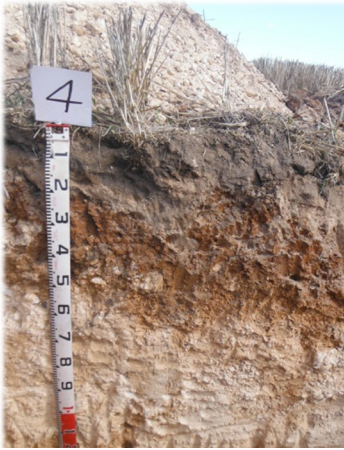


SOIL SMART: UNDERSTANDING YOUR SOILS



A farmer's guide to agricultural soils properties and their management.



Natural Resources
Northern and Yorke



Government of South Australia
Primary Industries and Regions SA



Government of South Australia
Northern and Yorke Natural Resources Management Board



Government of South Australia
Department of Environment, Water and Natural Resources

Collated by Primary Industries and Resources Rural Solutions SA Soils and Land Management Consultants, supported by the Department of Environment, Water and Natural Resources Sustainable Soils Group 2014.

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1. Understanding Your Soils

Looking beneath the soil surface where crop and pasture roots grow helps land managers to understand their soils better by investigating soil constraints and identifying opportunities to improve plant production.

Crop yield potential can be easily estimated from rainfall records. However in many years, crops do not meet their yield potential. Investigating why actual yields are significantly less than their potential can reveal opportunities to increase productivity.

Plant density, height and uniformity are good indicators of soil condition. Variations in crop growth or yield are influenced by factors including climate, disease, pests, weeds or nutrition. Improved agronomic practices have overcome many of these issues but on some soil types crops are not making the most of the rainfall and soil moisture available to them. It is likely that soil constraints are a significant part of the problem.

1.1 Soil sampling and analysis

Excavating soil pits or taking soil cores, combined with simple on-site soil tests and observations can provide useful information about soil characteristics. When backed up with laboratory analyses, many constraints and limitations to root growth and productivity can be identified.

1.2 Why have soils samples described and analysed?

Physical characteristics such as soil texture and structure can indicate a soil's drainage and ability to store water and nutrients.

Laboratory analyses can provide a range of information:

PBI = Effectiveness of phosphorus applications

Organic Carbon = Fertility, soil structure, soil texture and soil biological activity

Electrical conductivity = salinity

pH = Potential impact of acidity or alkalinity on nutrient availability and plant growth

Cation Exchange Capacity = Inherent fertility

Nutrients = Yield potential

Toxicities = Constraints to plant growth or crop types grown

They can also a “bank statement” for soil nutrients by:

- Indicating when the nutrient account is “overdrawn”
- Identify opportunities to reduce input costs where nutrient supplies are adequate
- Identify where soil nutrient reserves need to be built up or just maintained.

1.3 How to take a soil sample

Think about collecting a sample which is representative of the paddocks. Sample within a selected soil type or within precision agriculture management zones in the paddock. Avoid sampling headlands, firebreaks, sheep camps, across old fence lines etc. Consider the way fertilisers and soil conditioners are applied to the paddock for example, broadcast or banded. Sampling between rows of crop where the fertiliser is banded will probably not provide a result that is a true indicator of the soil's fertility.

Collect at least 15 soil cores of 0-10 cm depth. Soils that are suspected of having constraints lower down in the soil profile such as acidity or sodicity should also have samples taken from the 10-20 and 20-40 cm depths. Do not remove surface trash as often valuable surface soil is also removed from the sample. Thoroughly mix samples and take approximately 400 grams to send for analysis.

1.4 "Tricks" with soil testing results

Different laboratories use different methods for testing nutrient concentrations and different laboratories can use different units for expressing soil analysis results.

So

- Be aware of the tests that are appropriate for your area- i.e. Colwell vs. Olsen vs. DGT phosphorus.
- Use laboratories that use analytical techniques comparable to other sources of data and suitable for your soil type e.g. Walkley Black organic carbon; $\text{pH}_{(\text{CaCl}_2)}$ for acidic to neutral soils
- Be aware of different units of concentration used for different elements and by different laboratories, for example, mg/kg is equivalent to parts per million (ppm)

Know what the expected range and critical values should be for the various analyses.

2. Key Physical Properties of Soils

2.1 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.

