Understanding the properties of South Australian agricultural soils.[1]

SOUTH AUSTRALIA

Government of South Australia
Department for Environment and Water

Understanding Soils

South Australia's agricultural soils support the growth of a wide range of plants and organisms that function in the soil.

Looking beneath the soil surface to where plant roots grow helps land managers to understand soils better by identifying their limitations and opportunities for improvement.

Soils have inherent features that is, those that are result of soil formation processes. For example, there are high concentrations of salt in soils formed from marine sediments.

There are various ways to learn about soil properties:

- Refer to "Soils of Southern South Australia"

- View soil data from soil characterisation sites on NatureMaps (Figure 1)

Figure 1 Example of NatureMaps map showing soil characterisation data sites

- View soil profiles in walls of soil pits

- Examine soil cores

- Investigate soil properties using field tests or laboratory analysis.

Key Physical Properties

Soil texture

Soil texture refers to the percentage of sand, silt and clay particles that make up the mineral fraction of the soil (Figure 2). The texture classes can range from sand to heavy clay.
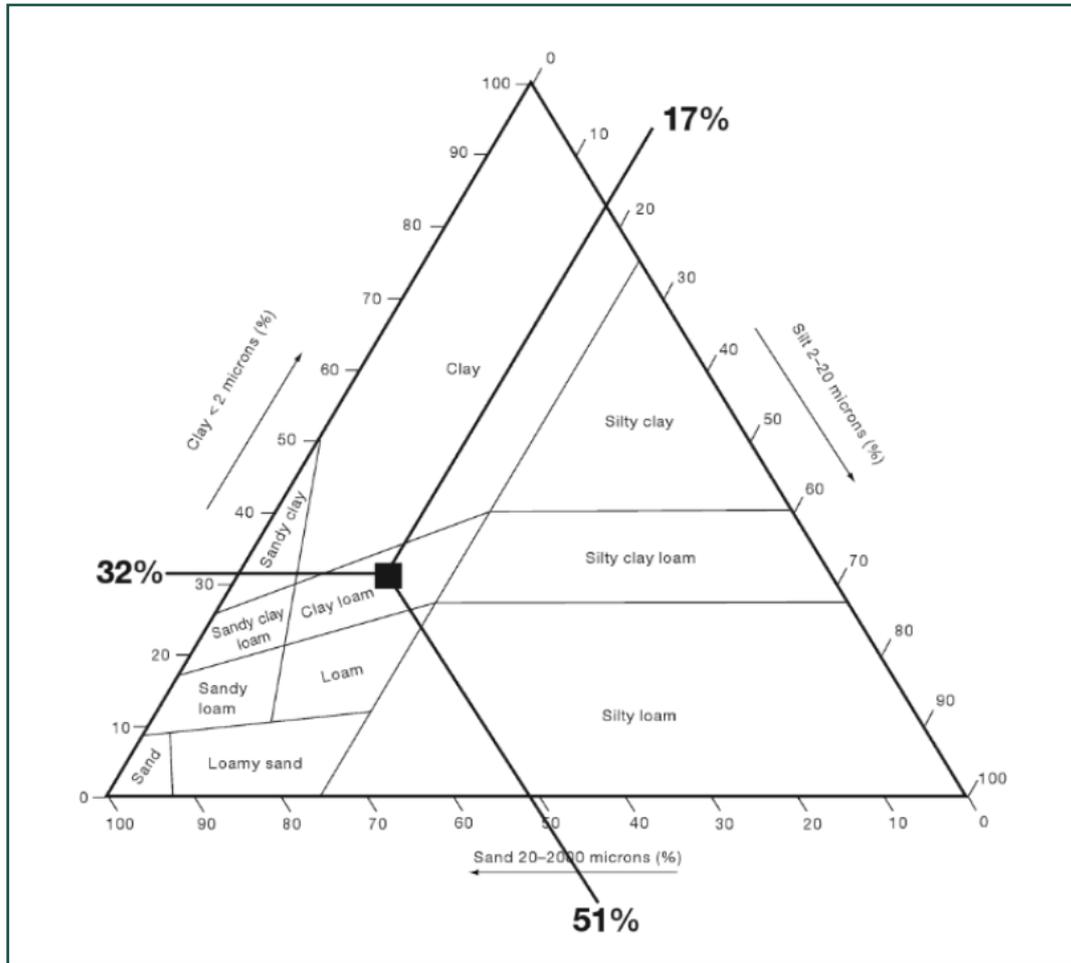

Figure 2: Composition of soil textural classes (from Price 2006)

The percentage of clay in a soil can be estimated in the field by making a ribbon of the wet soil and measuring the ribbon's length.

Take a handful of the soil and crumble it, then wet it. Work it in the hand until it is smooth and the moisture is even, (about 1 minute). Squeeze it out into a flat ribbon 2-3 mm thick and see how long a ribbon can be made (Figure 3). The length of the ribbon indicates the clay content of the soil (Table 1).

Figure 3: Determining soil texture in the field

Table 1: Field texture chart

Behaviour of soil ball	Ribbon (mm)	Clay Content (%)	Texture Grade
Ball will not form	0	0-5	Sand
Ball just holds together	5	5	Loamy sand
Sticky – ball just holds together – leaves clay stain on fingers	5-15	5-10	Clayey sand
Ball holds together – feels very sandy but spongy	15-25	10-20	Sandy loam
Ball holds together – feels smooth and silky	25	25	Silty loam
Ball holds together – feels smooth and spongy	25	25	Loam
Ball holds together firmly – feels sandy and plastic	25-40	20-30	Sandy clay Loam
Ball holds together firmly – feels smooth, silky and plastic	40-50	30-35	Silty clay loam
Ball holds together firmly – feels smooth and plastic	40-50	30-35	Clay loam
Ball holds together strongly – feels plastic	50-75	35-40	Light clay
Ball holds together very strongly - feels like plasticine	>75	40-50	Medium clay
Ball holds together very strongly, difficult to manipulate – feels like stiff plasticine	>75	>50	Heavy clay

Properties of texture grades

Soil texture affects the water holding capacity of the soil and the amount of plant available water (Figure 4). Sand holds little water, but gives it up to plants easily, whereas clay holds a lot of water but it can be held tightly within the clay structure and be more difficult for plants to extract.

