Apal
Agricultural Laboratory

Soil Test Interpretation Guide

Contents

1. Soil test Interpretation guide – Introduction

APALs soil test interpretation guide summarises the Lab methods undertaken and also provides a general interpretation guide. APALs tests and interpretation is based on up to date research and literature for Australian soils, promoting best industry practice. If there are any doubts around the interpretation of results be sure to speak to APAL or your local agronomist/advisor in regard to your specific region and soil type. Crop specific ranges are displayed in APALs soil reports. APAL have invested heavily into generating crop specific soil ranges for a broad range of crops, working closely with research organisations and consultants to review the latest up to date research and literature in soil nutrition.

APAL work closely with our clients to determine the correct testing requirements for specific regions and crops.

When considering soil test methods the key point to address:

'Use a test that has being as recently as possible correlated with plant yield response for your crop and soil type, where data is available to determine your crop response to the fertiliser being applied.'

For further information on lab methods please refer to:

www.apal.com.au/labmethods

For a full range of available tests please refer to APAL service guide:

www.apal.com.au/Service-guide

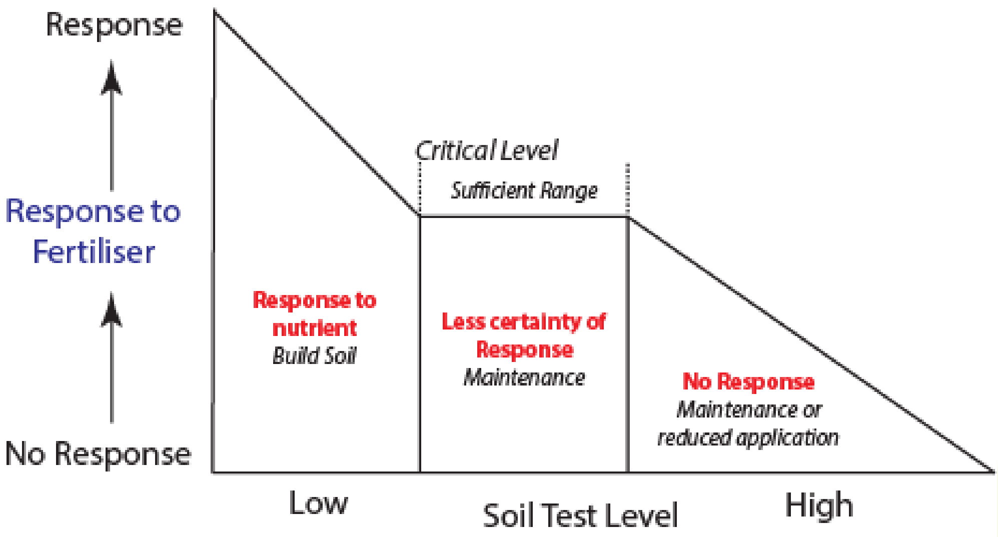
For further information on sampling instructions please refer to:

www.apal.com.au/samplinginstructions

Soil testing is a tool to assess the amount of plant available nutrients in the soil. A tool to identify limitations to production, which can include pH, soil structure, sodicity, salinity, low nutritional status or excessive nutritional status.

'The yield of a plant is limited by a deficiency of any one essential element, even though all others are present in adequate amounts'[1]

The interpretation of soil test data will be based on crop yields, stocking rates and production targets. Taking into account the nutritional status of the soil, ranges are generally based around the critical value required, which determines the value where 90-95% of maximum production or yield potential occurs. The confidence interval around the critical value indicates the reliability of the estimate, the narrower the range the more reliable the data. This data has being collated from fertiliser trials, where various fertiliser rates are applied and the crop yield response measured. Adequate levels are generally higher than the critical value to allow for field error and natural variation.



The following outlines interpretation data based on published research and the APAL database. Compiled from experience and observations from over 15 years of data and including input from local experts and agronomists in the field.

2. Soil Texture

Soil texture is dependent on how much sand, silt and clay is present. Soil texture will influence the physical and chemical properties of the soil. 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.

Critical values for some tests will vary with soil texture and soil type.

Lab texture method- Hand bolus

Field generated textures by suitable operators is considered the most accurate method of determining soil texture

- Field texturing techniques. McDonald RC, Isbell RF, Speight JG, Walker J, Hopkins MS (1998) Australian Soil and Land Survey Field Handbook. (Australian Collaborative Land Evaluation Program: Canberra).

3. pH

Methods:

pH (water) **4A1**- 1:5 soil/water extract

pH (CaCl2) **4B1**- 1:5 soil/0.01 M calcium chloride extract

pH is a measure of the soils acidity and alkalinity that gives an indication of the activity of the hydrogen ion (H+) and hydroxyl ion in (OH-) in a water solution. The more hydrogen ions held on the exchange complex, the greater the soils acidity. Solutions which contain equal concentrations of H+ and OH-ions are said to be neutral and have a pH of 7.0.

Acidic soils can restrict microbial activity; reduce the availability of essential nutrients and cause aluminum toxicity in the subsurface which retards root growth, restricts access to water and nutrients. Crops will display varying sensitivities to acidity and alkalinity.

General desired level **pH (water) 6.0 - 8.5 (6.0- 7.0, ideal)**

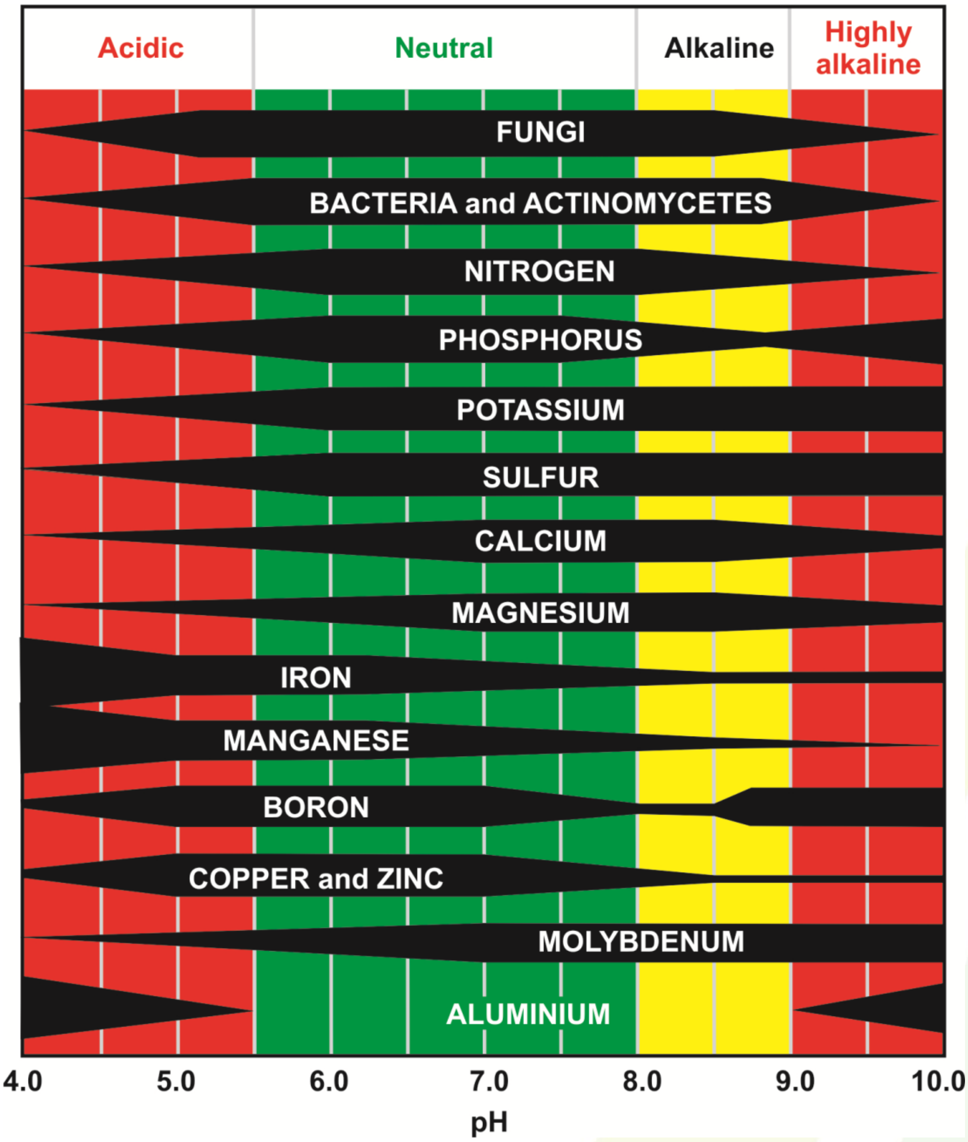
pH (CaCl2) 5.0 – 7.5 (5.0- 6.5, ideal)

