.4 Soil pH

Soil acidity and alkalinity are indicated by soil pH tests. Two laboratory methods are currently used to measure pH: the water method and the calcium chloride ($CaCl_2$) method. Both tests use a 1:5 ratio of soil:water or soil:$CaCl_2$. The results are usually reported in one of the following formats:

- If the water method is used, the results are reported as pHw, pH (water), pH (H_2O) or pH 1:5 water.
- If the calcium chloride method is used, the results are reported as pHCa, pH ($CaCl_2$) or pH 1:5 $CaCl_2$.

The water method has been the test most commonly used in Australia for over 50 years and more readily reflects current soil conditions for plants than does the calcium chloride method. However, the water method is more subject to seasonal variations. The pH (water) value may vary by as much as 0.6 units over the year.
The calcium chloride test is more useful for long-term monitoring of pH and is the one most agronomists tend to use when making management decisions regarding pH and for lime recommendations.

In the pH ($CaCl_2$) range 4 – 5, the mean difference between pH ($CaCl_2$) and pH (Water) is linearly and highly correlated at 0.84 units, the former being lower than the pH (water) value. However, the pH ($CaCl_2$) value can range from 0.2 to 1.0 unit lower than the pH (water) value.

The pH readings from the two testing methods will be much closer (0.2 – 0.3) if the soil contains high levels of salt. This is typical of soils that have a salinity problem or may be seen after a recent application of a fertiliser high in salt, such as muriate of potash. Most of the major soil testing laboratories will present pH results for both testing methods. It is important to be aware of which pH testing method has been used when interpreting a soil test and when discussing management options with an adviser or agronomist.

As soils become more acidic, it is common to see a rise in the plant availability of both aluminium (Al) and manganese (Mn), which can both be toxic to pasture plants and crops. Aluminium toxicity restricts root growth in sensitive plant species. Refer to Chapter 7.6 for further information about the availability of soil nutrients at different pH levels.

Soil acidity is corrected by applying agricultural lime or dolomite. Agricultural lime (calcium carbonate) is usually applied to dairy pastures to increase the pH and neutralise the effects of soil acidity. A clay soil will require more lime to raise the pH than a sandy soil, and the soil property that determines how much lime is required to raise soil pH by one unit is called ‘pH buffer capacity’. Commercial laboratories have a ‘**buffer pH**’ soil test that allows lime recommendations to be made for target soil pH of 5.5, 6.0 or 6.5. A good-quality lime (high neutralising value, fine particle size, low water content) will have the best effect on raising pH.

Different species have different pH tolerance levels for optimum growth (See Table 9.9) but little information can stipulate how much production may be lost in white clover grown at pH 5.6 versus 5.8. That is, where is the economic optimum compared to optimum growth potential? These are the ranges for optimum growth but many species will grow reasonably well at lower pH levels, e.g. Kikuyu at pH (water) 4.5. See Chapter 7.6.8 for details on liming and how to correct soil acidity.

Table 9.9 The optimum pH range of pastures and crops

Pasture Species	pH ($CaCl_2$)	pH (water)
Annual ryegrass	5.5	
Balansa, Berseen, Persians	5.2 – 7.5[1]	
Barleys & Wheat*	4.3 to 5.5 – 7.5[1]	5.5 to 7.0
Buffel	5.2 – 7.5[1]	
Cereal Rye	4.3 – 7.5[1]	
Cocksfoot	4.3 to 6.8[1]	5.0 to 7.5
Consul Love Grass	3.8 – 7.5	
Cowpeas*		5.5 to 7.0
Fescue	4.3 to 6.4	5.0 to 7.0
Kale*		5.3 to 7.0
Kikuyu	4.1 – 7.5[1]	5.5 to 8.0
Lucerne	4.8[1] 5.2 to 7.5	5.8 to 8.0
Lupins (Broad leaf)	4.3 – 7.5[1]	
Lupins (Narrow leaf)	4.1 – 7.5[1]	
Maize*	4.5 – 7.5[1]	5.5 to 7.0
Medic	5.3 to 8.0	6.0 to 8.5
Millet	4.5 – 7.5[1]	
Millet	4.5 – 7.5[1]	
Oats	3.9 – 7.5[1]	
Peas*		6.0 to 7.0
Perennial ryegrass	4.3 to 6.0	5.0 to 6.5
Phalaris	4.9[1] 5.2 to 7.3	6.0 to 8.0
Red Clover	4.4 – 7.5	
Red Clover*		6.0 to 7.0
Seradella	4.2 – 7.5[1]	
Sorghum, Sudan Grass* USA	4.4 – 7.5[1]	5.5 to 7.0
Sub clover	4.8 to 6.	5.5 to 7.0
Tall Wheat Grass	4.8 – 7.5[1]	
Triticale	4.1 – 7.5[1]	
Vetch*		5.5 to 6.8
White clover	5.0 to 6.0	5.8 to 6.5

Source: Adapted from [1]New South Wales Acid Soil Action Program, (2000), *Havlin *et al, (1999).*

9.2.5 Available Phosphorus

Available phosphorus (P) is the amount of phosphorus in milligrams per kilogram (mg/kg), or parts per million (ppm) extracted from the soil. Various chemical test methods are used to determine the amount of phosphorus from the three sources of P in the soil which include; the soil solution, labile phosphorus, and non-labile phosphorus.

Phosphorus tests include:

- Olsen P
- Colwell P
- Bray 1 P
- BSES P

It is important to use a soil test suitable for your region and situation. Soil testing methods are only meaningful where there has been research conducted to establish yield response curves for that specific soil test method, soil type and plant species (See Figure 15.1 for an example of a yield response curve). For this reason soil test methods tend to be specific to regions where robust yield response curves have been developed for particular soil tests. For example, Queensland dairy farmers would typically take soil samples from 0 – 10 cm and use a Colwell P test, while Tasmanian dairy farmers would take samples from 0 - 7.5cm and use an Olsen P test - See Chapter 8.3 for more information on soil sampling guidelines.

9.2.5.1 Which test to use for available phosphorus

The Olsen P (Olsen *et al*, 1954) and the Colwell P (Colwell *et al*, 1963) tests measure plant-available P, and are used to indicate whether or not additional phosphorus is required for plant growth. The Olsen P and the Colwell P tests have been extensively calibrated against pasture production over a range of soils and climates in Australia and New Zealand. Due to past research, pasture yield response curves for the Olsen P test method are well established in Victoria and Tasmania whereas pasture yield responses to the Colwell P test method are better established in all other Australian States.