Soils with low clay content (sands) have poor water holding capacity and poor nutrient storage characteristics but are usually well drained and highly pervious. Wind erosion and water repellence can be problems on sandy soils.

Clay soils have high nutrient and water storage properties, although heavy clays tend to hold water so tightly that it is difficult for plants to access. They can be more difficult to work and might have structural problems that restrict drainage, leading to waterlogging.

Sandy-loam surface soils can set hard and form a seal at the soil surface. For these soils, the application of gypsum and/or the retention of plant residues can help to improve water infiltration, workability and seedling emergence.
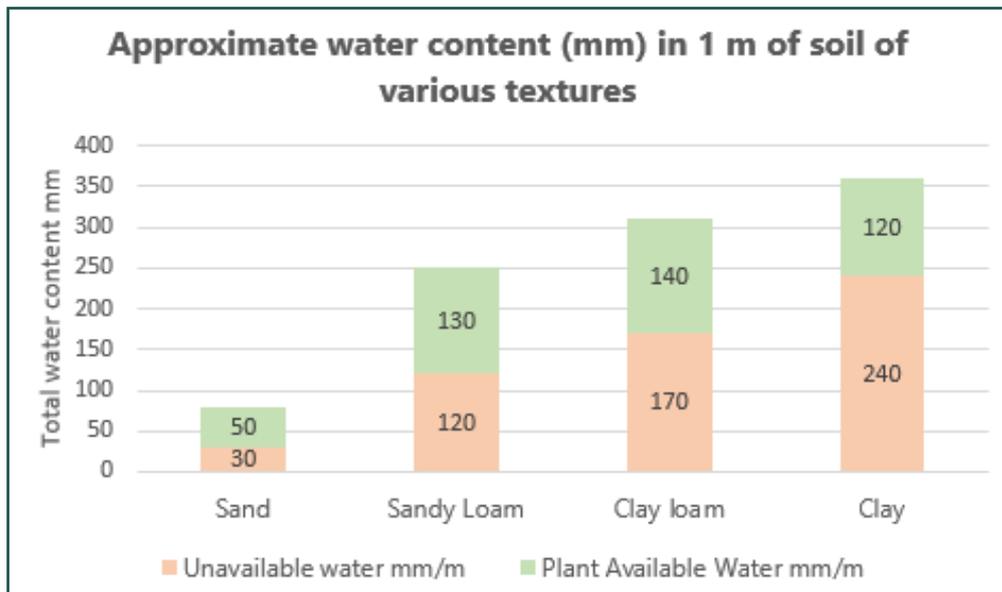
Figure 4: Plant-available water contents of different texture classes

Clayey sub-soils can affect root growth for similar reasons. Increasing clay percentages at depth increases the likelihood of high-strength clays that can form a physical barrier. There is also greater likelihood of unfavourable chemical characteristics including high pH, high boron concentrations, high sodium and high salt content.

They can also have very low permeability that causes waterlogging during periods of high rainfall. Restrictive sub-soils reduce effective soil depth and therefore water holding capacity. Frequent "top-ups" of rainfall are needed and there is greater dependence on rainfall during spring to finish crops.

Digging a soil pit can examine the depth to which roots are growing and possible constraints to their growth. A combination of laboratory analysis and the field method described above can identify these. The solution to physical root growth restriction may include deeper cultivation or ripping. If the problem is chemical in nature, then the solution may lie in the choice of crop or cultivar or the addition of gypsum and organic material.

Table 2: Properties of different soil textures

Property	Texture Grades				
	Sands	**Sandy loams**	**Loams**	**Clay loams**	**Clays**
Total available water	Very low to low	Low to medium	High to medium	Medium to high	Medium to low
Infiltration	Very fast	Fast to medium	Medium	Medium to slow	Slow
Nutrient supply capacity	Low	Low to medium	Medium	Medium to high	High
Leachability	High	High to moderate	Moderate	Moderate to low	Low
Tendency to hard setting or surface sealing	Low	High	High to moderate	Medium	Medium to low
Susceptibility to compaction	Low	Moderate	Moderate to high	Low	High

Soil Structure

Soil structure refers to the way soil particles are arranged together and interconnected. Well-structured soils enable better infiltration of rainfall, drainage and root growth. Poorly-structured soils can be subject to waterlogging, erosion and compaction.

Surface soil structure

The surface soil's structure is often indicated by how friable or loose the soil appears. Loose sand or crumbly soils allow water and air to enter and circulate freely in the soil. Massive or coarse-structured soils, soils that set hard upon drying, or slake and disperse upon wetting have poor soil structure.

Hard-setting soil can be caused by either lack of organic matter, sodicity, compaction or the proportions of sand to clay in the soil. Dispersive soils are structurally unstable and readily break down into constituent particles (clay, silt, sand) in water. Slaking soils slump and fall apart but do not have a cloudy suspension of clay particles surrounding the lumps of soil (Figure 5).

Clay dispersion (sodicity) results from high levels of exchangeable sodium. This is distinct from salinity that has high levels of sodium chloride (common salt) and has the opposite effect. Slaking is found in clays that are highly weathered and/or have low organic carbon levels.

To test for dispersion and slaking, place a large crumb of clay (about the size of a marble) in a glass or jar of distilled water or clean rainwater without shaking or stirring the sample. (Do not use mains or bore water as they contain salts that can prevent dispersion or slaking.) Slaking clay will slump and fall apart in the water, forming a small blob of mud on the saucer, but the water will remain clear. Dispersion will result in a milky cloud forming around the soil crumb after 30 minutes.
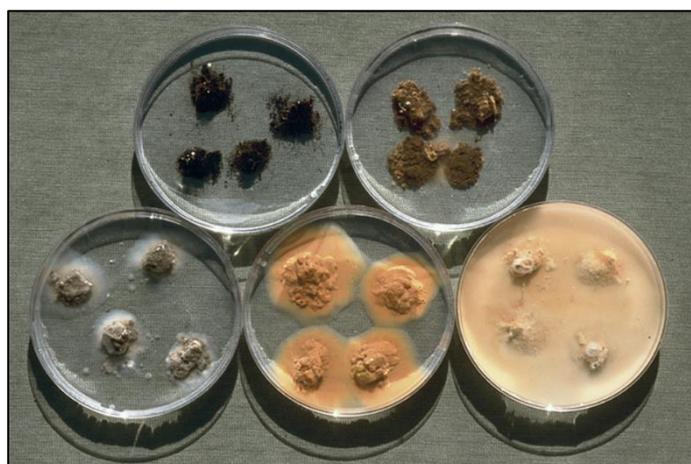