pH calcium chloride will generally be 0.7- 1.2 units lower that pH water.

pH (Water)	
pH	**Interpretation**
<5.4	Strongly acidic Aluminium (Al) or Manganese (Mn) toxicity Can have Molybdenum deficiencies Ca, Mg, and K deficiency (Due to possible leaching) Reduced microbial activity
5.5-6.4	Moderately acidic
6.5-6.9	Slightly acidic
7.0	Neutral
7.1-7.5	Slightly Alkaline
7.6-8.3	Moderately alkaline
>8.4	Strongly alkaline
pH ($CaCl_2$)	
<4.8	Strongly acidic Possible Al and Mn Toxicity and Mo Deficiency
4.8-5.2	Moderately high acidic Acceptable for acid tolerant species
5.2-5.5	Moderately acidic
5.5 -7.5	Moderately acidic to slightly alkaline Above 6.5 - Often high in Mg and calcium carbonate
>7.5	Moderately to strongly alkaline

The pHCa test is considered more reliable when assessing acidity and varies less through the season while the pHw is fine for neutral to alkaline soils. pH water readings can increase with winter or spring rains, under dry conditions soluble salts are thought to be higher and therefore depress the pH reading.

Acidic and alkaline soils will have effects on the availability of nutrients and soil biological activity. The diagram below indicates the availability of nutrients at various pH, with the widest bar representing availability.



Source: Arris Pty Ltd. www.arris.com.au

4. Electrical Conductivity (EC)

Methods:

EC **3A1** - 1:5 soil: water extract

EC_e Estimated EC (from 1:5 soil: water extract using texture conversion factor)

EC_{se} Saturated soil extract

EC testing is reliable way to assess how salts are affecting plant growth. The EC of soil or water is influenced by the concentration and composition of dissolved salts. Salts increase the ability of a solution to conduct an electrical current, so a high EC value indicates a high salinity level.

Generally an EC (1:5) water extract <0.15 will not affect plant growth.

Soil texture influences the degree to which the amount of salt present in the soil will affect plant growth. Therefore the value for EC (1:5) can be converted to an estimated electrical conductivity of a saturation paste (EC_e) by multiplying with a texture factor.

EC_e estimated = EC 1:5 x texture conversion factor.

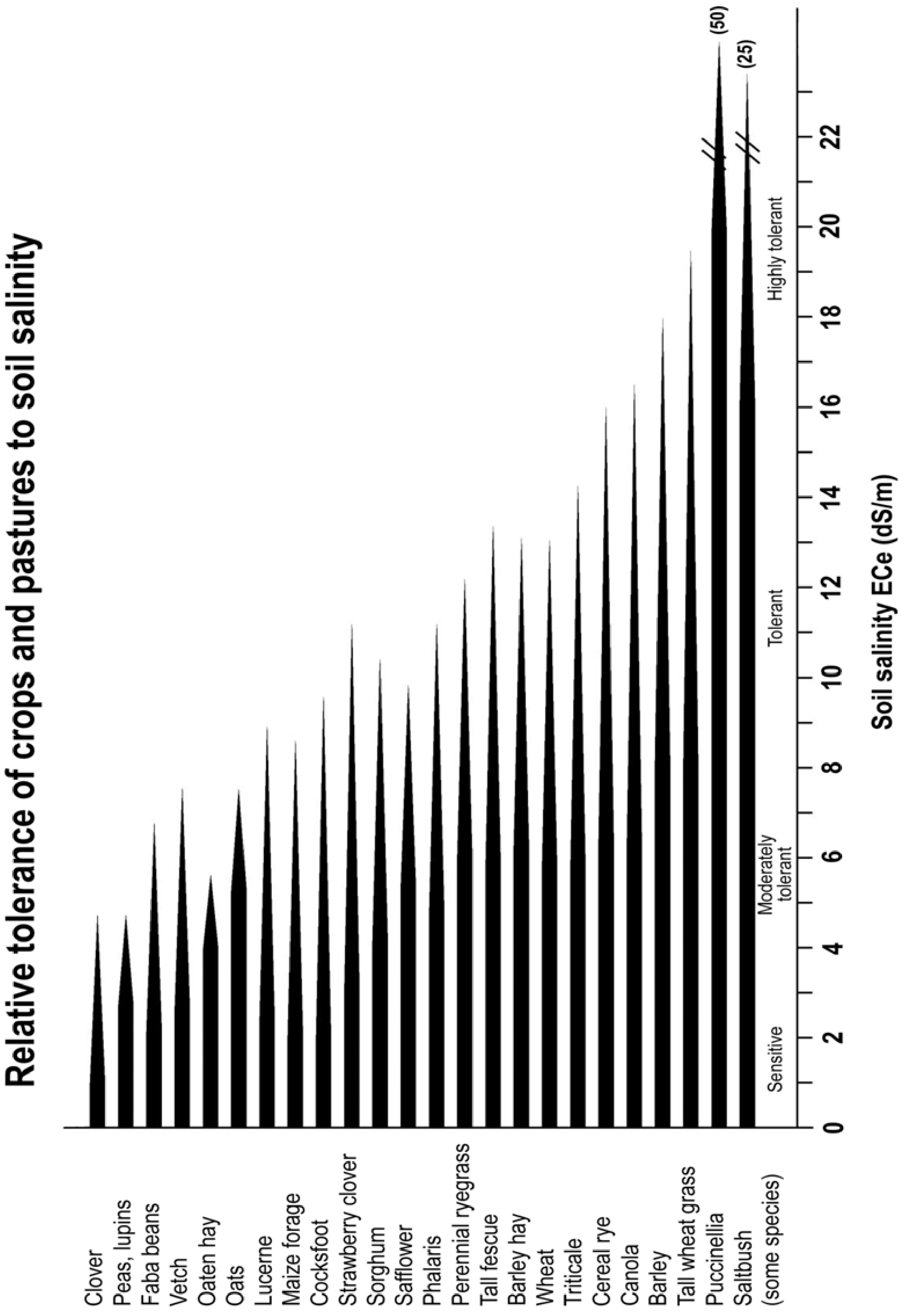
Soil Texture	Multiplication factor
Sand, loamy sand, clayey sand	23
Sandy loam, fine sandy loam, light sandy clay loam	14
Loam, fine sandy loam, silty loam, sandy clay loam	9.5
Clay loam, silty clay loam, fine sandy clay loam, sandy clay, silty clay, light clay	8.6
Light medium clay	8.6
Medium clay	7.5
Heavy Clay	5.8
Peat	4.9

Source: Slavich and Petterson (1993)

Criteria	ECe (estimated)
Low salinity	0 - 2
Sensitive plants affected	2 - 4
Many plants affected	4 -8
Tolerant plants affected	8 -16
High salinity	>16

Source: Natural Resources South East. Brian Hughes, David Davenport and Lyn Dohle

EC_{se} Saturated soil extract, this test is used by soil surveyors and is regarded as a more accurate measure of soil salinity than EC (1:5).