Hard-setting and Surface Sealing

Hard-setting soil can be caused by either lack of organic matter, sodicity, compaction or the proportions of sand to clay in the soil. A simple but reasonably objective test to measure soil strength is to try to insert a 300mm length of 2.4mm welding rod into the soil. If the rod can be pushed through the soil with an open palm, strength is less than 1Mpa and root growth is unimpeded. If the rod can be inserted using a coin to protect the palm, strength is between 1 and 3 MPa, meaning root growth is likely to be partly restricted. Above 3Mpa, root growth is largely restricted to old root channels and cracks. This test is highly moisture dependent, so should be done when root growth is critical (e.g. at emergence, initiation of tillering and completion of tillering).

Dispersive and slaking soils

Dispersive soils are structurally unstable and readily break down into constituent particles (clay, silt, sand) in water. Highly dispersive soils are very erodible if exposed to water movement and are likely to give problems relating to workability and seedling emergence.

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.



Figure 1. Field dispersion of a number of clay samples

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 chemicals which may 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 (Figure 1). Dispersion will result in a milky layer forming around the soil crumb after 30 mins.

Slaking soils often do not respond to gypsum applications, soil structure can be improved by reducing the mechanical disturbance and increasing soil organic carbon. Gypsum addresses sodicity by replacing sodium ions with calcium ions that hold the clay structure together. It is possible for the clay to be both slaking and dispersive.

The dispersiveness of a soil may also be indicated by a soil test in which exchangeable sodium percentage (ESP) is measured. Critical values are detailed in the table below.

Table 1. Exchangeable sodium as indicator of sodicity.

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

NOTE: Depending on the laboratory used the exchangeable sodium percentage can be overestimated where high levels of sodium chloride are present. **Do not apply gypsum to saline soils as it is unlikely sodium will be displaced and the high salinity is the main issue to be addressed.**

NOTES:

2.2 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.

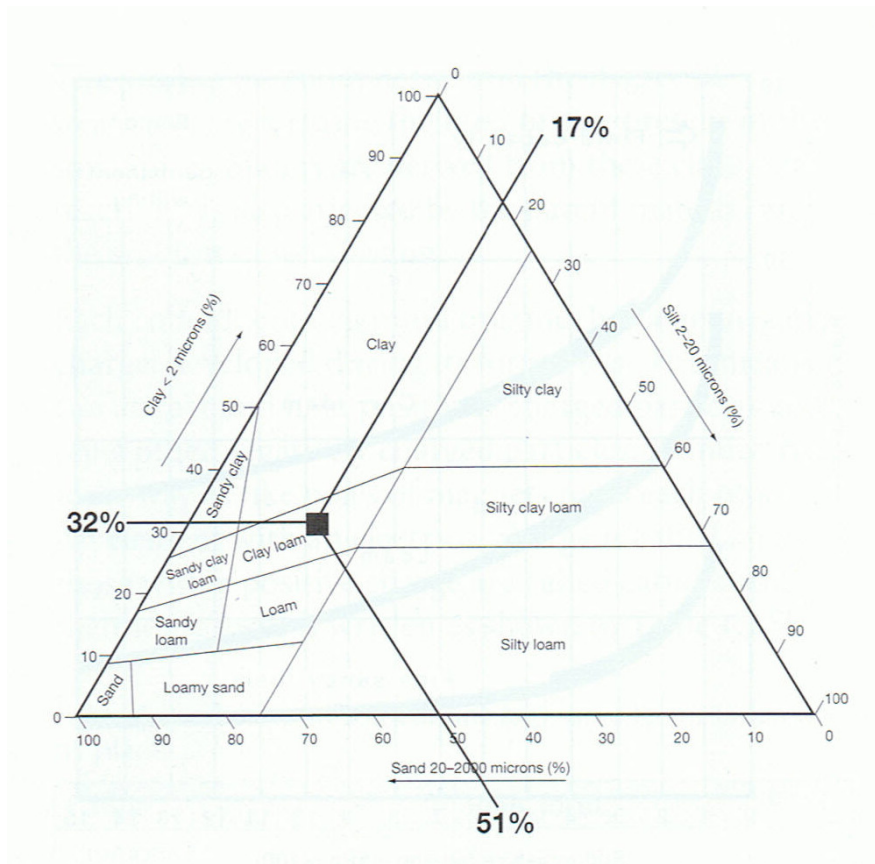


Figure 2. Composition of soil textural classes

The percentage of clay in the soil can be estimated by making a ribbon of the wet soil and measuring the 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).