Olsen P test
Olsen's method (1954) uses an extracting solution, sodium bicarbonate ($NaHCO_3$), in the ratio of 1:20 soil:solution and the sample is then turned end for end for 30 minutes (Rayment and Higginson, 1992). This provides a measure of the more readily plant-available P from the soil solution and mineralised P from organic matter.

Soil test P values derived using the Olsen procedure are not affected by the capacity of the soil to sorb P and therefore the Phosphorus Buffering Index (PBI) is not required to interpret the soil test results. However, the PBI is used to determine the amount of capital P fertiliser required to raise the soil Olsen P or Colwell P by one unit (1 mg/kg) – See Chapter 15.8.1.

The test has been extensively calibrated against pasture production (including the 'Phosphorus for Dairy Farms Project' and other trials) over a range of soils and climates in Australia and New Zealand. Olsen P has been the most commonly used P test in Victoria, Tasmania and NZ.

Colwell P Test
The Colwell P test (1963) is a modification of the Olsen procedure and also uses sodium bicarbonate ($NaHCO_3$) as an extractant but in a ratio of soil:extractant solution of 1:100, and the sample is turned end for end for 16 hours (Rayment and Higginson, 1992). Colwell P not only gives a measure of the readily available P, but also some of the less available labile or adsorbed P in the sample, hence producing higher values than Olsen P tests. Soil test values obtained using the Colwell P procedure are strongly affected by the capacity of soil to sorb P. The capacity of different soil types to sorb P is ranked using the PBI.

**When Colwell P is used, the PBI needs to be measured also
for correct interpretation of soil test results**

In the past Colwell P has been estimated by converting the Olsen P value to Colwell P, or vice versa, by use of a conversion ratio. However, there was far too much variation (1:1 up to 5:1) for the conversion to be reliable.

Colwell P is most commonly used in NSW, SA, QLD and WA, and in cropping areas of Victoria where soils tend to be neutral to alkaline. Colwell P provides a wider range in soil test P values for sandy soils than the Olsen method making it a better method for providing fertiliser advice on these soils.

Bray 1 P Test
The Bray 1 test uses Ammonium Fluoride and dilute Hydrochloric Acid as the extractant solution, mixed in a 1.4:10 soil:solution ratio and vigourously mixed for 1 minute (Rayment and Higginson, 1992). The Bray 1 is not suitable for calcareous soils as the small amounts of calcium carbonate neutralises the acidity and precipitates fluoride. Bray 1 soil test results are usually very similar to those obtained with the Colwell procedure, although the relationship is influenced by the type of fertiliser previously applied to the soil.

The Bray 1 test has several advantages when compared with the Colwell test. The acidic extractant dissolves very little organic matter by comparison with that of the alkaline bicarbonate extractant. Consequently, interferences due to extracted organic matter are of no consequence in the Bray 1 procedure (Allen and Jeffery, 1990). The Bray 1 test is used in the more temperate areas on acid soils such as along the northern coastal areas of NSW and central and southern NSW (Department of Primary Industries New South Wales, 2004).

BSES P Test
The BSES P test (Kerr and von Stieglitz, 1938) was developed by the Bureau of Sugar Experimental Stations for the sugarcane industry. The test uses dilute sulphuric acid as the extractant, mixed in a soil:solution ratio of 1:200 and mixed for 16 hours. The BSES P test measures both the labile (plant available) and non-labile (slowly released) P pools. The non-labile pool will not release enough P within an annual crop cycle to sustain yields however it may partially replenish available P reserves over a period of years (Guppy, Bell, and Moody 2012).

The suitability of the BSES extractable P for predicting fertiliser response is thought to be more important where large root/fungal networks exist, especially as the crop matures. These root/fungal networks are primarily located in the subsoil where soil moisture is greatest thus subsoil testing and soil volume may improve the usefulness of BSES-P in predicting P fertiliser response. This test has been used for pastures (and other crops) in acid soils, and sometimes used in combination with Colwell P as an indication of P ‘in reserves’ for the long term.

Phosphorus Buffering Index
The Phosphorus Buffering Index (PBI) is used widely to formulate the recommended rate of phosphorus fertiliser to apply in the next growing season. It is also used in conjunction with the Colwell P test to determine if Soil P levels are adequate. The PBI test (Burkitt *et al*, 2002) measures the P-sorbing capacity of a soil. P-sorption is the process by which soluble P becomes adsorbed to clay minerals and/or precipitated in soil. P-sorption also determines the partitioning of P between the solid and solution phases of the soil (See Chapter 3.4.2.2 for information on the P cycle and forms of P).

9.2.5.2 P Soil test interpretation

Soil test interpretation is based on the results of trials and research which have been used to calibrate soil test values to yield response. The soil test guidelines below (Tables 9.10 to 9.12) show the expected pasture performance for different levels of available P for each Australian dairy region. Take care to select the correct table and soil test guidelines for your region.

The production response curve for most plant nutrients tends to 'flatten out' towards maximum yield potential (i.e. 95% - 98%). This means that the yield response to higher soil test levels diminishes to a point where further applications of fertiliser become uneconomical.

Table 9.10 also explains what action is required to maintain a 95% - 98% maximum potential pasture yield. For example, if a soil sample from a Victorian dairy farm has an Olsen P test level of 20 mg/kg, maintenance applications of fertiliser would be required to maintain yields at 98% of the maximum potential yield. See Chapter 15.7 for more information on how to calculate maintenance applications of fertiliser. The tables 9.10 to 9.12 are based on calibrated results from the 'Better Fertiliser Decisions Project'. The response relationships are based on a large amount of data collated from an extensive national review of soil test – pasture response experiments conducted over the past 50 years (Gourley *et al* 2007). Note that the Olsen P levels used in Tasmania are higher than those used in the Victoria due to higher P fertility levels associated with a shallower sampling depth of 0 – 7.5 cm (compared to 0 – 10 cm in all other Australian states).

Table 9.10 Phosphorus soil test guidelines for 0 -10 cm samples for dairy systems aiming for 95 - 98% potential yield at "Adequate" soil test result - For use in **Victoria, QLD, NSW and South Australia**.