Figure 5: Slaking (top row right) and dispersion (bottom row) of samples of clay soils (from Maschmedt 2002)

Slaking soils often do not respond to gypsum applications. Soil structure can be improved by reducing mechanical disturbance and increasing soil organic matter. Gypsum ($CaSO_4$) ameliorates sodicity by replacing sodium ions with calcium ions that hold the clay structure in stronger ionic bonds. It is possible for a clay to both slake and disperse.

The dispersiveness of a soil can be indicated by a soil test in which exchangeable sodium percentage (ESP) is measured. Critical values are provided in Table 3.

Table 3: Exchangeable Sodium Percentage as an indicator of sodicity

Non sodic	ESP < 6%
Sodic	ESP 6 - 15%
Strongly Sodic	ESP > 15%

(from Maschmedt 2002)

In some laboratory analyses, exchangeable sodium percentage can be overestimated where high concentrations of sodium chloride are present. In such soils, salinity must be addressed rather than soil sodicity.

Sub-surface soil structure

The subsoil's structure is the inherent physical nature of a soil, determined mainly by soil texture, clay type and the cation composition of clay exchange surfaces. Structure is assessed according to the size, shape and strength of soil aggregates.

High concentrations of exchangeable calcium cause aggregation of clay particles, forming good, friable structure. High exchangeable sodium concentrations of 6% or more cause dispersion of clay particles and clogging of soil pores. Poor structure restricts drainage, causes waterlogging and impedes root exploration of the soil, limiting plants' access to water and nutrients. High exchangeable potassium concentrations can (rarely) cause dispersion. High exchangeable magnesium concentrations are often associated with poor soil structure.

Non-wetting soils

Non-wetting or "water repellence" occurs where waxy residues of broken down plant material coat sand particles, resulting in uneven soil wetting. Generally found in the top 5 centimetres of sandy soils, this property affects crop germination and emergence, reducing yields and increasing wind erosion risk.

A quick field method of assessing water repellence is the water / ethanol absorption test. Drops of rainwater and ethanol are applied to a soil sample. Methylated spirits at a concentration of 24 ml to 200ml of water can be substituted for ethanol. The rate at which water enters the soil is measured (Table 4)

Table 4: Field measurement of water repellence

Non repellent	Water absorbed in less than 10 seconds
Repellent	Water takes longer than 10 seconds to be absorbed. Ethanol/ methylated spirits is absorbed in less than 10 seconds
Strongly repellent	Ethanol/ methylated spirits takes longer than 10 seconds to be absorbed

(from Maschmedt 2002)

Clay spreading and delving are effective methods for overcoming water repellence. Clay particles can have up to ten thousand times the surface area of sand particles therefore mixing clay into sand increases the surface area of soil particles and water is absorbed more quickly.

Stones

The presence of surface stone can indicate that a soil is shallow or there are stones within the profile. Either way, the water holding capacity of the soil is reduced, affecting a plant's ability to grow. The type of stone can provide an indicator of soil characteristics, for example, limestone (calcrete) is often linked to calcareous soil types that have nutrient deficiencies and limit crop choice.

Colour

When soil pits are dug, layers or horizons of soil are often differentiated by colour. The colour of a soil is an indicator of soil condition and potential rooting depth.

- Soils with bright colours (particularly red) indicate they are well aerated and moderately well drained.

- Darker coloured surface soils indicate high organic carbon levels and are often more fertile.

- Very pale or white colours indicate considerable leaching and poor fertility

- Reddish colours often indicate the presence of iron.

- Lighter pale red or off-white colours down the profile and into the sub-soil may be related to the presence of soil carbonates (lime), either as soft, fine earth carbonate or rubble.

- Grey clayey subsoils with orange and yellow mottles and often a light bleached layer above the clay, indicate poor drainage. Anaerobic conditions during waterlogged periods or leaching of elements change the colour of the soil.

Key Chemical Properties

Soil pH

The pH of a soil indicates whether it is acid or alkaline which in turn provides an indication of nutrient availability. Soil pH can also affect the way in which agricultural fertilisers and herbicides react in the soil for example, sulfonylurea herbicides break down very slowly in alkaline soils compared to neutral or acidic soils. Most agricultural plants and soil biota prefer a pH of 6 – 8.5 (H_2O) or 5 – 7.5 ($CaCl_2$).

Soil pH can be measured in a laboratory or assessed using a field test kit.

In the laboratory, two methods are used – one where a reading is taken using water, the other using calcium chloride in the testing solution. Results are given indicating the solution used in the analysis, i.e. pH (H_2O) or pH ($CaCl_2$). A $CaCl_2$ analysis gives a more accurate result in neutral to acid soils but is 0.5 to 1.0 units lower than the pH(H_2O) result. Therefore, interpretation of pH results always needs to consider which test was used.

A field pH test kit (Figure 6) gives a reasonably accurate (within 0.5 pH units) measurement to a laboratory pH(H_2O) value but is likely to be between 0.5 to 1 units higher than the laboratory pH($CaCl_2$) value. Kits are usually available in hardware or garden stores and can do up to 100 tests.

Figure 6: Examples of pH field test kits

The field test requires placing some soil on a plastic card. Indicator solution is dripped onto the soil then a puff of white powder is applied. The colour the white powder turns to is compared against a colour chart that indicates the soil's pH.

The pH scale ranges from 1 to 14 and is a measure of hydrogen ions in the soil – the more hydrogen, the greater the acidity. Low pH values have high concentrations of hydrogen ions and are considered acid. High pH values reflect low levels of hydrogen ions and are alkaline (Table 5).