Relative tolerance of crops and pastures to soil salinity (from Herrmann, 1995).

Relative tolerance of plants to soil salinity (Source: Rural Solutions SA)

Soil salinity ECe (dS/m)	Grain crops	Pastures	Vegetables	Fruit Crops
16				
		Puccinellia		
15				
		Saltbush (selected species)		
10	Barley	Tall wheat grass		
9				
	Canola			
8	Cereal rye			
	Triticale			
	Wheat	Barley hay		
7		Perennial ryegrass		Date palm
6	Safflower	Kikuyu		
		Tall fescue		
		Phalaris	Zucchini	
	Oats			
5	Sorghum		Beetroot	
		Strawberry clover		
		Oaten hay		
	Germinating cereals		Broccoli	
4		Vetch		
		Burr medic		Fig, olive
		Lucerne	Tomato	
		Cocksfoot	Cucumber	
		Maize	Pea	
3	Peas, lupins		Broad bean	
	Faba beans		Sweetcorn	
		Annual medic	Potato	Walnut, grape
		Annual clover	Lettuce	Citrus, pome
2			Carrot, onion	Peach, plum
			Green bean	Apricot, almond
1				Strawberry

Crop tolerance and yield potential of selected horticultural crops affected by soil salinity.

	Yield Potential				
	100%	90%	75%	50%	0%
Fruit	**Soil ECe (dS/m)**				
Orange	1.7	2.3	3.2	4.8	8.0
Grape	1.5	2.5	4.1	6.7	12.0
Almond	1.5	2.0	2.8	4.1	6.8
Avocado	1.3	1.8	2.5	3.7	6.0
Grapefruit	1.8	2.4	3.4	4.9	8.0
Peach	1.7	2.2	2.9	4.1	6.5
Apricot	1.6	2.0	2.6	3.7	5.8
Date Palm	4.0	6.8	11.0	18.0	32.0
Plum	1.5	2.1	2.9	4.3	7.1
Strawberry	1.0	1.3	1.8	2.5	4.0
Vegetables					
Broccoli	2.8	3.9	5.5	8.2	14.0
Bean	1.0	1.5	2.3	3.6	6.3
Cabbage	1.8	2.8	4.4	7.0	12.0
Carrot	1.0	1.7	2.8	4.6	8.1
Cucumber	2.5	3.3	4.4	6.3	10.0
Lettuce	1.3	2.1	3.2	5.1	9.0
Onion	1.2	1.8	2.8	4.3	7.4
Potato	1.7	2.5	3.8	5.9	10.0
Pepper	1.5	2.2	3.3	5.1	8.6
Squash - zucchini	4.7	5.8	7.4	10.0	15.0
Squash - scallop	3.2	3.8	4.8	6.3	9.4
Tomato	2.5	3.5	5.0	7.6	13.0
Irrigated pasture					
Barley forage	6.0	7.4	9.6	13.1	
Clover, white	1.5	2.3	3.6	5.6	
Clover, strawberry	1.6	2.6	4.0	6.0	
Fescue	3.9	5.8	8.6	13.3	
Lucerne	2.0	3.4	5.4	8.8	
Sorghum	2.8	5.1	8.6	14.4	

This data is a guide to relative tolerances among crops. Absolute tolerance varies depending upon climate, soil conditions and cultural practices. – Source: Brian Hughes (rural solutions SA).

Source: Irrigation and Drainage Paper (1989). Water quality for agriculture 29 rev. 1 FAO, United Nations, Rome.

5. Effective Cation Exchange Capacity (ECEC)

Methods:

ECEC **15J1** – Effective CEC is the sum of exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) plus exchange acidity (Al^{3+}, plus H^{+}) ($cmol_c$/kg)

Desired range 5-25 cmol/kg.

Where ECEC is less than 5, is indicative of low soil fertility.

Cation exchange capacity (CEC) is the total capacity of a soil to hold exchangeable cations. It influences soil structure stability, nutrient availability, soil pH and the soils reaction to fertiliser and ameliorants. Soil with higher clay content will have a higher CEC. The CEC of soils varies according to the clay %, the type of clay, soil pH and amount of organic matter

The main ions associated with CEC in soils are the exchangeable cations calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}), which are generally referred to as base cations (CEC). In the majority of cases, the additions of the analysed base cations gives an accurate measure of CEC. However we need to take into account that as soils become more acidic these cations are replaced by H^{+}, Al^{3+} and Mn^{2+}, therefore common methods will produce much higher values than what occurs in the field. APAL therefore includes 'exchange acidity' when summing the base cations, with this measurement referred to as the effective CEC (ECEC). This test is undertaken through a two-step titration, testing Al and a second titration to test for exchangeable acidity (or H+).

6. Organic Carbon (%) Walkley and Black

Methods:

Organic C **6A1** – Concentrated acid (H_2SO_4) is added to soil wetted with a dichromate solution ($Cr_2O_7^{2-}$). Colour development is assessed against standard sucrose.

Desired range – 1 to 2 % (Broad acre cropping)

2-5 % (Pasture, high rainfall zones)

Desired ranges of OC will vary with soil texture and rainfall zone. A lower eCEC soil will have a lower organic carbon level. Increasing OC levels will increase the soils CEC and nutrient holding capacity resulting in increased productive capacity in some soils. Higher rainfall or finer texture will generally have higher OC levels. Levels should be higher when >500mm rainfall. Organic carbon is not directly calibrated against yield but closely linked with soil health.

Example: Wheat.

Sand	>0.5
Sandy loam	>0.7
Loam	>0.9
Clay Loam/Clay	>1.2

Higher organic carbon levels can be observed under long term pasture or soils where water logging has allowed build up. High levels can be a sign of low levels of biological activity due to acidity and water logging (Natural Resources SA).

Soil carbon is part of the soil organic matter (SOM), which includes other important elements such as calcium, hydrogen, oxygen, and nitrogen.

Understanding the types of carbon is important and this can greatly impact soil productivity as the amount of carbon varies significantly and different types can be altered through management practices. CSIRO have identified these groups as follows;

- **crop residues** – shoot and root residues less than 2 mm found in the soil and on the soil surface
- **particulate organic carbon** – individual pieces of plant debris that are smaller than 2 mm but larger than 0.053 mm
- **humus** – decomposed materials less than 0.053 mm that are dominated by molecules stuck to soil minerals
- **recalcitrant organic carbon** – this is biologically stable; typically in the form of charcoal.

CSIRO have also identified the key function of each of these fractions of carbon.