Pasture performance compared to potential yield*	**<90%**	**90% - 95%**	**95% - 98%**	**98% - 99%**	**100%**
*(after fertiliser is applied)	**Deficient** large capital fertiliser required	**Marginal** moderate capital fertiliser required	**Adequate** maintenance fertiliser required	**High** low fertiliser maintenance required	**High** Trial data shows no fertiliser response
Victoria	**Olsen P (mg/kg)**				
All soils	<9	9 - 14	14 - 20	20 - 27	>27
QLD, NSW, SA	**Colwell P (mg/kg)**				
PBI 0-15 (Very sandy)	<15	15 - 23	23 - 30	30 - 41	>41
PBI 15-35 (Sand, Sandy loams)	<17	17 - 26	26 - 34	34 - 47	>47
PBI 35-70 (Sandy/Silty loams)	<19	19 - 30	30 - 39	39 - 53	>53
PBI 70-140 (Sandy/Silty clay loams)	<22	22 - 35	35 - 45	45 - 61	>61
PBI 140-280 (Clay loams)	<26	26 - 42	42 - 54	54 - 74	>74
PBI 280-840 (Clay loams & Clay)	<37	37 - 58	58 - 75	75 - 102	>102
PBI >840 (Volcanic clays, Peat)	<50	50 - 90	90 - 120	120 - 150	>150

Source: Adapted from Department of Primary Industries Victoria, (2011)

Table 9.11 Phosphorus soil test guidelines for optimum pasture production on **Tasmanian dairy farms** using 0 - 7.5 cm soil samples

	Very low	Low	Optimum	High	Very High
Tasmania	Olsen P (mg/kg)				
All soils	<10	10 - 20	20 - 30	30 - 60	>60

Source: Adapted from University of Tasmania and the Tasmanian Institute of Agriculture, ND.

Table 9.12 Phosphorus soil test guidelines for **Western Australia** dairy systems aiming for 95% potential yield and 0 -10 cm soil samples

Western Australia		Phosphorus Status at 95% of maximum production		
		Low	Medium	High
Capacity of soil to sorb P	PBI	Critical Colwell Soil Test (mg/kg)		
Exceedingly low	<5	<7	7-10	>10
Exceptionally low	5 - 10	<10	10-15	>15
Extremely low	10 - 15	<15	15-20	>20
Very very low	15 - 35	<20	20-25	>25
Very low	35 - 70	<25	25-29	>29
Low	70 - 140	<29	29-34	>34
Moderate	140 - 280	<34	34-40	>40
High	280 - 840	<40	40-55	>55

Source: Adapted from Bolland *et al*, 2010

9.2.5.3 Capital P Applications

The PBI test allows for a more accurate phosphorus fertiliser decisions based on a farm's soil type. Firstly, the PBI is useful when looking to boost soil fertility with capital fertiliser applications to desired or targeted levels. These are referred to as Capital P applications. As different soils have different phosphorus buffering capacities, they require different amounts of phosphorus to raise their plant available P level. See Chapter 15.8.1 for more information on how to calculate capital P applications.

9.2.5.4 Maintenance P Applications

The intent of maintenance P applications is to keep the soil nutrient status at a steady level of high productivity. For full details on how to work out maintenance P applications see Chapter 15.7.

9.2.6 Available Potassium

The amount of potassium (in mg/kg, or parts per million) available for plant growth is measured by one of three methods: the Colwell K (1963) soil test; Skene K (1956) soil test; or it is estimated by multiplying the exchangeable potassium test result by 391 (See 'Exchangeable potassium' in Section 9.2.9.5). For the same soil sample, all three soil test K procedures provide very similar soil test K values, except in alkaline soils or recently limed soils.

The appropriate level of available potassium for good pasture growth depends on soil type. Clay soils have a higher nutrient holding capacity and need higher levels of available K than do sandy soils. Refer to Table 9.13 for the Colwell K soil test guidelines for all states except Western Australia, and take care to use the correct guidelines for your dairy region. Refer to "plant tissue testing for potassium on sandy soils" for information relevant to WA.

9.2.6.1 Tests for available Potassium

There are several analytical methods for determining soil K but all measure the true plant available K in the soil. These tests measure either “exchangeable K” or “extractable K”.

Exchangeable K is usually determined by replacing the K^+ ions on the exchange sites with other cations such as NH_4^+, Ba_2^+ or Na^+. **Extractable K** tests generally use stronger extractants, which aims to measure the exchangeable K along with some non-exchangeable K, which would contribute to plant-available K during the growing season.

The concentration of potassium is usually measured by use of an Ammonium Acetate extract after a 30 minute shake in a 1:10 soil:solution ratio. The ammonium ions displace the adsorbed potassium ions from the clay complex into the soil solution after which the potassium concentration is measured by a spectrometer. Another technique using Barium Chloride as the extractant produces very similar results to the Ammonium Acetate method.

The **Skene K** soil test (Skene, 1956) has been used in Victoria for many years and also in some areas of Queensland (at double the soil:solution ratio). The **Colwell K** test (1963) has been widely used in South Australia, Tasmania, Western Australia and New South Wales. Both tests are well correlated to the concentration of potassium using the ammonium acetate extractant except in alkaline or recently limed soils. Also, calcareous soils are generally high in K, so care needs to be taken when interpreting K tests results. Both the Skene and Colwell K tests measure similar K values in any given soil and a conversion factor used on the exchangeable K value all produce similar K availability results. That is, Skene K (mg/kg) = Colwell K (mg/kg) = extractable potassium (amm. Acetate cmol (+)/kg X 391).

Research into yield responses to K have not been as extensive as for P, however the more commonly used K tests have a greater degree of field calibration. Because of the K buffering capacity of soils and many other influences on K concentration in the soil, K levels can vary throughout the year, and substantially from year to year. It is therefore important to monitor K regularly, and in most regions soil testing is used to monitor K levels. Test strips can also be used to detect responses to potassium fertiliser (See Chapter 8.7 for information on how to set up a fertiliser test strip). Soil testing for K is less reliable on sandy soils in higher rainfall zones, so under these situations plant tissue testing for K is recommended. Plant tissue testing is also recommended for peat soils in which fewer trials have been done to correlate yield responses on these soil types.

The optimum plant available K levels are dependent on soil texture. Clay soils have a higher nutrient holding capacity and need higher levels of available K than do sandy soils. See Table 9.13 for the soil test guidelines for Colwell K on various soil types.