Figure 3. Hand texturing soil samples in the field

Table 2: Field texture chart

Texture 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.

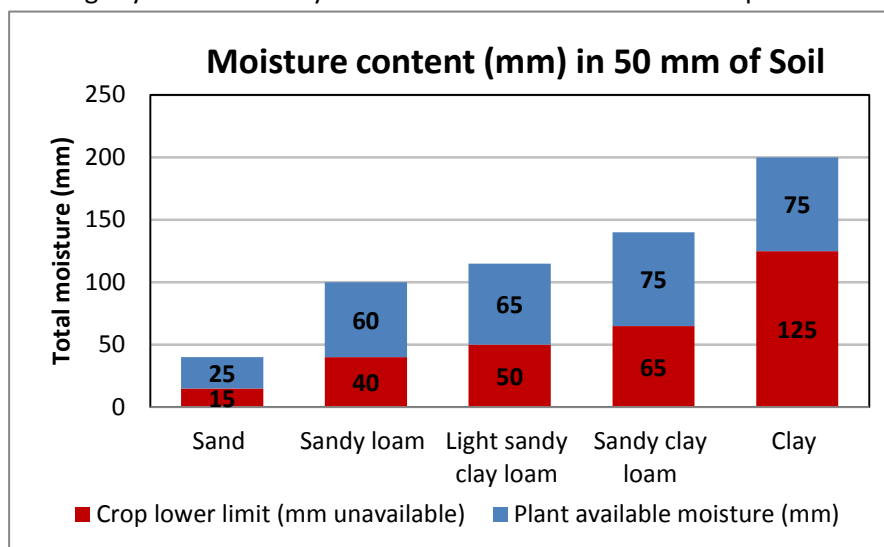


Figure 4. Plant available moisture content for different texture classes

Soils with low clay content (i.e. 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 also be more difficult to work, and can have structural problems that restrict drainage leading to waterlogging.

Sandy-loam surface soils can set hard and seal over. For these soils, the application of gypsum and/or the retention of plant residues can help to improve water infiltration, workability and seedling emergence.

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.

The can also have very low permeability which can result in water logging 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 methods 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 3: Properties of different soil texture grades

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	Low	High	High to moderate	Medium	Medium to low
Susceptibility to compaction	Low	Moderate	Moderate to high	Low	High

2.3 Non-wetting

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 5cms of sandy soils, this property impacts on crop germination and emergence, decreasing yield 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.

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

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. Thus by mixing clay into the sand, surface area is increased and water is absorbed more quickly.

2.4 Stones

The presence of surface stone may indicate that the soil is shallow or there are stones within the profile. Either way, the water holding capacity of the soil is reduced, having an impact on the plant’s ability to finish satisfactorily. Surface stone can damage and abrade equipment, and in severe stony conditions, stone picking or rolling may be necessary. 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.

2.5 Colour

When soil pits are dug, the layers or horizons are often differentiated by colour. The colour of the 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. Reddish soils can often indicate the presence of iron.
- Clayey soils that are grey 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.
- 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.
- On sandy soils there can often be a lighter coloured (bleached) layer below the darker organic surface layer. This can indicate leaching of organic matter and nutrients through the profile.

3. Key Chemical Properties of soils

3.1 Soil pH and carbonates

3.1.1 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. A field pH reading can provide an guide to a soil's acidity or alkalinity. Most agricultural plants prefer a pH of 6 – 8.5 (water).

Testing pH in the field

A field pH test kit (Figure 5) gives a reasonably accurate (within 0.5 pH units) measurement to a laboratory $\text{pH}_{(\text{water})}$ value but is likely to be between 0.5 and 1 unit higher than the laboratory $\text{pH}_{(\text{CaCl}_2)}$ value. Kits are available in most hardware or garden stores, and will do up to 100 tests.



Figure 5. Some commonly available pH field test kits

When using one of these kits, put some soil on the plastic card provided. Drop some indicator solution on the soil, mix it in then puff a little bit of the white powder onto it. The powder changes colour. Compare this colour to that on the pH card provided in the kit.