- crop residues
    - readily broken down and provide energy to soil biological processes
- particulate organic carbon
    - broken down relatively quickly but more slowly than crop residues
    - important for soil structure, energy for biological processes and provision of nutrients
- humus
    - plays a role in all key soil functions
    - particularly important in the provision of nutrients - for example the majority of available soil nitrogen derived from soil organic matter comes from the humus fraction
- recalcitrant organic carbon
    - is usually charcoal - a product of burning carbon-rich materials. As 'biochar', it is attracting interest as both a carbon sink and, possibly, a source of soil benefits.
    - decomposes very slowly and is therefore unavailable for use by micro-organisms
    - many Australian soils have high levels of charcoal from millennia of burning.

The Walkley and Black method only measures readily oxidisable/decomposable carbon, not total SOC. The method on average will measure about 80% of the SOC.

Total Organic carbon (TOC) can be tested via Dumas high temperature combustion (6B2). The Leco test uses high temperature combustion in an O_2 atmosphere. This test is not suited to calcareous soils and lime will be combusted as well as organic carbon. To correct for this a fizz test is performed on the samples to identify the presence of carbonate. Carbonate is tested an adjusted for in the TOC measurement.

Soil organic matter and organic carbon are often confused, the below formula can be used for conversion.

Organic matter (%) = Total organic carbon (%) x 1.72

7. Nitrogen

Methods:

Nitrate (NO_3) **7C2a**

Ammonia (NH_4) **7C2a**

Total N **7A5** – Extra which can be added to the APAL standard test groups.

Nitrogen has to be in a mineralised form (Nitrate or Ammonia) to be readily available to plants. Total nitrogen measures the total amount of Nitrogen in the soil, much of which is tied up in organic matter and is not readily available to plants. The nitrogen in these organic matter pools is mineralised to form Nitrate and Ammonia during the season, becoming plant available for crop growth. High Ammonia relative to Nitrate can indicate reducing conditions (eg waterlogging). Nitrate or Ammonia can be leached down the soil profile so deep testing is required to get a more accurate result.

Total Nitrogen measures the total amount of N present in the soil, much of which is held in organic matter and not immediately available to plants.

Desired range: Nitrate 10-50 mg/kg

Ammonia 0-5 mg/kg

Total N (%)

Rating (% by weight)	Description
<0.05	Very low
0.05 – 0.15	Low
0.15 – 0.25	Medium
0.25 – 0.50	High
>0.5	Very High

8. What Phosphorus test do I use?

The interpretation for crop P requirements will differ depending on what test is used in addition to the crop that is being grown. Ultimately it is important to use a test that has being correlated with plant yield response for your crop and soil type, where data is available to determine your crop response to P. Preferably data needs to be as recent as possible to encompass significant changes that have occurred in some agricultural systems e.g. broad acre where there has been a shift to no-till and hi-analysis fertilisers (e.g. MAP and DAP). Inherent soil properties, soil test values along with recent fertiliser history and crop removal will determine which soils are likely to be responsive.

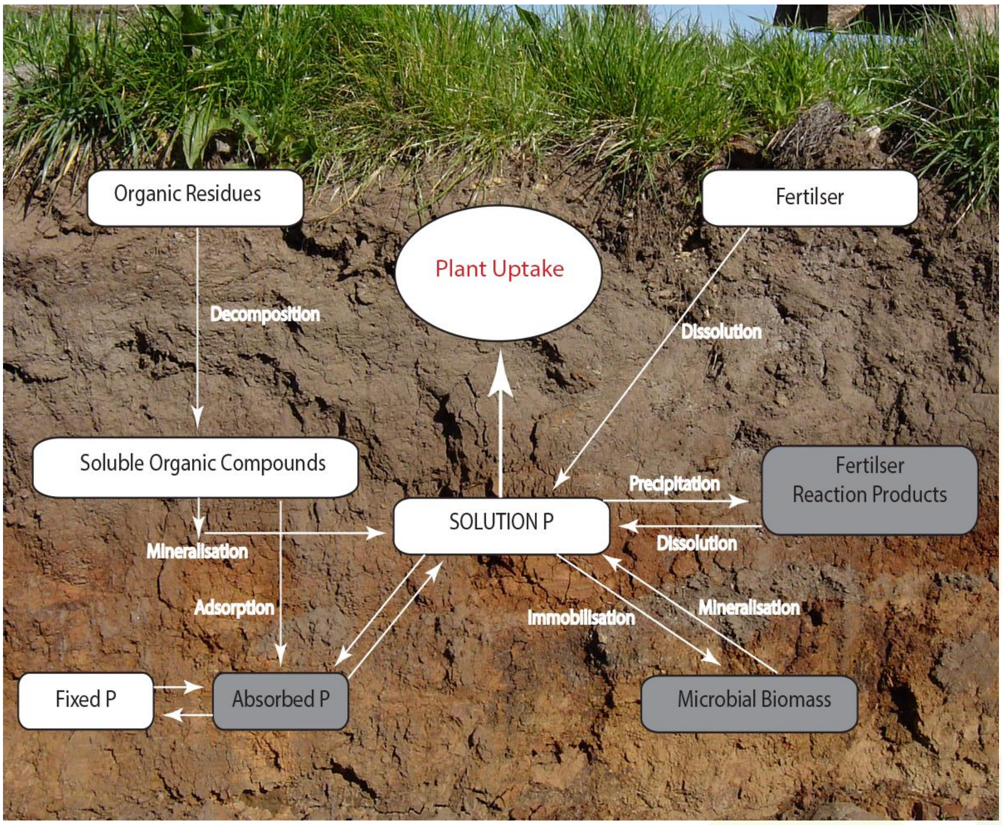
A series of interpretations are presented because there is considerable local variation in the use and interpretation of these tests. Different P tests have shown to extract varying levels of P, extracting varying fractions of your soil P reserves based on pH, organic matter and soil type (e.g. Calcarosol, Ferrosol). Most soil tests will measure the solution P pool (readily available) and some component of the P pool (organic/in organic) which becomes available over the growing season (See figure below) when P pools are initially depleted. Two aspects of P availability with respect to soil P tests will discussed below and those are intensity and quantity fractions, definitions are below.

Intensity – Concentration of P in soil solution that is readily available for P uptake

Quantity – Component of P off soil solid phases that may be potentially available during the course of the life of the plant when the intensity pool is depleted by plant uptake.

The diagram below outlines the P cycle and the interactions in soil. The soil solution is the immediate source of P to plant roots (Intensity). As this soil solution P is depleted by root uptake, P is replenished, primarily from diffusion. This replenishment occurs from the areas highlighted in grey in the diagram below (Generally from absorbed P, Fertiliser reaction products and microbial biomass).

Phosphorus absorption (Absorbed P) primarily occurs by the covalent bonding of phosphate ions to hydrous oxides of Fe and Al. In alkaline soils, calcium carbonate as well as Fe oxides are positively correlated to P sorption. The effect of organic matter will depend on the nature of organic matter present and how much Al and Fe is associated with it.



The Better fertiliser Decisions project (BFD) provides valuable national data on N, P, K and S response relationships and critical soil test values for pastures and cropping systems. Obtainable field trial results from 1960's to recent have been collated in a central database called the interrogator (for cropping only). The tool allows for response curves to be generated using several filters including crop type, soil type, soil P test, region and time period. Asris database is an important tool for determining which soil type classification dominates in a particular region. *References:*

www.bfdc.com.au

www.asris.csiro.au

http://www.apsim.info

Each of the state agriculture departments (VIC DPI, rural solutions SA) also have a number of reference materials in respect to interpretation of soil tests and ranges. GRDC have a number of technical updates in regard to soil tests and interpretation. If you require further references in regard to specific crops please contact APAL and we can point you in the right direction.

www.grdc.com.au

www.ruralsolutions.sa.gov.au

www.**dpi.vic**.gov.au

www.**dpi.nsw**.gov.au

http://www.daff.qld.gov.au

www.agric.wa.gov.au

The following section will deal with each of the phosphorus tests available and their interpretation and extraction from different P pools in your soil. Soil methods will measure solution P (Intensity pool) and varying levels of the phosphorus pools becoming available during the season (Quantity). This needs to be considered in the interpretation of P data.