Table 9.13 Soil test guidelines for Colwell K

Pasture performance compared to potential yield*	**<90%**	**90% - 95%**	**95% - 98%**	**98% - 99%**	**100%**
*(after fertiliser is applied)	**Deficient** large capital fertiliser required	**Marginal** moderate capital fertiliser required	**Adequate** maintenance fertiliser required	**High** low fertiliser maintenance required	**High** Trial data shows no fertiliser response
Victoria, QLD, NSW, SA (0-10cm)	**Colwell K (mg/kg)**				
Sand	<70	70 - 120	120 - 170	170 - 230	>230
Sandy/Silty loam	<80	80 - 130	130 - 190	190 - 250	>250
Sandy/Silty clay loam	<90	90 - 130	130 - 190	190 - 260	>260
Clay loam and Clay	<100	100 - 150	150 - 220	220 - 280	>280
Peat*†	<200	200 - 270	270 - 350	350 - 400	>400
Victoria, QLD, NSW, SA (0-10cm)	**Exchangeable K (meq/100g)**				
Sand	<0.18	0.18 - 0.31	0.31 - 0.44	0.44 - 0.6	>0.6
Sandy/Silty loam	<0.20	0.20 - 0.33	0.33 - 0.49	0.49 - 0.64	>0.64
Sandy/Silty clay loam	<0.23	0.23 - 0.33	0.33 - 0.53	0.53 - 0.66	>0.66
Clay loam and Clay	<0.26	0.26 - 0.39	0.39 - 0.56	0.56 - 0.72	>0.72
Peat*†	<0.51	0.51 – 0.69	0.69 – 0.90	0.90- 1.02	>1.02
Tasmania†† (0 – 7.5cm)	**Colwell K (mg/kg)**				
Sand	<70	70 - 120	121 - 170	171 - 230	>230
Sandy loam	<90	90 - 150	151 - 220	221 - 290	>290
Sandy clay loam	<100	100 - 150	151 - 220	221 - 300	>300
Clay loam and Clay	<115	116 - 170	171 - 250	251 - 320	>320

Sources: Adapted from Department of Primary Industries Victoria, (2005), *J. Gallienne, Pers. Com. May 2013.
†Plant tissue testing is recommended for peat soils because fewer trials have been done to correlate yield responses on these soil types.††Derived from Gourley *et al* (2007) Making better fertiliser decisions for grazed pastures in Australia. Victorian Government, Department of Primary Industries, Melbourne (multiplied by 1.15 for depth adjustment).

Plant tissue testing for potassium on sandy soils

Plant tissue testing is recommended on sandy soils in higher rainfall zones, such as in areas of Western Australia. This is due to potassium being easily leached from the pasture root zone, but typically no deeper than 20 cm. Dairy production in south-western Australia differs greatly from dairy production in eastern Australia. Most annual dairy pastures in this region are rain-fed ryegrass and clovers on sandy soils.

Clover is very sensitive to K deficiency which reduces pasture dry matter production and seed production. As a result clover rapidly disappears from K deficient pastures. In contrast, ryegrass rarely shows yield responses to applied fertiliser K regardless of the soil test K value, except when high yielding silage and hay crops are harvested and fed to cows in other paddocks (M. Bolland, Pers. Com. April 2013).

9.2.7 Available Sulphur

This is the amount of sulphur (mg/kg or ppm) available for plant growth as measured by CPC S, MCP or the KCl 40 S (sometimes referred to as Blair S or Blair KCl 40) test methods.

The **CPC S test** , which contains charcoal, estimates the water soluble and exchangeable sulphate sulphur using calcium orthophosphate ($Ca(H_2PO_4)_2$), sometimes referred to as calcium hydrogen phosphate test. The **MCP test** uses a similar extractant as for CPC but without charcoal. The KCl 40 S test uses heated potassium chloride extract to measure the readily available pools of both inorganic and organic S.

Although data from field-calibrated trials is limited, it is suggested that the **KCl 40** test be used as it should vary less with time of sampling and soil type compared to the CPC test. It is also a quicker and cheaper test and has been adopted in most soil testing laboratories. Other tests for S are the Total S and Organic S tests both of which provide little information on the amount of plant-available S.

The major laboratories now use the Blair KCl 40 test because it provides an improved indicator of sulphur status. Although the adequate ranges are similar, the KCl 40 test is more accurate because it takes into account some of the sulphur that will become available from the breakdown of organic matter. This is relevant for dairy pastures because over time large organic matter levels accumulate in the topsoil of dairy pastures. Pasture plants take up S from soil as sulphate-S. As a consequence of soil organism activity, much sulphate-S is released (mineralised) from soil organic matter. This sulphate-S is either taken up by plants or leached.

If the sulphur level is high to very high there could be a number of causes: it is possible that gypsum may have been recently applied; the soil may be saline; or the soil may be a potential acid sulphate soil. See Table 9.14 for the CPC and KCl 40 soil test guidelines.

Sulphur on sandy soils in high rainfall areas

Sulphur deficiency is generally confined to high rainfall (greater than 800 mm annual average) pastures on sandy soils in wet years, as a result of leaching of sulphate sulphur below the root zone. In these circumstances soil testing cannot be used to confidently determine fertiliser sulphur requirements for the next growing season.

In south-western Australia, intensively rotationally grazed ryegrass dominant dairy pastures need to be treated with fertiliser N and fertiliser S after each grazing to prevent both elements decreasing pasture DM yields. A ratio of 3-4 N and 1 S is required, achieved by applying half urea (46% N) and half ammonium sulphate (21% N and 24% S) after each grazing. Tissue testing can be used to assess and improve sulphur management (M. Bolland, Pers. Com. April 2013).

Table 9.14 Soil test guidelines for available Sulphur

Pasture performance compared to potential yield*	**<90%**	**90% - 95%**	**95% - 98%**	**98% - 99%**	**100%**
*(after fertiliser is applied)	**Deficient** large capital fertiliser required	**Marginal** moderate capital fertiliser required	**Adequate** maintenance fertiliser required	**High** low fertiliser maintenance required	**High** Trial data shows no fertiliser response
VIC, QLD, NSW, SA (0-10cm)	**Sulphur (KCl-40) (mg/kg)**				
All soils	<4.5	4.5 - 7.5	7.5 - 10.5	10.5 - 14	>14
	Sulphur (CPC S) (mg/kg)				
All soils	<1.5	1.5 - 3	3 - 4	4 - 6	>6
Tasmania[††] (0-7.5cm)	**Sulphur (KCl-40) (mg/kg)**				
All soils		<8	8 - 16	16 - 32	>32

Sources: Adapted from Department of Primary Industries Victoria, (2007)
[††]Derived from Gourley *et al* (2007) Making better fertiliser decisions for grazed pastures in Australia. Department of Primary Industries Victoria (multiplied by 1.15 for depth adjustment).