Table 5: pH ranges

	pH ($CaCl_2$)	pH (H_2O)
strongly acid	< 4.5	< 5.5
acid	4.5 – 5.4	5.5 – 6.4
neutral	5.5 – 6.9	6.5 – 7.9
alkaline	7.0 – 8.5	8.0 – 9.2
strongly alkaline	> 8.5	> 9.2

Acidic soils can have low availability of magnesium, copper and zinc and be high in concentrations of toxic elements such as aluminium and manganese (Figure 7). Soils with pH above 8 are alkaline and suggest the presence of calcium carbonate which reduces the availability of phosphorous, iron, zinc, manganese and copper.
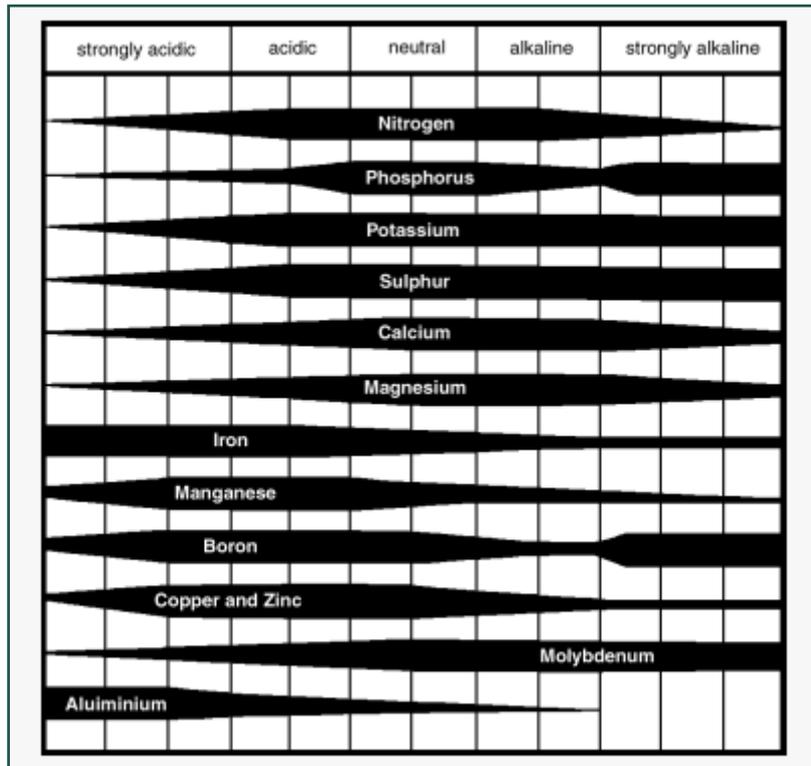
Figure 7: Influence of pH on nutrient availability (from Brady, 1984).

Carbonates

Carbonates are a group of compounds that include calcium (lime, calcrete) and magnesium carbonates (dolomite). High carbonate levels affect soil pH and can "tie up" nutrients. The presence of soft carbonates indicates the depth of the wetting front over a very long (geologic) time – in drier environments, soft carbonates are at or near the soil surface whereas in wetter environments, carbonate has been leached from the soil profile.

The presence of carbonates can be determined by dripping a weak acid solution (usually 1 part hydrochloric acid to 9 parts water) onto a soil sample (Figure 8). If the soil contains carbonate, the carbonate will react, making a fizzing sound and a visible reaction. The strength of the reaction indicates the amount of carbonate present (Table 6)

Figure 8: Acid reaction (Fizz test) for detecting carbonates

Table 6: Acid reaction test (Fizz test) as an indicator of carbonate content

Reaction	Strength of Effervescence	Approx. % carbonate
Nil	none	less than 0.5
Slight	audible	0.5 to 1.5
Moderate	audible and slightly visible	1.5 to 8
High	easily visible	1.5 to 8
Very High	strong visible fizz, bubbles jump up	more than 8

(from Maschmedt, 2005)

A fizz test shows the presence of carbonate but is an imprecise estimation of the amount of it and a laboratory test is required for greater accuracy if using for a purpose such as clay spreading. A rule of thumb for checking clay for clay spreading is "if it has high fizz, don't spread it!" as phosphorus and manganese deficiencies are likely to result.

Organic Carbon (%)

Soil organic carbon (SOC) is the measurable part of carbon in soil organic matter (OM) and includes all living and dead organic material less than 2mm in size. Soil OC is approximately 58% of OM by weight, with the remaining 42% mostly consisting of hydrogen, oxygen, with lesser amounts of nutrients such as nitrogen, sulphur, phosphorus, potassium, calcium and magnesium.

SOC is critical for soil health and function including stabilising soil structure, improving water infiltration and storage, capture and release of nutrients, sustaining and diversifying soil biota and offsetting greenhouse gas emissions.

There are several methods for measuring organic carbon. Some methods also measure inorganic carbon such as that found in lime and for this reason the most common analysis used in South Australia is the Walkley/Black method.

Soil organic carbon stocks are fundamentally related to:

- The amount of organic input which is largely determined by rainfall. Constraints to production, type of land use and management practices influence the achievement of maximum growth per millimetre of rainfall.

- The carbon retention capacity of the soil which is largely determined by clay content, management practices and temperature.

  Pasture and crop residues provide organic matter to soils but residues are rapidly broken down in soils by microbial activity. Tillage increases oxygen supplies to soil biota thereby accelerating breakdown of organic matter. Tillage also physically breaks down fungal hyphae and clay aggregates. Clay aggregates encase and protect organic carbon from microbial attack, so breaking up clay aggregates accelerates depletion of soil organic carbon.

Organic carbon percentages for different soil textures are shown in Table 7.

Table 7: Organic carbon percentage values for different soil texture classes.

Texture	Low	Moderate	High
Sand	< 0.5	0.5 - 1.5	> 1.5
Loamy sand	< 0.7	0.7 – 1.8	> 1.8
Sandy loam	< 0.9	0.9 – 2.3	> 2.3
Loam	< 1.1	1.1 – 2.5	> 2.5
Clay loam	< 1.2	1.2 – 2.3	> 2.3
Clay	< 1.0	1.0 – 1.9	> 1.9
All textures	< 1.0	1.0 – 2.2	> 2.2

(from Schapel et al, 2021)

Ion exchange properties and Cation Exchange Capacity (CEC)

Physical and chemical properties of most soils are influenced by their ion-charge characteristics, including the amount and balance of individual ions. Of particular importance are the exchangeable cations (calcium, magnesium, sodium, potassium and aluminium) and the cation exchange capacity.