8.1 Phosphorus (Colwell)

Method:

Phosphorus (Colwell) **9B** – 0.5M Bicarbonate (HCO_3), pH 8.5

Most accurate on slightly acid to alkaline soils.

- 1:100 soil to extract
- Shake time 16 hours

P Pools extracted- Available P pool (Intensity) and the Quantity pool (becoming available during the growing season).

Colwell P has been the main test used in Australian agriculture since its introduction in 1960's and therefore has the luxury of a huge database of data to draw upon.

The Colwell P test, derived from the Olsen test was developed using the same extracting solution, however increasing the soil: solution ratio and increasing the extraction time. The extended shake time and wider soil to solution ratio affects the release of soil bound P and therefore the Colwell method extracts more quantity P than the Olsen test. Colwell P has been considered a test that measures the quantity (potentially available) P. For a considerable period of time reported critical Colwell P values have been dependant on soil type and therefore one critical value might not be applicable across a range of soil types. Recently it has been proposed that the critical Colwell P value can be interpreted from PBI values and this is highly recommended (see below).

Note* While Olsen P values can be converted to Colwell P values and vice versa on some occasions, variability in the Olsen/Colwell P ratio can occur with particular soil types and therefore this conversion is not recommended.

Colwell critical levels vary from 20 to 100 mg/kg depending on soil texture, type and crop type.

8.2 PBI (Phosphorus Buffering Index)

Method: Addition of 1000 mg/kg of P (100 mg/L) to soil at 1 to 10 ratio, shaken for 17 hours.

PBI is a relatively easy test that measures the ability of a soil type to remove P when applied as a solution. It can in part simulate the ability of the soil to remove applied P as fertiliser from the solution P pool. The main difference is that the application rate (1000mg/kg) is considerably higher than standard application rates. Low PBI values indicate that the soil P has limited ability to tie up applied P and therefore should indicate higher fertiliser efficiencies in the short term and more P is available to the plant. Conversely high PBI values outlines soil types that have the ability to quickly bind up P and make it unavailable to the plant. The main drivers of high PBI values are high amounts of Iron (Fe) e.g. Ferrosol, Aluminium (Al) e.g. in some acidic soils and (Ca) in high pH soils e.g. Calcarosol). Soils with very low PBI have the potential to leach phosphorus in high rainfall areas or events and this is an important issue in catchments or near waterways.

Low PBI soils will generally have lower amounts of quantity P and therefore drawdown of P from grain/plants removed off the paddock will be potentially quicker as there are limited resupply opportunities (low solution P buffering potential). The opposite can occur with moderate to high PBI soils in that the can resupply sources of P when the soil solution pool is depleted (higher buffering potential).

Soil type	Typical PBI range
Tenosol	<50
Chromosol	10-100
Kandosol	30-150
Calcarosol*	150-300
Ferrosol	>200

*Contains > 10% CaCO3

Examples of PBI values expected from selected soil types.

Apart from being a useful indicator of potential fertiliser requirements PBI is a useful tool in determining critical Colwell P values and reducing the wide range of critical values outlined above. Theory is that as the P buffer capacity/index increases so does the quantity of P (Colwell P) required maintaining a solution P (plant available) concentration that is adequate for crop demand (Moody 2007). Relationships of varying degrees have been obtained between PBI and the critical Colwell P determined from replicated field trials for pasture, wheat and potato (see table below).

PBI Categories and Colwell P Critical values for pastures/wheat and potatoes are outlined below.

PBI Category		Critical Value Pasture*	Critical Value Wheat	Critical Value Potato
<15	Extremely low	23 (20 -24)	10	14
15-35	Very very low	26 (24 -27)	16	29
36-70	Very low	29 (27 -31)	22	44
71-140	Low	34 (31 -36)	29	65
141-280	Moderate	40 (36 -44)	38	96
280-840	High	55 (44 -64)	43	118
>840	Very High	n/a	n/a	n/a

*for midpoint of PBI category (range). Critical Colwell P value (mg/kg) at the midpoint of PBI category. Values in parenthesis are critical Colwell P values at the lowest and highest PBI value within the category.

Source: Wheat: Moody 2007

The following table indicates a guide on capital P requirements, Kg/ha P per mg/kg increases in soil concentration in relation to PBI.

PBI Category		P (Colwell)	P (Olsen)
<15	Extremely low	1.5	1.5
15-35	Very very low	2	5

36-70	Very low	2.5	7
71-140	Low	3	9
141-280	Moderate	3.5	11
280-840	High	4	13
>840	Very High	4.5	15

Recent research in to critical values for Colwell P often refers to a soil type as well as or instead of PBI.

For a summary of soil types you can refer to the Australian Soil Classification (ASC), which is a tool to define the properties of our soils. It relies on chemical properties as well as texture, depth, organic matter and profile types.

http://www.clw.csiro.au/aclep/asc_re_on_line/soilhome.htm

The classification system can also be viewed in the app SoilMapp (CSIRO)

https://wiki.csiro.au/display/soilmappdoc/SoilMapp+Home

The table below outlines recent literature from the GRDC in regard to critical levels for crops in varying soil types.

Crop	Soil type	Critical Value	Critical Range
Wheat and Barley	Vertosol	17	(12 –25)
	Chromosol/Sodosol	22	(17 –28)
	Brown/Red chromosol	25	(18 –35)
	Calcarosol	34	(26 –44)
Barley	Ferrosols	76	(46 –130)
Canola	All Soils	18	(16 –19)
Field Pea	All Soils	24	(21 –28)

Source: GRDC Crop Nutrition fact sheet. Soil testing for crop nutrition

8.3 Phosphorus (Olsen)

Method:

Phosphorus (Olsen) **9C** – Bi carbonate 1:20 extraction, pH 8.5

- 1:20 soil to extract
- Shake time 30 minutes

P Pools extracted- Available P pool (Intensity) and a smaller amount of the Quantity pool (becoming available during the growing season). *Smaller soil to extract solution and shorter shake time.*

The Olsen test is applicable to soils that are mildly acidic to alkaline pH. Where soils are quite acidic <5.5 the Olsen test can give an inaccurate assessment, overestimating plant available P.

As discussed previously the Olsen P has a much shorter shake time. For this reason Olsen P estimates the intensity fraction of the available P in addition to a smaller component of the quantity fraction compared to Colwell P. The Olsen P test has been shown to be the most reliable indicator of available P for pastures. Olsen P is also calibrated for wheat and a number of horticultural crops. The interpretation for pastures is based on the national collation of experimental data and not differentiated by soil texture or PBI. The critical value identified in the Making Better fertiliser decisions for pasture project was 15 with a confidence interval of 14-17.

http://www.asris.csiro.au/downloads/BFD/Making%20Better%20Fertiliser%20Decisions%20for%20Grazed%20Pastures%20in%20Australia.pdf

8.4 Phosphorus (Bray 2)

Method:

Phosphorus (Bray 2)– 0.03 M

- 1:7 soil to extract
- Shake time 40 seconds

P Pools extracted- Available P pool (Intensity)

Phosphorus (Bray) **Note Bray will not be tested above pH 7.5**

Bray P is used in acid to neutral soils and is calibrated for a range of pastures and horticultural crops in NSW.