Interpreting pH results

pH test results from a laboratory will usually come back with two results: pH in water ($\text{pH}_{\text{H}_2\text{O}}$) and a reading where a salt (calcium chloride) has been added to the soil solution ($\text{pH}_{\text{CaCl}_2}$). Measurement of soil pH is highly dependent upon soil moisture content and the $\text{pH}_{(\text{water})}$ value will fluctuate depending on seasonal conditions. The addition of Calcium chloride to the soil solution can help reduce the variation in measurement and as such is a more accurate indication of the “true” pH of the soil. **$\text{pH}_{(\text{CaCl}_2)}$ values are usually 0.5 to 1.0 units lower than $\text{pH}_{(\text{water})}$**

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 levels of hydrogen ions and are considered acid. High pH values reflect low levels of hydrogen ions and are alkaline (Table 5).

Table 5: Range of pH(water) values (readings in CaCl₂ are approx. 0.5 to 1.0 units lower)

Strongly acidic	< 5.4	Slightly alkaline	7.1-7.5
Moderately acidic	5.5-6.4	Moderately alkaline	7.6-8.3
Slightly acidic	6.5-6.9	Strongly alkaline	> 8.4
Neutral	7.0		

Soils with pH less than 5.5 are acidic, and might have low available levels of magnesium, copper and zinc and be high in toxic elements such as aluminium. (Figure 6).

Soils with pH above 8 are alkaline and indicate the presence of calcium carbonate that reduces the availability of phosphorous, zinc, manganese and copper.

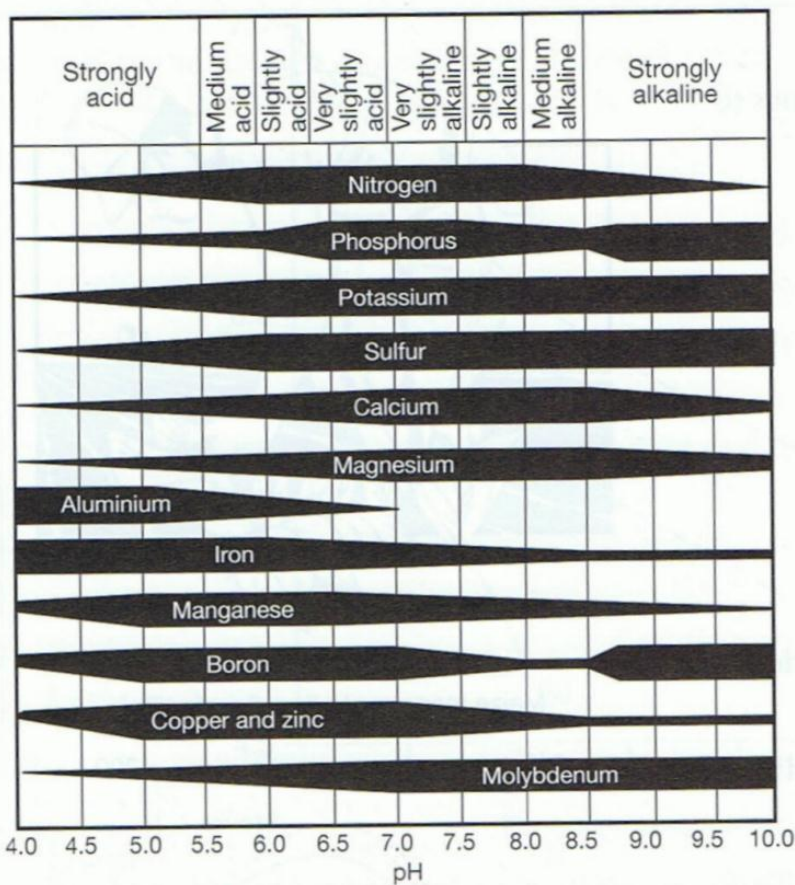


Figure 6. Influence of pH on nutrient availability

High pH levels (greater than 8.3) indicate the presence of toxicities such as sodium bicarbonate. Sodium is often associated with boron, so clays with a very high pH can be high in lime, salinity and boron.

3.1.2 Carbonates (Fizz Test)

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 such as described earlier. The presence of soft carbonates indicates the depth of the wetting front over a very long (geologic) time.

The presence of carbonates can be identified by adding a weak acid solution (usually 1 part hydrochloric acid to 9 parts water) to the soil (Figure 7). If the soil contains carbonate, the carbonate will react, making a fizzing sound and a visible reaction.

Acid is dangerous! Take care and follow all safety instructions!



Figure 7. “Fizz” test for carbonates. .

Table 6: Acid reaction test (Fizz test) as an indicator of carbonate content (Source: Maschmedt 2004)

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

A fizz test will show the presence of carbonate but only an imprecise estimation of the actual carbonate content and a soil test is required for greater accuracy if using for a purpose such as clay spreading. In this case a rule of thumb is, “if it has high fizz, don’t clay spread it”! Phosphorus and manganese deficiencies are likely to occur.