Exchangeable cations are positive ions bound to the surfaces of clay particles (that are mostly negatively charged) and organic carbon (-ve and +ve) (Figure 9)
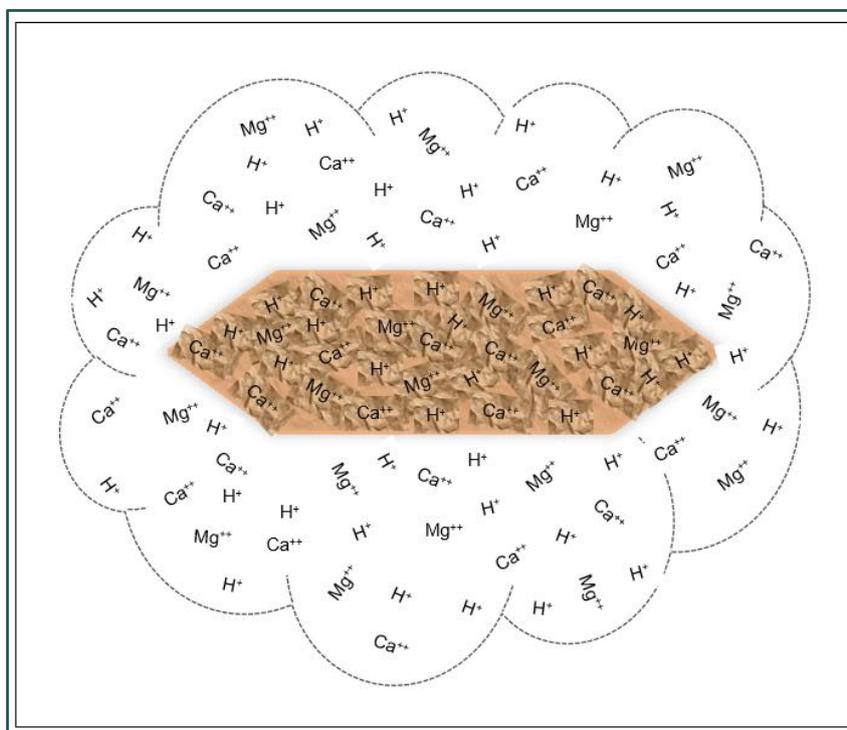

Figure 9: A clay particle's surface of negative charges balanced by swarms of adsorbed positive ions (cations)

The Cation Exchange Capacity (CEC) is a measure of the soils ability to attract, hold and exchange cations. The cation exchange capacity is associated with the amount and type of clay and organic carbon and, to a lesser extent, soil pH. The higher the CEC, the higher the potential fertility of a soil and the lesser the leaching of nutrients (Table 8).

Table 8: Range of common CEC values for different soil textures

Sands	1 - 4
Sandy loams	7 - 12
Loams	12 - 20
Clay loams	15 - 25
Clays	20 – 60

(from Hughes 2005)

Very low CEC values (<5) are an indication of low inherent soil fertility. These values are commonly found in sandy soils and some acidic soils.

Ratios of cations can influence soil structure. High proportions of sodium, potassium and magnesium relative to calcium may indicate a soil structure problem. A ratio of calcium: magnesium <2, or an exchangeable sodium percentage of >6, suggest that problems such as poor drainage might occur. Exchangeable calcium ideally accounts for at least two thirds of the CEC.

Salts, gypsum or carbonate in soils can cause an over-estimation of exchangeable cations resulting in higher CEC values than for other soils in the same texture class. Different methods of measuring CEC can give different results, particularly when using tests developed overseas that have not been calibrated for Australian soils.

Plant nutrition and soil

Plants require eighteen nutrients. Each nutrient, although required in differing amounts, is important for healthy plant growth. Macronutrients are those required in relatively large amounts whereas micronutrients (or trace elements) are required in small or even minute amounts (Table 9).

Table 9: Nutrients required for plant growth

Non Mineral	Macronutrients	Micronutrients ("Trace Elements")
Carbon	Nitrogen	Iron
Hydrogen	Phosphorus	Copper
Oxygen	Potassium	Zinc
	Sulphur	Manganese
	Calcium	Molybdenum
	Magnesium	Boron
		Nickel
		Sodium
		Chlorine

Most plants derive mineral nutrients from the soil through their roots (except for legumes where nitrogen from the atmosphere is converted to nitrate in root nodules). Nutrients enter the root via (Figure 10);

- Soil solution;
- Exchangeable ions that bind to soil particles;
- Readily decomposable minerals.

There is strong interaction between these sources. Some ions are largely in the soil solution e.g. nitrite, chloride and sodium while others are held more as exchangeable ions on soil particles e.g. potassium, bicarbonate and phosphorus.
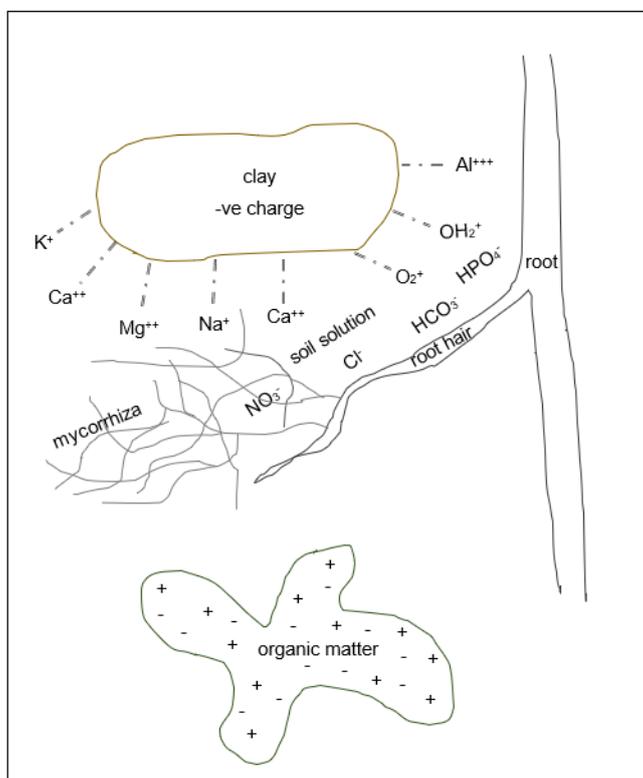

Figure 10: Soil nutrients around plant root

Soil analysis for plant nutrients and critical values for major nutrients in dryland agriculture.