The fluoride extractable P test attempts to integrate both the intensity and quantity fractions of available P with a very rapid shaking time (1 minute). Various performances in relation to predicting plant responses to P have been observed and have an ability to extract non-available P forms from soils with high Al contents.

The Bray method can be subject to variation due to the very short shake time.

8.5 Phosphorus (DGT)

Method:

Iron oxide gel (sink) placed on saturated soil sample (100% WHC)

- 16-24 hours

P Pools extracted- Available P pool (Intensity), Diffusional P supply

DGT differs from a conventional soil extraction in that it mimics the action of plant roots, binding forms of P that are able to diffuse through the soil and through an additional gel membrane.

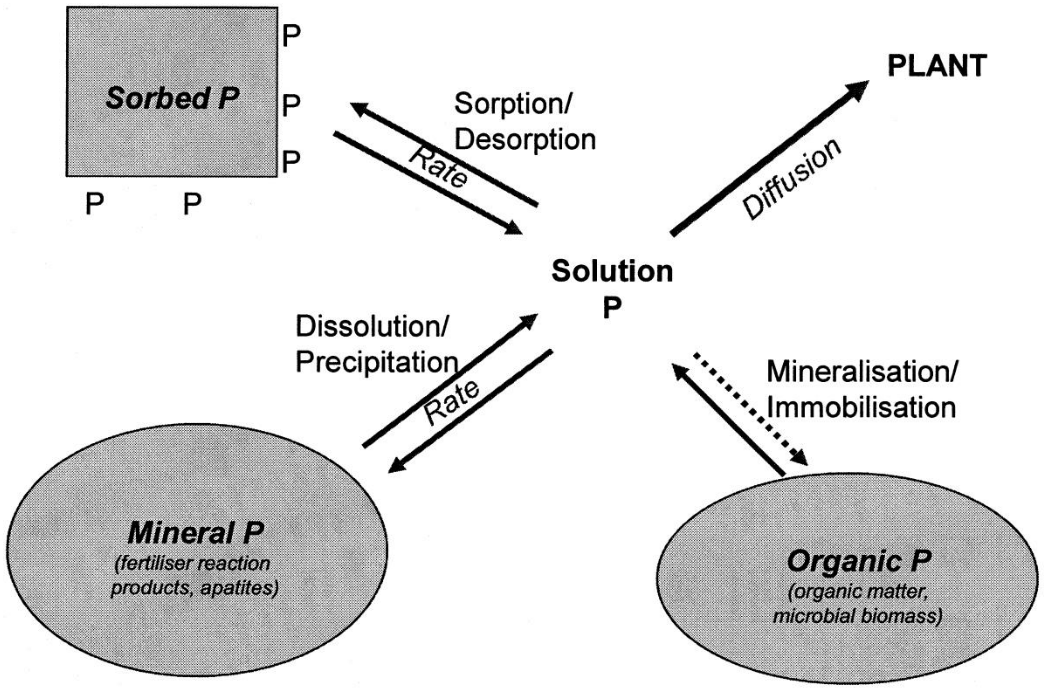


Fig. 1. Soil phosphorus pools and processes.

Source: Moody et al. 2013

Introduction to Australia and validation of the accuracy of DGT occurred because existing soil test methods such as Colwell P were showing to be poor predictors of available P on certain soil types. Generally calcareous or acid soils with high iron or aluminium generally had high relative Colwell P values but were still deficient in P. APAL was the first commercial laboratory in Australia to offer the DGT test.

The DGT (diffusive gradients in thin films) test uses a plastic device with an iron oxide gel which acts as a sink for P and is placed in contact with moist soil (100%) for 16-24 hours, binding forms of P that are able to diffuse through the soil and through an additional gel membrane.

The amount of P bound to the gel is then measured after an elution step with dilute acid. The DGT test is able to measure both the initial soil solution P (intensity) and sources of P that the soil is able to resupply into the soil solution pool in response to the initial removal. It is designed to mimic the action of plant roots and is proving to be a very reliable predictor of soil P requirements and of likely response to P fertiliser application of various broad acre crops. Other research has also shown that DGT is potentially a suitable test for other plant species including Maize and tomato. The method differs from conventional P testing in that it mimics the plants roots by up taking P through diffusional sources only by employing an Fe based membrane, rather than a chemical extraction which can changed soil conditions drastically e.g. pH and dilution.

DGT interpretation ranges are outlined below (Mason, unpublished data, GRDC)

Category	CROP			
	BARLEY	WHEAT	FIELD PEA	CANOLA
Very Low	0-20	0-20	0-17	0-10
Low	21-45	21-45	18-34	11-20
Marginal	45-67	46-56	35-74	21-24
Adequate	68-110	57-100	75-100	25-44
High	>110	>100	>100	>44

Required P rate at certain DGT values (wheat only);

DGT (ug/L)	P RATE (kg/ha)
13	25
15	23
20	18
25	14
30	11
35	9
40	7
45	5
50	4
55	3
60	2

Limitations of DGT at the moment are that due to its recent introduction it has a small database of results in comparison to established tests e.g. Colwell P. In theory DGT cannot attempt to mimic the action of some plant roots which are able to significantly modify the soil chemistry in their immediate vicinity through root exudates in order to mobilise sources of P. Therefore it may not be applicable to all plant species.

8.9 Total Phosphorus

Method:

Total P (9A)-

Unlike the above methods that test plant available P, total P determines the total amount of P in your soil, both available and unavailable. This can be a useful tool in assessment of the soils P storage capacity and overall decline or mining of soil P.

8.10 Still not sure which soil test you should use? Test them out yourself

There will be continued debate over which soil P test if most suitable in a given situation therefore if you are unsure include your own response trial. This will be particularly important if you combine two soil tests (e.g. DGT vs Colwell P) and values indicate contrastingly levels of available P for your soil type. Strip trials while simplistic should provide an idea which test is suitable and whether or not a shift needs to be made. There are some important things to consider if you chose this approach.

Strip trial (area of no P fertiliser, either broad acre crops or pastures)

1) Make sure there is an area/strip of no P fertiliser – soil test critical values have been established from response trials that have assessed the penalty in regards to % maximum yield if no P inputs were made.
2) Run each strip up and down any slope or variation in the landscape not across them
3) If using MAP or DAP make sure that N is either balanced or non-limiting to ensure any response is from P and not N
4) Why not add a couple of rates? Standard rate one side and double the rate the other side – this will provide confidence that standard/maintenance rates are adequate for your particular scenario.

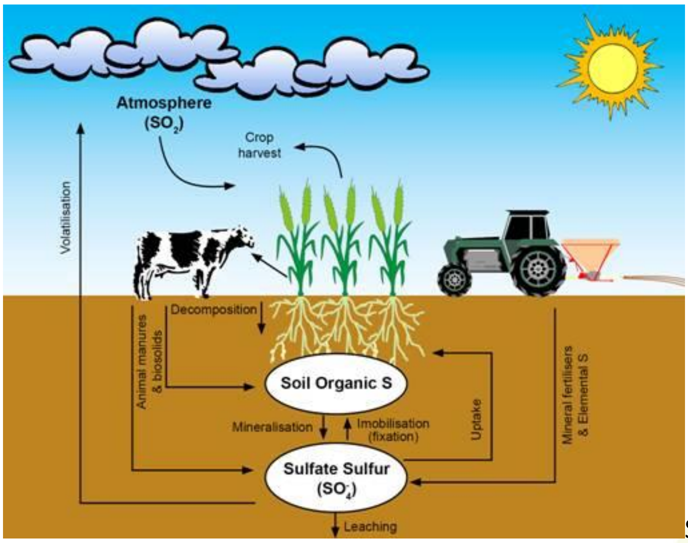
9. Sulphur (KCL & MCP)

Sulphur (KCL) **9C** – Potassium Chloride

Sulphur (MCP) **9C** – 0.01 M monocalcium phosphate (MCP)

Plants require S in the sulphate form and hence the majority of tests measure this fraction. A large percentage of S in the soil is organic bonded and divided into sulphate ester S and carbon bonded S. Although not readily available these organic S compounds may potentially contribute to the S supply during the growing season (through mineralisation).