9.2.8 Available Nitrogen

Pastures

It is difficult to measure the amount of nitrogen (N) available for plant growth in soils because the form and availability of nitrogen in the soil can change quickly, particularly in grazed dairy pastures. Therefore by the time the soil samples are received and analysed by the laboratory the amount of mineral N in the sample may have changed. Even if the amount of mineral N is correctly analysed by the laboratory by the time the soil test results are returned to the farmer changes may have already occurred in the N content of the soil.

Nitrogen fertiliser applications for pastures are better calculated by using a pasture production target, rotation length during the growing season, or obvious symptoms of N deficiency. Soil nitrogen, and the practical application of nitrogen fertilisers in pastures, is covered in Chapter 12.

Crops

In some cropping regions plant available N can accumulate in the soil profile and becomes a valuable source of N for the subsequent crop. In Queensland and Northern New South Wales extraction of nitrate N with KCl has been found to be useful to determine its contribution to plant-available N (Russell 1968; Hibberd et al.1986; Holford & Doyle 1992; Strong 1990 as cited in Peverill et al, 1999). Soil nitrogen is to be interpreted in consideration of other factors including: soil water content at planting, in-crop rainfall, yield target, and the likely crop response. These factors are accounted for in calculating N fertiliser requirements – For more information refer to the following link: http://www.daff.qld.gov.au/26_18112.htm.

In contrast to this, crop response to applied N in Western Australia is poorly correlated to nitrate concentration in the surface 10 cm (M.G. Mason unpublished data, cited in Peverill et al, 1999). In western and southern Australia surrogate tests of the soil's capacity to increase mineral N supply, such as total N or C contents, are used (Pyane & Ladd 1994: Bowden & Diggle 1995, cited in Peverill et al. 1999). Soil testing and interpretation of soil nitrogen for field crops is regionally specific and is a specialised area, and as such is not covered in this manual. See '*Soil Analysis: an Interpretation Manual'* (Peverill et al. 1999) for more information.

9.2.9 Cation Exchange Capacity (CEC)

Cation Exchange Capacity is a measure of the soil's capacity to hold and exchange cations (positively charged ions). CEC provides a buffering effect to changes in available nutrients, pH, calcium levels and soil structural changes. As a result, CEC is a major influence on soil structure stability, availability of nutrients for plant growth, soil pH and the soil's reaction to nutrient application and soil ameliorants.

9.2.9.1 Measuring CEC

CEC is usually measured by displacing the exchangeable cations (Na, K, Mg and K) with another strongly adsorbed cation, followed by determining how much of the strongly adsorbed cation is retained by the soil. The details of the methods used and their pros and cons are discussed in Rayment and Higginson (1992) and Rengasamy and Churchman (1999).

The soil CEC is now measured in terms of centimoles of positive charge per kilogram [(cmol (+)/kg] of soil and is numerically equivalent to the previously used unit of milli-equivalents per 100 grams (meq/100 g) as follows:

1 cmol (+)/kg = 1 meq/100 g.

After the cations (calcium, magnesium, potassium, sodium and sometimes aluminium) have been measured, they are totalled and this is referred to as the sum of cations. A sum of cations above 15 meq/100 g (15 cmol (+)/kg) means that a soil has a good ability to retain nutrients for plants. Their proportional relationship to one another is calculated as a percentage of the total for some of the cations.

On some soil tests, aluminium levels will be assessed by the $CaCl_2$ (Calcium Chloride) or KCl (Potassium Chloride) methods, which are reported in milligrams per kilogram (mg/kg) or parts per million (ppm). When this happens, exchangeable aluminium is not included in the cation exchange capacity test.

9.2.9.2 Interpreting CEC levels

Soil tests will report on exchangeable calcium, exchangeable magnesium, exchangeable sodium, exchangeable potassium, and exchangeable aluminium.

For many years the use of the 'Balanced' Ca, Mg, and K ratios, as prescribed by the basic cation saturation ratio (BCSR) concept, has been used by some private soil-testing laboratories for the interpretation of soil analytical data. However, a recent review by Kopittke and Menzies (2007) of data from numerous studies (particularly those of Albrecht and Bear who are proponents of the BCSR concept) would suggest that within the ranges commonly found in soils, the chemical, physical, and biological fertility of a soil is generally not influenced by the ratios of Ca, Mg, and K. However, some ratios have been used to indicate the potential for animal health issues and are also important to soil structure.

The five most abundant cations in soils are Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} and, in strongly acidic soils, Al^{3+} (Table 9.15). Other cations are present but not in amounts that contribute significantly to the cation complement.

Table 9.15 Levels of exchangeable cations (cmol (+)/kg)

CATION	VERY LOW	LOW	MODERATE	HIGH	VERY HIGH
Ca	0 – 2	2 – 5	5 – 10	10 - 20	>20
Mg	0 – 0.3	0.3 – 1.0	1 - 3	3 - 8	>8
K	0 – 0.2	0.2 – 0.3	0.3 – 0.7	0.7 – 2	>2
Na	0 – 0.1	0.1 – 0.3	0.3 – 0.7	0.7 – 2	>2

Source: Metson, (1961)

CEC is a good indicator of soil texture and organic matter content. The CEC of clay minerals is usually in the range of 10 to 150 cmol (+)/kg, while that of organic matter may range from 200 to 400 cmol (+)/kg. The CEC of sand and sandy soils is usually below 10 cmol (+)/kg. So, the type and amount of clay and organic matter content of a soil can greatly influence its CEC.

A high CEC soil means that the soil has high resistance to changes in soil chemistry that are caused by land use. Where soils are highly weathered and the organic matter level is low, their CEC is also low. Where there has been less weathering and organic matter content is higher, CEC can also be quite high. Clay soils with a high CEC can retain large amounts of cations against leaching. Sandy soils with a low CEC retain smaller quantities of cations, and this has important implications when planning a fertiliser program. In soils with a low CEC, consideration should be given to splitting applications of K and S fertilisers. Table 9.16 below relates soil texture to the CEC.