Soil analysis can determine the concentrations of many nutrients in the soil however the form and availability of some nutrients (e.g. sulphur and nitrogen) is highly variable depending on soil moisture and temperature.

Soil tests provide important information for fertiliser management but results must be interpreted in the context of other soil data including texture, pH, CEC and concentrations of other nutrients. Paddock history, knowledge and experience of soils on a property, should also be taken into consideration as there are few, if any "right" levels. An "adequate" phosphorus level on one soil in a specific season might be marginal or deficient in a different season or for a different soil type. If the potential of a soil is limited due to factors other than nutrition e.g. root disease, no amount of fertiliser will lift the yield beyond that potential.

Phosphorus and Potassium

Table 10 shows critical values for phosphorus and potassium that have been developed from field trial data.

Table 10: Critical values for phosphorus and potassium in dryland agricultural production*

	High	Adequate	Marginal	Low	Very low
Phosphorus (Colwell test) *mg/kg*					
Crops Non-calcareous soils	> 45	30 - 45	20 - 30	10 - 20	< 10
Crops Calcareous soils	> 45	35 - 45	25 - 35	15 - 25	< 15
Pastures	> 45	25 - 45	18 - 25	10 - 18	< 10
Extractable **Potassium** *mg/kg*					
Permanent pasture and dryland cropping	> 250	120 - 250	80 - 120	< 80	

*note values calibrated for 0-10 cm soil depth
(from Hughes et al -)

Colwell test phosphorus values are only a guide for crop or pasture phosphorus fertiliser requirements. Phosphorus requirements are based on previous and targeted crop yields, stocking rates and paddock history, as well as soil phosphorus status. On sandy soils that readily leach, adequate values can be considerably lower or difficult to reach. Colwell P values of highly calcareous soils are compromised by high P fixation.

PBI - Phosphorus buffering index

Phosphorus applied in granular fertilisers dissolves rapidly and is then subject to a range of processes such as combining with other soil elements (such as iron and aluminium), adsorption to clay and organic carbon particles, and leaching. PBI supports Colwell P analysis by providing a measure of bonding and leaching potential.

Higher PBI values indicate a stronger potential for "tie up" and a significant proportion of applied phosphorus will be unavailable to plants. A very low PBI indicates that there may be potential for phosphorus to leach (these soils often have low Colwell P values as well).

Colwell P, PBI and a crop's expected phosphorus demand, all need to be considered when determining fertiliser applications. A soil with a high PBI value will quickly tie up P and make it unavailable to plants therefore phosphorus fertiliser rates might need to be increased to compensate for the P that is unavailable (Table 11).

Table 11: Critical Colwell P values for PBI ranges

PBI		Critical Colwell P value or range (mg/kg)	
Value	Category	Pasture	Wheat
< 15	Extremely Low	20-24	10
15 – 35	Very, very Low	24-27	16
36 - 70	Very Low	27-31	22
71 - 140	Low	31-36	29
141 - 280	Moderate	36-44	38
281 - 840	High	44-64	43
> 840	Very High	n/a	n/a

(based on Moody 2007 and Gourley et al 2007)

DGT – Diffusive Gradients in Thin-films Phosphorus

DGT phosphorus measures the diffusion of available phosphorus sources in the soil towards a phosphorus sink in the form of a ferrihydrite (iron oxide) gel.

It overcomes other tests' over-estimation of available phosphorus on certain soil types such as calcareous soils or acidic soils with high amounts of aluminium and iron.

The DGT test not only measures available phosphorus but also can predict phosphorus rates required to maximise yields. Table 12 provides phosphorus status of soils according to DGT values.

Table 12: Phosphorus status of soils according to DGT test values for selected crops

Crop	Very Low	Low	Marginal	Adequate	High
Wheat	0 - 20	21 - 45	46 - 56	57 - 100	> 100
Barley	0 - 20	21 - 45	46 - 67	68 - 110	> 110
Field Peas	0 - 17	18 - 34	35 - 74	75 - 100	> 100
Canola	0 – 10	11 – 20	21 – 24	25 – 44	> 44

(from Mason -)

Nitrate Nitrogen

Nitrate is highly mobile in the soil, transported in soil solution and can rapidly change its form through mineralisation. Soil testing to depths of 60 cm for nitrate can help measure plant-available nitrogen.

Measurements of soil nitrate and ammonium in a depth of soil can be converted to kilograms per hectare of available nitrogen by calculating:

Available soil N (kg/ha) = (nitrate N (ppm) + ammonium N (ppm))
X soil bulk density
X depth (cm) / 10

Bulk densities for soil texture classes are provided in Table 13.

Table 13: Bulk densities (g/cm3) of various texture classes

Texture class	Bulk density (g/cm^3)
sand - siliceous	1.3 – 1.8
sand - shell	1.0 – 1.2
sandy loam	1.3 – 1.7
hard massive loam	1.3 – 1.6
calcareous loam	1.1 – 1.4
friable clay loam	1.3 – 1.5
hard massive clay loam	1.3 – 1.6
self-mulching clay	1.2 – 1.3
friable subsoil clay	1.3 – 1.5
poorly structured subsoil clay	1.5 – 2.1

(from Maschmedt 2002)

Sulphate Sulphur

Most sulphate ions are in soil solution as they are not strongly adsorbed by clay and organic matter exchange surfaces. Sulphate moves through the soil in the soil solution and is readily leached from plants' root zones. In low rainfall environments, sulphate accumulates in the subsoil. Soil testing to depths of 60 cm provides a more accurate estimation of soil sulphur reserves. Measurements of sulphate in ppm can be converted to kg/ha as for nitrate nitrogen.