The amount of inorganic S in the soil at any time is the net effect of the mineralisation of the organic S, the net immobilisation or leaching of mineral S and inputs from fertiliser or the atmosphere. Soil microorganisms are primarily responsible for the mineralisation of organic S, therefore biological activity and factors that influence microbial populations (temperature/moisture) will determine the rate of S available to plants.



Source:Arris (www.arris.com.au)

The percentage of adsorbed sulphur depends on the amount of Al and Fe oxides, the type of clay and the presence of organic complexes and carbonates.

What is the difference between MCP and KCL Sulphur?

The KCl-40 soil sulfur test uses weak potassium chloride heated to 40•C for three hours to extract sulfur from the soil. It removes most of the sulfur already in the sulfate form and releases some organic sulfur. The fraction of sulfur released is about the amount that is available to plants. The key difference between the KCl-40 and MCP tests is the inability of the MCP to sample the organic sulfur pool, and hence it can underestimate the soil sulphate supplying capacity.

This is particularly relevant for dairy pastures, which often have thick root mats and therefore a significant potential to supply sulphur via organic matter breakdown. The accumulation of organic matter is soil can occur through the incorporation of stubbles, pasture residues, animal excreta or by reduced tillage, which can all increase the organic sulphur pool.

Although the adequate ranges are similar, the KCl 40 test is considered more accurate because it takes into account some of the sulphur that will become available from the breakdown of organic matter. So if your soils are high in organic matter lean towards the KCL method.

Sulphur like Nitrate N is affected by soil mineralisation and leaching processes so is more accurate when measured to depth.

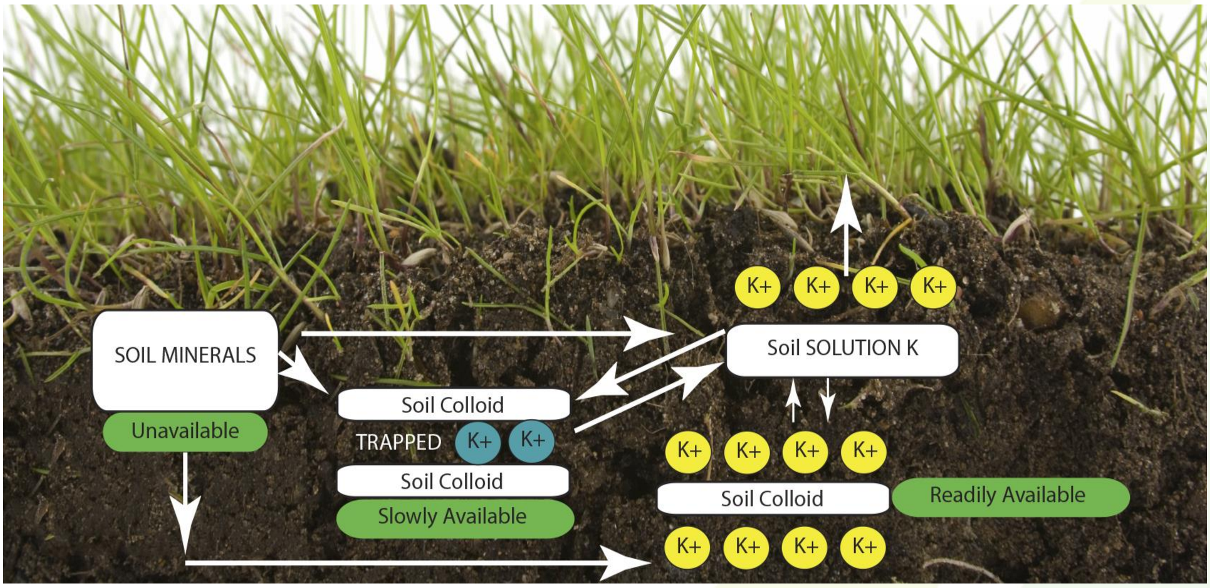
10. Potassium (Colwell)

Soil tests will measure exchangeable K or extractable K. Colwell K will measure extractable K in soil solution. Exchangeable K methods are discussed in exchangeable cations. The critical values for

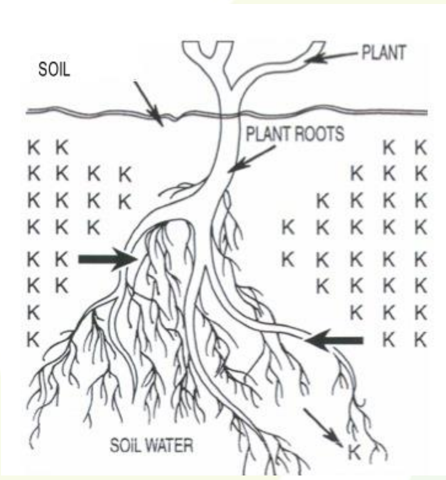
surface soils are generally around 0.2-0.5 cmol(+)/kg or 80-250 mg/kg (ppm). The levels can be significantly lower on sandier soils.

Potassium is one of the most abundant elements in soil. The total K in soil will be dependent on soil parent material, the extent of weathering and leaching of soil minerals, the type of clay minerals, soil texture, organic matter content and K fertiliser history. Much of the potassium occurring in soils is not available to plants and crops, therefore soils containing high levels of K can still be responsive to K fertilisers.

The uptake of K by plants is almost entirely from the K in soil solution. Colwell (extractable K) will measure the water soluble (Soil solution K), exchangeable and a small amount of fixed K fractions.



Soil solution K is found in soil water and moves by diffusion into the plant root. Exchangeable K is on the surface of clay and organic colloids, the size of this fraction will depend of CEC of the soil as well as pH. K is displaced in acid soils. The trapped K (between certain clays) is only very slowly available.



Source: IPNI: Potassium moves to plant roots either by slow diffusion or it taken up directly in exchange with soil colloids. Both can be slow processes. Because of the way K moves and is taken up, there are several things that cause problems when trying to predict K responsiveness using soil tests. These include:

1. Dry soil will mean K cannot be accessed, due to limited diffusion
2. In high yielding situations K diffusion can be slow and may not meet crop demands
3. Rooting patterns differ among crops, with fibrous rooted plants tend to exploit more K than that of tap rooted plants
4. Different species have different K demands
5. Other Cations can affect K demand through competition, substitution or physical disruption

Potassium interpretation is reliant on soil texture/soil type, as sandy soils have a lower potassium holding capacity than clay soils and K may leach before the plants can use it. A soil with higher clay content will have the ability to fix or provide more exchangeable K.

Potassium has being examined looking at surface texture by critical value relationship for pastures (Gourley et al, 2007). The desired crop ranges presented in APAL reports will take into account soil texture. Where soil texture is not tested, we calculate from CEC.