Table 9.16 Soil texture, CEC rating and the Cation Exchange Capacity.

TEXTURE†	CEC RATING††	CEC (cmol (+)/kg)
Sand	Very low	<6*
Sandy loam to Silt loam	Low	6 – 12
Silt loam to Clay loam	Moderate	12 - 25
Clay loam to Clay	High	25 - 40
Clay	Very high	>40

Source: Adapted from †University of New South Wales, (2007), and ††Metson, (1961).
* Soils with CEC <3 are usually very low in fertility and susceptible to soil acidification.

As CEC increases, the soil also tends to become more structurally resilient. The sum of exchangeable calcium, magnesium, potassium and sodium in soil, provides a rough index of the shrink-swell potential (resilience) of soil. A resilient soil is a soil with the ability to develop a desirable structure by natural processes after destructive forces (e.g. soil compaction from animal hooves) have been removed (University of New South Wales, 2007).

Soil that is capable of naturally enhancing the development of shrinkage cracks through the process of shrinking when dry and swelling when wet, will aid the formation of stable vertical cracks into the soil. These cracks facilitate root growth and incorporation of organic matter and water into the subsoil. In addition, the activity of soil fauna such as ants and earthworms will be assisted. Table 9.17 provides an indication of the shrink-swell of soils with increasing CEC values.

Table 9.17 Levels of exchangeable cations (cmol (+)/kg)

SHRINK-SWELL POTENTIAL	VERY POOR	POOR	MODERATE	GOOD
CEC (cmol (+)/kg)	<10	10-20	20-30	30-40

Source: Adapted from University of New South Wales, (2007)

The desired ranges, relationships or limits for the various cations are discussed in Sections 9.2.9.3 to 9.2.9.7. Also discussed is how CEC is most useful for determining soil structural problems and high aluminium levels in the soil.

9.2.9.3 Exchangeable calcium

Exchangeable calcium should make up the largest amount of the cations in the soil. Deficiency of calcium for plant growth is not common in Australian soils, however many soils have inadequate concentrations for a healthy soil structure (Hamza, 2008). High levels of exchangeable Ca increases flocculation and can improve soil structure in clay soils. The level of exchangeable Ca in the soil reflects the following:

- Interacting effects of the total amount and the solubility of Ca sources
- CEC
- Competition from Al, Mg or Na
- Ca-removing processes

In general, neutral and alkaline soils possess higher concentrations of exchangeable Ca relative to acid soils. Ca saturation is correlated with soil pH and inversely related to Al saturation. In this case soil amendments such as gypsum and lime are required to increase the saturation percentage. Acid soils with low CEC in high rainfall environments are most likely to be low in Ca (Hamza, 2008).

The ratio of exchangeable calcium to exchangeable magnesium provides some guide to a soil's structure and any potential problems that might be influencing soil drainage, root development and subsequent plant growth. The ratio is usually written as the **calcium/magnesium ratio** on a soil test.

Well-structured soils have a calcium/magnesium ratio greater than 2:1. In other words, the amount of calcium cations is more than two times greater than the amount of magnesium cations.

The stability of heavier soil types (clays and clay loams) is possibly reduced where the calcium/magnesium ratio is less than 1:1. In other words, the amount of magnesium ions exceeds the amount of calcium ions. This is not as important for lighter soils (sands and loams). However, if the exchangeable sodium is greater than 6% of the CEC, then soil structure may be affected and addition of gypsum may be required. A calcium-to-magnesium ratio of more than 10:1 indicates a potential magnesium deficiency in pasture species (this can be confirmed with a plant tissue analysis).

9.2.9.4 Exchangeable magnesium

Exchangeable magnesium should make up the next largest amount of the cations. The ratio of magnesium to potassium should be greater than 1.5:1. In other words, the amount of magnesium should be more than one and a half times greater than the amount of potassium. A magnesium/potassium ratio of less than 1.5:1 indicates an increased chance of grass tetany; however there are many other factors that can influence the occurrence of grass tetany.

If the exchangeable magnesium is more than 20% of the cations, it may cause a potassium deficiency. Conversely, if the exchangeable potassium is more than 10% of the cations, it may cause a magnesium deficiency. See 'Exchangeable calcium' for the recommended ratio between magnesium and calcium.

9.2.9.5 Exchangeable potassium

Exchangeable potassium should make up the third largest amount of the cations. The value of potassium in relationship to magnesium plus calcium should be less than 0.07. A result of 0.07 or higher indicates a greater danger of grass tetany; a result less than 0.07 indicates minimal danger of grass tetany. (Note that animal symptoms or blood tests are the most accurate indicators for grass tetany.) To determine the relationship, use the following formula containing the exchangeable values for:

K ÷ (Ca + Mg)

For example, if a soil test showed potassium as 0.47 cmol (+)/kg, calcium as 5.60 cmol (+)/kg, and magnesium as 1.4 cmol (+)/kg, then the calculation would be:

0.47 ÷ (5.6 + 1.4) = 0.067

This level is just under the grass tetany danger level of 0.07 or greater.

9.2.9.6 Exchangeable sodium

Exchangeable sodium should be the fourth largest amount of the cations. Often referred to as the **Exchangeable Sodium Percent (ESP)**, the desirable level is less than 6%. Although not needed for plant growth, Na is needed by animals. However, a high CEC Na value can cause crusting/dispersion in sodic clay soil with low organic carbon (OC) (see Chapter 7.2.2), and this is made worse with high Mg ratios. This often occurs where sodium cations make up 6% or more of the cation exchange capacity – see also Section 9.2.9.3.

9.2.9.7 Exchangeable aluminium

Exchangeable aluminium (Al_{ex}) should be the lowest amount of the cations but is not needed by plants. The desirable amount is less than 1% and is toxic to the roots of many plant species, especially lucerne.

Exchangeable aluminium is used to indicate the need for lime for aluminium-sensitive species such as: lucerne and white clovers; and to a lesser extent, sub clovers. High aluminium levels can be toxic to plants, but aluminium generally falls to harmless levels once the pH ($CaCl_2$) exceeds 5.0 – See Table 9.18 for critical acidity and aluminium levels for crops and pastures.