Trace elements

Soil test interpretation is difficult as critical concentrations vary between soil types and plants. Availability varies through the season. Provided the growth status of the plant is not significantly constrained by other factors such as low rainfall or root disease, plant tissue analysis is more useful in determining trace element deficiencies. It is probably the only method appropriate for calcareous soils but for other soil types, a combination of soil and tissue testing can be used. Availability of trace elements will vary depending on a range of factors including:

- Amount of carbonate present - manganese and iron are less available in high pH calcareous soils, resulting in low values.

- Soil texture - generally "adequate" levels are lower in sandy soils than loams and clays.

- Soil moisture – dry conditions can result in less movement of nutrients into the plant.

- Soil, disease or nutritional constraints that limit root growth

Marginal levels of trace elements can result in deficiencies occurring in drier conditions – particularly manganese and copper.

Soil types and characteristics where trace element deficiencies are most likely to occur, and critical soil test values are provided in Table 14.

Table 14: Situations where main trace element deficiencies are most likely to occur, soil tests values and reliability.

Trace element	Situation of likely deficiency	Soil test type and values
Copper	Mainly acid and calcareous sands. Intermittently on a range of other soil types.	DTPA Critical value <0.2 – 0.4
Manganese	Highly calcareous soils, particularly sands with more than 60% free carbonate. Ironstone soils and some acid sands. Soils that have been over-limed or irrigated with alkaline water.	DTPA Critical value < 5 mg/kg unreliable test
Zinc	Calcareous soils of all texture ranges including clays. Acid sands and acid to neutral sandy or loamy texture contrast soils.	DTPA Critical value <0.2 – at least 0.4 mg/kg; higher on alkaline clay soils. Critical values vary with pH, clay content and organic matter content
Molybdenum	Sandy, acid or ironstone soils in high rainfall areas.	$CaCl_2$ Mo < 0.1 mg/kg unreliable test
Iron	Calcareous or poorly drained soils.	
Boron	Sandy acidic soils with low organic matter. Boron toxicity is more often a problem than boron deficiency.	HWS B Critical value deficiency <0.5 mg/kg Critical value toxicity (sensitive crops) > 5.0 mg/kg Critical value toxicity (tolerant crops) > 15.0 mg/kg

(from Anon 2013)

Soil toxicities

Salinity

Two forms of salinity commonly occur in dryland agricultural areas of South Australia. These are:

- Dryland Salinity or "Water table induced salinity" – this type of salinity is caused by rising ground water tables, often the result of the clearance of deep rooted perennial vegetation. Management of this type of salinity requires either using water before it reaches the water table (through high water-use perennial vegetation, crops or pastures) or lower the ground water table at the discharge point by improved drainage.

- Dry Saline Land or "Magnesia patch" is caused by the natural presence of high levels of salts in the soil profile. Salts in soil solution move up and down the soil profile depending on rainfall (leaching) and evaporation (capillary rise or "wicking"). Symptoms of dry saline land are generally more noticeable in drier years where the wetting front does not extend very deeply into the soil.

A field method for measuring salinity is by using a salinity meter and a soil-water mixture of 1 part soil to 5 parts water. The electrical conductivity (EC) of the 1:5 soil/water suspension is measured (dS/m). The reading is then multiplied by a texture-based conversion factor (Table 15) to give an estimate of electrical conductivity (ECe).

Table 15: Texture factors for converting EC to ECe

Soil Texture	Factor 1:5 soil:water by volume	Factor 1:5 soil:water by weight
sand to clayey sand	6.0	14.0
sandy loam to clay loam	5.0	9.5
clays	3.5	6.5

(from Maschmedt 2002)

Laboratory analysis uses a Saturation Paste Extract method to determine an ECe. The method resembles soil conditions experienced by plants more closely and provides more repeatable results.

Table 16 shows classification of salinity according to ECe values.

Table 16: ECe values and (surface) salinity grade

ECe (mS/cm)	Assessment
0-2	Low salinity
2-4	May affect sensitive crops
4-8	Yields of many crops affected
8-16	Only tolerant crops yield well
16-32	Salt tolerant species only
32+	Too salty for plant growth

(from Hall et al 2009)

Boron

Boron toxicity can occur in dryland cereals where boron levels exceed 15 mg/kg (ppm) and in sensitive crops when greater than 5 mg/kg. High boron levels usually occur with carbonate and high soil salinity and can be an indicator of the historic wetting front.

Aluminium

High levels of soil extractable aluminium are closely related to soil pH. In soils where significant amounts of aluminium are present aluminium toxicity becomes an issue when soil pH (CaCl2) is less than 5.0. Where extractable aluminium is >2 mg/kg, sensitive plants will be affected.

Chloride

High levels of chloride are an indicator of salinity. Generally, plant damage can occur where chloride levels are in the range 120 mg/kg in sands to 300 mg/kg in clays.

Calculating Fertiliser Requirements

Determining how much of nutrients are needed in fertiliser applications requires consideration of soil test analyses, the amount of nutrients removed in products (Table 17) and the amount of expected "tie up" according to soil type. Enough fertiliser should be supplied to replace what has been removed in previous crops and to meet the nutritional needs of the next crop (based on a target yield) as well as adding to the "soil nutrient bank" where soil tests indicate deficiencies

To convert from a mg/kg result from a soil test to kg/ha of nutrient, 1 mg/kg is approximately 1 kg/ha (assuming a soil bulk density of 1). For a more accurate determination, use bulk densities for various soil textures listed in Table 13.

Common fertiliser products

Phosphatic fertilisers include single, double and triple superphosphate; and ground phosphate rock, ranging in phosphorus contents of nearly 9% to 20%.

Phosphorus-nitrogen blends include ammonium phosphate sulphate, mono-ammonium and di-ammonium phosphate and have phosphorus contents ranging from 7% to 20% and nitrogen proportions of 9% to 18%.

Nitrogenous fertilisers include urea, anhydrous ammonia, aqua ammonia, ammonium nitrate and ammonium sulphate.

Gypsum is a soil conditioner but as it has a sulphur component of approximately 10% to 18%, it is commonly used to provide sulphur for crops.