Soil texture	Critical value[1]	Confidence interval[2]	Number of experiments	Equation[3] % maximum yield =
Sand	126	109-142	50	$100 \times (1 - e^{-0.024 \times \text{Colwell K}})$
Sandy loam	139	126-157	122	$100 \times (1 - e^{-0.022 \times \text{Colwell K}})$
Sandy clay loam	143	127-173	75	$100 \times (1 - e^{-0.021 \times \text{Colwell K}})$
Clay loam	161	151-182	194	$100 \times (1 - e^{-0.019 \times \text{Colwell K}})$

[1] Soil test value (mg/kg) at 95% of predicted maximum pasture yield.
[2] 95% chance that this range covers the critical soil test value.
[3] e = Euler's constant (approx 2.71828).

Predicating K response is reliable on sandier soils, but due the increase trapped and fixed K fractions in heavier soil it can be less reliable. The Better Fertiliser decision for Crops (BFDC) project collated a large data set on K responses and critical values for Colwell K. In using this interpretation data we need to keep in mind that is was predominantly correlated on sandier soils (Western Australia). The critical ranges for heavier soil types will be increased. Deeper sampling is being used more frequently where k can leach on coarse acid soils (Anderson, et al 2013).

Critical 0 to 10 cm Colwell-K soil test ranges (Brennan and Bell 2013) for a range of soil orders (values in mg/kg). Values are the 95 per cent confidence range to achieve 90 per cent of maximum yield.

Soil	Wheat	Canola	Lupin
All Soils	**41-49**	**43-47**	**22-28**
Chromosols	35-45		
Ferrosols (Brown)	57-70		
Kandosols	45-52		
Tenosols	32-52	44-49	22-27
Tenosols 2-3 t/ha	37-48		
Tenosols > 3 t/ha	51-57		

Recent research in the northern cropping zones has shown that K is becoming depleted, particularly in the subsoil. Deeper soil tests have become more common (30cm) and estimates of the buffering capacity and associated cations used to re define the critical levels. The following table shows the expected effects of CEC, profile and other cations on the critical level.

The following research was conducted in northern vertosols. As magnesium and sodium can affect the availability of K they are shown as High Mg (>30% of CEC) and High Na (> 6 % of CEC).

CEC	**Topsoil (0-10 cm)**		**Subsoil (10-30 cm)**	
	Ex-K (mg/kg)	**If High Mg/Na***	**Ex-K (mg/kg)**	**If high Mg/Na***
< 30 cmol/kg	80	160	40	80
30-60 cmol/kg	160	240	120	200
> 60 cmol/kg	200	400	200	310

11. Exchangeable Cations (Ca, Mg, K, Na)

Method: Ammonium Acetate

Cation exchange capacity is the capacity of the soil to hold and exchange cations. Refer to ECEC above for more information. All exchangeable cations (Ca, Mg, K, Na) are plotted against crop nutritional requirements) or critical levels. For plant nutrition, a critical factor is whether the net amount of cations (Ca or K) in the soil is adequate for plant growth.

ECEC Percentages (Base saturation modelling)

As part of APALs premium report cation ratios (or ECEC base saturation %) are presented as well as the critical factors for plant nutrition. Testing exchangeable acidity allow the laboratory to accurately indicate the presence of Al and H+ ions in acidic soils.

The eCEC portion of your soil test is most useful for determining soil structural problems and high aluminium or sodium levels. A good indication of excess cations in your soil which may affect structure or nutrient availability. CEC is also a good indicator of soil texture. The CEC depends on the amount and kinds of clay and organic matter that are present. A high clay soil can hold more nutrients than a low clay soil. Also CEC increases as organic matter increases. Therefore, sandy soils with low organic matter have a lower CEC than clay soils.

The ratio of exchangeable calcium to exchangeable magnesium provides a guide to a soil's structure and any potential problems that might be influencing soil drainage, root development and subsequent plant growth. Well-structured soils have a calcium-to-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 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. A magnesium-to-potassium ratio of less than 1.5 indicates an increased chance of grass tetany (although many other factors influence the occurrence of grass tetany as well).

Exchangeable Sodium Percentage (ESP) is used to indicate if soils have sodic properties, i.e the cation exchange complex is saturated with too much sodium. Sodic soils are often dispersive with poor structural characteristics.

ESP Classification:

<6% non sodic

6-15% sodic

>15% strongly sodic

Exchangeable Cation	eCEC %	Comments
Calcium	60-75	
Magnesium	10-20	>20% may cause K deficiency or Ca deficiency on Ca sensitive plants such as apples, sometimes related to poorly structured surface soils.
Potassium	3-8	>10% may cause Mg deficiency, can lead to dispersion in combination with sodium (CROSS ratio)
Sodium	<1	>6%, then the soil may be sodic and susceptible to dispersion – where a soil may lose structural integrity, compact and form surface crusts. High Na levels can induce K deficiency
Aluminium	<1	
Hydrogen	5-10	

eCEC base saturation <5 should be treated with caution as it can give misleading results in regard to soil structure.

Note, on calcareous soils inflated levels of Ca are extracted and on saline soils soluble sodium needs to be identified to give accurate ESP.

12. Chlorides

It is speculated that Cl can compete with Nitrate uptake in plants. Most soil Cl is highly soluble and is found predominantly dissolved in the soil water. Chloride is found in the soil as the Chloride anion. Being an anion it is fully mobile except where held by soil anion exchange sites (Iron and Aluminium

Oxides). In areas where rainfall is relatively high and internal soil drainage is good, it may be leached from the soil profile.

The interpretation will take into account soil texture. Critical levels for salinity;

120 sands to sandy loam

180 loam to clay loam

300 clays

13. Aluminium

Method:

Extractable aluminium closely follows soil pH and becomes a problem when the pH (water) is less than 5.5. Where extractable aluminium is >2, sensitive plants will be affected.

Aluminium toxicity:

Excess soluble/available aluminum (Al^{+++}) is toxic to plants and can cause a number of issues. Some issue cause can include

- Direct toxicity, primarily seen as stunted roots
- Reduces the availability of phosphorus, through the formation of Al-P compounds
- Reduces the availability of sulfur, through the formation of Al-S compounds
- Reduces the availability of other cations through competitive interaction
- Reduced rhizobium levels on legumes

14. Trace elements (DTPA)

Method: DTPA

Although only required in small amounts, minor nutrients (micronutrients or trace elements) are essential for plant growth. Critical levels for trace elements will vary between soil types and plants. Soil testing for trace elements can be a guide; however we always recommend further confirmation or investigation through tissue sampling. Availability of trace elements will depend on a range of factors:

- Amount of carbonate present- Mn, Zn, Cu are less available and tied up into insoluble forms in high pH and calcareous soils. Use leaf tissue analysis
- Iron deficiency- is often observed on calcareous and high pH soils. Can be amplified by poor drainage or wet conditions
- Soil texture- adequate levels will reduce in sandy soils than loams and clays. Sands are often inherently low on trace elements
- Soil moisture- dry conditions can result in less movement of nutrients into the plant. Marginal levels can result in deficiencies occurring in dryer conditions-particularly for Mn and Cu.

15. Extractable Boron

Method: 0.01 M Hot Calcium Chloride

- 1:2 soil: extract

Boron is quite often present in subsoil layers, this needs to be considered when interpreting Boron results in the 0-10 layer. Boron deficiency is more common in horticultural crops, in particularly on acid soils. Deficiencies are seen less in broad acre crops and pastures. Boron toxicity may occur in sensitive crops when >5. Toxic layers are more frequent at depth. For cereal crops the most reliant indicator of boron toxicity is analysis of the grain.

Soil levels >15 are generally considered toxic for dry land cereals.

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