Table 9.18 Critical acidity and aluminium levels for crops and pastures

		VERY SENSITIVE PLANTS	SENSITIVE PLANTS	TOLERANT PLANTS	VERY TOLERANT PLANTS
Examples of plants		Barrel Medic, Canola, Lucerne	Wheat, sensitive Phalaris, Barley	Wheat, Phalaris, Sub clover, Cocksfoot, Perennial ryegrass	Lupins, Triticale, Oats, Serradella
pH ($CaCl_2$) below which yield declines		4.3 – 4.7 depending on soil group	4.1 – 4.5 depending on soil group	4.0 – 4.3 depending on soil group	4.0 – 4.2 depending on soil group
Extractable Al in $CaCl_2$ solution above which yield declines		0.1 - 0.4 ppm	0.4 - 0.8 ppm	0.8 -1.6 ppm	1.6 - 2.7 ppm
Exchangeable Al as a percentage of CEC	EC[1]<0.07 (Infertile soils low CEC)	9 - 16	16 - 21	21 - 32	32 - 43
	EC 0.07- 0.23 (Most fertile soils, low CEC)	8 - 12	8 - 12	12 - 21	21 – 30
	EC>0.23 (Fertile bands, saline soils)	0.5 - 2	2 - 6	6 – 10	10 - 16

[1]EC Electrical conductivity 1:5 dS/m.
Source: Adapted from Geeves *et al* (1990), Fenton *et al* (1993), Fenton and Helyar (2007), cited in 'Interpreting Soil Tests: Pam Hazelton and Brian Murphy NSW DNR 2007' Retrieved:
http://www.bellingerlandcare.org.au/documents/InterSoilTestResults.pdf

Lucerne establishment and persistence are particularly susceptible to high exchangeable aluminium in both the topsoil and the subsoil. The desirable aluminium levels in the topsoil for lucerne establishment, as measured by the three methods, are as follows:

- Less than 1%, if measured as part of the cation exchange capacity.
- Less than 2 mg/kg (or ppm), if measured by the $CaCl_2$ method.
- Less than 50 mg/kg (or ppm), if measured by the KCl method.

Subsoils should also be soil tested if lucerne is to be grown. Lucerne is a deep-rooted plant, and it should not be sown if the level of aluminium in the subsoil, as measured by the KCl method, is above 50 mg/kg.

Table 9.19 explains management options and the likely response to lime applications for a range of crops, pH levels, and Exchangeable Aluminium (Al_{ex}) levels.

Table 9.19 Likely responses to lime application over a range of pH and Exchangeable Aluminium (Al_{ex}) levels.

SOIL PH ($CaCl_2$)	EXCHANGEABLE ALUMINIUM	MANAGEMENT
> 5.4	0 – 5%	There are no problems from soil acidity and there is net movement of lime effect down the soil profile
< 5.3	0 – 5%	There is a chance of molybdenum deficiency (Check local advice)
< 5.1	0 – 5%	The effectiveness of rhizobia that inoculate acid sensitive legumes e.g. Lucerne, faba beans, is reduced. Liming will increase rhizobia effectiveness and production of their crops and pastures
< 4.8	>5%	Pastures and crops that are sensitive to soil acidity (Table 9.9) will give an economic response to lime.* If pH is less than 4.6 the speed of nitrification process will increase with liming regardless of Al_{ex}.
< 4.8	>10%	Crops that are sensitive to soil acidity will show an economic response to lime. Sensitive and tolerant pastures will also show a response but its economics may be marginal.
< 4.8	>15%	Crops that are tolerant will give an economic response. The response of sensitive and tolerant pasture will increase with higher aluminium, but its economics may be marginal.
< 4.8	>20%	Highly tolerant crops and pastures will give a small response

*Economic response will depend on cost of applied lime and level of response.
Source: Fenton (1999).

9.2.10 Salinity

Soil salinity refers to the accumulation of water soluble salts comprised mainly of sodium; but also potassium, calcium and magnesium; and may include chlorides, sulphates or carbonates.

Salinity levels are usually determined by measuring the **electrical conductivity** of soil/water suspensions. Traditionally, the electrical conductivity of saturated extracts was used (ECe) but the tests are time consuming and difficult to determine.

Now, electrical conductivity is determined more rapidly and more easily on a mixture of 1 part soil to 5 parts distilled water. This test is called the EC 1:5 method, and the unit of measurement is deciSiemens per metre (dS/m). The soil and water are continuously mixed for one hour before the electrical conductivity is tested.

The EC 1:5 (dS/m) values are converted to the appropriate value of ECe (dS/m) value based on the estimated water holding capacities of the soil, which is based on its soil texture. Multiplication factors are dependent on soil type as shown in Table 9.20.

Example:
A clay loam soil has an EC 1:5 test of 0.4 dS/m. The multiplication factor for clay loam is 8.6.
ECe value = 0.4 dS/m x 8.6 = 3.44 dS/m.

It is important to check the results of the soil test to see which method was used to report the EC value.

Table 9.20 Conversion factor of various soil types for EC 1:5 to EC_e

SOIL TEXTURE GROUP	MULTIPLICATION FACTOR
Sand, loamy sand, clayey sand	23
Sandy loam, fine sandy loam, light sandy clay loam	14
Loam, very fine sandy loam, silty loam, sandy clay loam	9.5
Clay loam, silty clay loam, very fine sandy clay loam, sandy clay, silty clay, light clay	8.6
Light medium clay	8.6
Medium clay	7.5
Heavy clay	5.8
Peat	4.9

Source: Adapted from Slavich and Petterson, (1993)

Soil scientists use deciSiemen per metre (dS/m) as the standard scientific unit of EC but other numerically equivalent units are also used:

- 1 dS/m = 1 mS/cm = 1 mmho/cm
- dS/m is deciSiemen per metre; mS/cm is milliSiemen per centimetre; mmho/cm is millimoho per centimetre
- 1 dS/m = 1000 microSiemen per centimetre (µS/cm or EC units)

Data on the salt tolerance of plants is usually based on a different test, the electrical conductivity of a saturated extract. This is called the ECe method and is also measured in deciSiemens per metre. A plant growing in saline conditions will make adjustments to cope with the increase in salt levels in the soil solution. The ability of the plant to continue this adjustment is a measure of its tolerance to salinity. See Chapter 7.5 for more information on salinity, salt tolerance of plants, and salinity management:

- Soil classification and salinity measurement
- What does salinity look like?
- Plant tolerances to salty conditions
- How can we best manage salinity?