Some of these fertilisers can be coated with sulphur or blended with certain elements such as zinc and copper to provide additional nutrients.

The composition of various fertilisers and soil amendments is provided in Table 18.

The appropriate application rate of a fertiliser is calculated from determining the desired application rate of a nutrient (kg/ha) and dividing it by the percentage of that nutrient in the selected product. For example, the amount of single superphosphate (8.6% P) required to supply 18 kg/ha of P is:

$$\frac{18 \text{ kg/ha}}{8.6/100} = 18 \times 100/8.6 = 209 \text{ kg/ha of single superphosphate}$$

Table 17: Nutrients removed in crop and livestock products

Product	N	P	K	S	Ca	Mg	Cu	Fe	Mn	Zn
	kg nutrient / t product						g nutrient / t product			
Wheat – high protein	21.8	3.3	3.3	1.4	0.3	0.9				
Wheat – standard protein	17.7	2.4	3.4	1.4	0.3	1.0				
Barley	19.2	2.9	4.4	1.1	.4	1.1	3		11	15
Oats	16.5	3.0	3.9	1.5	0.5	1.0	3		40	17
Lupin – sweet	51.2	3.0	8.0	2.3	2.2	1.6				
Lupin – Albus	57.3	3.6	8.8	2.5	2.0	1.3				
Field pea	37.1	4.0	8.2	2.0	0.7	1.2				
Chick pea – Desi	32.2	3.6	8.2	1.8	1.8	1.4				38
Chick pea – Kabuli	34.4	3.8	8.9	1.8	1.1	1.2				
Faba bean	38.6	3.8	9.8	1.4	1.1	1.0	10		30	28
Common vetch	44.4	3.8		0.8						
Lentil	38.4	3.2		0.6						
Canola	40.0	6.5	9.2	9.8	4.1	4.0	4		40	40
Safflower	26.0	4.1	8.0	4.0	2.0	2.2	7		30	25
Cereal hay	20.0	2.0	12.0	1.5	12.0	3.0				
Legume hay	30.0	3.0	22.0	2.0	10.0	5.0				
Mixed hay	25.0	2.5	17.0	2.5	9.0	4.0	8		15	20
Greasy wool	170	0.3	15.8	28.5	1.2	0.3				
Milk	5.7	1.0	1.4	0.3	1.2	0.1				
Sheep live	34.0	7.0	2.3	4.0	14.4	0.4				
Cattle live	32.6	8.0	2.2	3.9	16.4	0.4				
Sheep live wt gain	21.0	6.0	1.8	1.7	11.0	1.7				
Cattle live wt gain	21.0	8.0	1.8	1.5	14.0	1.5				
Dung	3.0	0.7	1.3	0.4	2.0	0.7				

(from Price (ed) 2006)

Table 18: Composition of fertilisers and soil amendments

Fertiliser	Approximate percentage of principal elements				
	N	P	K	S	Ca
Anhydrous ammonia	82				
Aqua ammonia	20.5				
Urea	46				
Ammonium nitrate	34				
Calcium ammonium nitrate	21-27				8-14
Calcium nitrate	15.5				19
Ammonium sulphate	20-21			24	
Ammonium phosphate sulphate	14-18	7-12		12-17	
Mono-ammonium phosphate (MAP)	10-12	22		1-2	
Sulphur-coated MAP	9	19		12	1.7
Di-ammonium phosphate (DAP)	18	20		1-3	
Sulphur-coated DAP	16	18		12	0.6
Sodium nitrate	16				
Ground phosphate rock / reactive phosphate rock		11-16			30-37
Single superphosphate		8.9		11	18-20
Sulphur-fortified single superphosphate		5-8		25-45	12-17
Double / triple superphosphate		17-20		1-4	15-16
Sulphur-coated triple superphosphate		16		20	11.8
Powdered sulphur				100	
Gypsum				10-18	12-20
Lime					35-40
Dolomite (8-13% magnesium)					16-21
Potassium chloride (muriate of potash)			48-51		
Potassium nitrate	13		37-38		
Potassium sulphate (sulphate of potash			40-42	16	
Blood and bone	4-7	3-9			8-15

(from Price (ed) 2006)

Common soil amendments in agriculture

It is possible to overcome some soil constraints using soil amendments.

- **Lime** (calcium carbonate) $CaCO_3$
  - counteracts soil acidity
  - can help to improve soil structure on dispersive soils with low pH
- **Dolomite** (magnesium carbonate) $MgCO_3$
  - counteracts soil acidity soils where magnesium is also required
- **Gypsum** (calcium sulphate) $CaSO_4$
  - counteracts soil sodicity;
  - used to provide sulphur and calcium as nutrients
  - does NOT correct pH on acid soils.
  - ineffective on saline soils in discharge zones.

Calculating Water Holding Capacity

The amount of water stored in the soil profile can be estimated from the depth of the rooting zone and the textures of the layers of soil in that rooting zone.

Table 19 provides a guide to the available water holding capacities for a range of texture classes.

Table 19: Approximate water holding capacities of various soil textures

Texture Group	Total Available Water (8 – 1500 kPa) mm water / m soil
Medium to coarse sand	40 – 80
Fine sand	60 – 100
Loamy sand	80 – 120
Sandy loam	100 – 140
Light sandy clay loam	110 – 170
Loam	140 – 200
Sandy clay loam	130 – 180
Clay loam	150 – 220
Clay	120 – 220

(from Maschmedt 2002)

Figures should be reduced proportionally according to the stone and gravel content of layers. The low end of the range should be used for dense, poorly structured or low organic matter soils while the higher values used for friable, well structured soils with high organic matter levels.

As an example, assume a soil has a rooting depth of 60 cm. Beyond this, root growth is restricted by salt and high alkalinity.

The top 15 cm is a sandy loam, from 15 to 40 cm is a light clay and from 40 to 60 cm is a medium clay with 25% gravel.

The amount of available water is estimated as:

0.15 m (depth) x 120 mm/m (Sandy loam Table 19)	=	18 mm
0.25 m x 160 mm/m (Light clay)	=	40 mm
0.20 m x 180 mm/m (Medium clay) x (100-25)% (gravel content)	=	27 mm
Available water in total root zone	=	85 mm

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