9.3 Interpreting plant tissue tests

Plant tissue testing is the preferred method for diagnosing trace element toxicities, deficiencies, and imbalances for plants. Tissue tests, also known as plant or leaf analysis, determine the chemical analysis of the nutrients present in plant tissue. Tissue tests are also used to confirm that plants are accessing the nutrients that have been applied and to confirm a diagnosis made by other means. Both the major nutrients and the micronutrients (trace elements) are covered in plant tissue tests (see the example in Figure 9.3a).

Plant tissue testing is also very useful to corroborate animal nutritional or deficiency problems such as copper (Cu), cobalt (Co) and selenium (Se). Both plant nutrient and animal health problems can be diagnosed by comparing results from healthy and unhealthy samples. However, the rapid growth and quick maturity of annual crops combined with daily management (e.g. irrigation, fertiliser), and the effects of grazing on pasture plants, can make assessments of subclinical deficiencies or toxicities difficult.

Tissue testing is carried out by comparing samples with standard results recorded in various publications (see references at the end of this section). However, where animal health is a concern, blood testing is often more useful and it is more cost effective to treat the animals directly.

Clover samples are generally used to diagnose trace element deficiencies in dairy pastures where clover is prevalent, however lucerne or ryegrass samples can also be used. Plant tests are also used to confirm that plants are accessing the nutrients that have been applied, and to confirm a diagnosis made by other means.

Interpretation of the results of a plant tissue test is complex and depends on a number of factors. It is therefore recommended that interpreting the results of plant tissue tests should be done by a trained professional. This is because actual adequate levels for any nutrient varies depending on species, plant part, time of year, and stage of growth.

When using plant tissue tests to determine nutrient levels in plants, it is vital to take the sample correctly and to provide as much information as possible to aid interpretation. Supplying relevant information will help the person interpreting the results to correctly calculate the level of nutrients in your sample. If possible, tissue samples of identical plant parts and age should be taken from ‘good’ and ‘poor’ areas to allow a direct comparison of tissue nutrient levels. See Chapter 8.4 for details on sampling for tissue tests.

Results from laboratories will be analysed by trained professionals who will take into account the information you have provided and will interpret the results. The results are usually shown with a number and an interpretation of this (for example, deficient, adequate, high). Based on this interpretation, you can then make decisions about nutrients required in your fertiliser program.

More information about interpretation of tissue test results can be found in *Plant Analysis: An Interpretation Manual* (Reuter and Robinson, 1986) and *Plant Nutrient Disorders 4: Pastures and Field Crops* (Weir and Cresswell, 1994).

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Nutrient Advantage Advice® Recommendation Report

Report Print Date: 10/04/2013
Agent/Dealer:
Advisor/Contact:
Phone:
Purchase Order No:

Grower Name:
Sample No:
Paddock Name:
Sample Name:
Nearest Town:
Test Code: T5
Sample Type: Tissue
Sampling Date:

Analyte / Assay	Unit	Value	Very Low	Marginal	Optimum	High	Excess	Optimal
Nitrogen (Kjeldahl)	%	4.90						3.2 - 5.5
Nitrate Nitrogen	mg/kg	110.00	Not referenced					
Ammonium Nitrogen	mg/kg	240.00	Not referenced					
Phosphorus	%	0.40						0.25 - 0.5
Potassium	%	2.50						1.2 - 2.5
Sulphur	%	0.34						0.25 - 0.4
Calcium	%							0.8 - 2.5
Magnesium	%	0.24						0.15 - 0.5
Sodium	%	0.56						< 0.5
Chloride	%	1.10						< 1.7
Manganese	mg/kg	96.00						25 - 300
Iron	mg/kg	250.00						50 - 200
Copper	mg/kg	10.00						5 - 30
Zinc	mg/kg	46.00						15 - 50
Molybdenum	mg/kg	2.60						0.5 - 10.0
Boron	mg/kg	18.00						25 - 100
Cobalt	mg/kg	0.14						> 0.1
Selenium	mg/kg	<0.13						> 0.1

The results reported pertain only to the sample submitted.
Analyses performed on plant material dried at 70 degrees Celsius and ground to <2mm
* One or more components of this test are below their detection limit. The value used is indicative only.

Analyses conducted by **Nutrient Advantage Laboratory Services**

NATA Accreditation No: 11958
Certificate of Analysis is available upon request.

8 South Road, Werribee VIC 3030
Tel: 1800 803 453
Email: lab.feedback@incitecpivot.com.au

Figure 9.3a An example plant tissue test

Nutrient Advantage®

Nutrient Advantage Advice® Recommendation Report

Grower Name:		**Nearest Town:**	
Sample No:		**Test Code:**	T5
Paddock Name:		**Sample Type:**	Tissue
Sample Name:		**Sampling Date:**	

Comments

NITROGEN:
Nitrogen (N) status satisfactory at time of sampling and yield is unlikely to be affected.

PHOSPHORUS:
Phosphorus (P) nutrition appears adequate.

POTASSIUM:
Sufficient potassium (K) nutrition - monitor with soil test.

SULPHUR:
Sufficient sulphur (S) nutrition indicated at the time of sampling.

CALCIUM:
This level should be adequate for maximum pasture and animal production.

MAGNESIUM:
This level should be adequate for maximum pasture and animal production.

SODIUM:
Production losses due to high sodium (Na) may exist at this site, the cause of which should be explored. Burning of the leaf tip and yellowing or scorching of the margins are the most common symptoms.

CHLORIDE:
Satisfactory chloride (Cl) levels at time of sampling.

MANGANESE:
Sufficient at time of sampling.

IRON:
Iron (Fe) status higher than normal at time of sampling, which may indicate soil contamination of the tissue sampled.

COPPER:
Sufficient at time of sampling.

ZINC:
Sufficient at time of sampling.

MOLYBDENUM:
This level should be adequate for maximum pasture. As copper (Cu) and molybdenum (Mo) are antagonistic, the high molybdenum levels in the sample indicate that scrutiny of copper levels is required.

BORON:
Tentative guide only.

COBALT:
This cobalt (Co) level should be adequate for maximum pasture and animal production.

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Figure 9.3b Explanation of an example plant tissue test

9.4 Summary

- Soil and tissue tests provide valuable information about soil properties (mostly chemical properties) that affect plant growth.
- After soil and tissue test results come back from the lab, it is important to determine what they actually mean and act upon the advice.
- The interpretation of results from soil and tissue tests will help to make more informed, cost-effective fertiliser decisions.

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