3.2 Organic Carbon (%)

Organic carbon supports provides a food source for soil biology, aids in improving soil structure, water holding capacity and nutrient retention. High organic carbon levels are generally favourable however, can also indicate low levels of biological activity due to acidity or waterlogging.

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

Table 7: Organic carbon % figure for different textural classes

Texture	Low	Moderate	High
Sand	<0.5	0.5 - 1.0	>1.0
Sandy loam	<0.7	0.7 - 1.4	>1.4
Loam	<0.9	0.9 - 1.8	>1.8
Clay loam/clay	<1.2	1.2 - 2.0	>2.0

Soil organic carbon levels are fundamentally related to:

- The amount of organic input – the upper limit is largely determined by rainfall with soil constraints to production, land use and management influencing achievement of rainfall potential.
- The carbon retention capacity of the soil - largely determined by clay content, management, and temperature.

The retention of pasture and crop residues provides organic matter to the soil but this is rapidly broken down in the soil by microbial activity. Tillage increases the oxygen supply to soil biota therefore accelerating the breakdown of organic matter and also breaks down clay aggregates that protect organic carbon from microbial attack, resulting in depletion of soil organic carbon levels.

3.3 Surface cover for erosion protection

The key benefit of maintaining surface cover and reducing tillage is protection from wind and water erosion. In order to protect sites which are inherently at risk of water erosion, ground cover on paddocks growing annual crop and pasture species should be managed to maintain a level of more than 50% surface cover in April. On steeper water erosion prone land, more cover (75%) should be maintained to slow run-off and protect against erosion.

On soils prone to wind erosion, well anchored plants or plant residues offer more protection than a surface mulch that can be blown away. Taller plants or plant residues provide better protection against wind erosion that shorter ones by deflecting wind away from the soil surface.

Soil surface cover:

- cushions soils from damaging impact of rain drops and hoofs.
- prevents wind from picking up soil particles.
- slows run-off, allowing it more time to infiltrate the soil and reduce the risk of carrying soil particles away
- minimises germination of and competition from annual grasses and broadleaf weeds in perennial grassy systems.
- binds soil particles into stable aggregates in the roots
- provides a food source for soil microbes

- traps seed and loose organic material and provides better conditions for seed germination.

Surface cover levels for erosion protection are described in the “Soil Erosion Protection Field Survey Manual” (Forward 2011). Minimum cover levels regarded as adequate to protect soils from erosion under “average” climatic conditions are detailed below (Table 8).

Table 8: Minimum surface cover levels for protection against erosion

Wind erosion prone soils	Water erosion prone soils
2 cms height of relatively even but thin plant growth or residues On high risk sites – residues 2-10 cm of moderate bulk. Plant/butt density of established grasses or cereals around 100 per square metre. Most residues well anchored	50% surface cover on flat – gently sloping land 75% surface cover on moderate – steeply sloping land.

4. Common Soil Amendments and their Agricultural Uses.

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

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

5. Soil and Plant Nutrients

5.1 Major and Minor (Trace) Elements

Plants require nineteen chemical elements. Each nutrient, although required in differing amounts, is important to the overall health of plant growth.

Table 9: Nutrients required for plant growth.

Non Mineral	Macro Nutrient	Micro Nutrients ("Trace Elements")
Carbon	Nitrogen	Iron
Hydrogen	Phosphorus	Copper
Oxygen	Sulphur	Zinc
	Potassium	Manganese
	Calcium	Molybdenum
	Magnesium	Boron
	Chlorine	Nickel
		Chloride
		Cobalt

Soil testing can identify the levels of many soil nutrients however the status of some nutrients (e.g. sulphur and nitrogen) is highly variable depending on soil moisture and temperature. While soil tests provide important information to support fertiliser management, results must be interpreted in relation with other soil data including texture, pH, CEC and the levels 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 and/or in a different soil type. If the potential of a soil is limited due to factors other than nutrition, no amount of fertiliser will lift the yield beyond that potential.

5.2 How do plants get their nutrients from the soil?

In legume crops nitrogen from the atmosphere is converted to nitrate in root nodules. However in all other cases nutrients must enter the root from either (Figure 8);

- Soil solution
- Exchangeable ions – bind to soil particle.
- Readily decomposable minerals

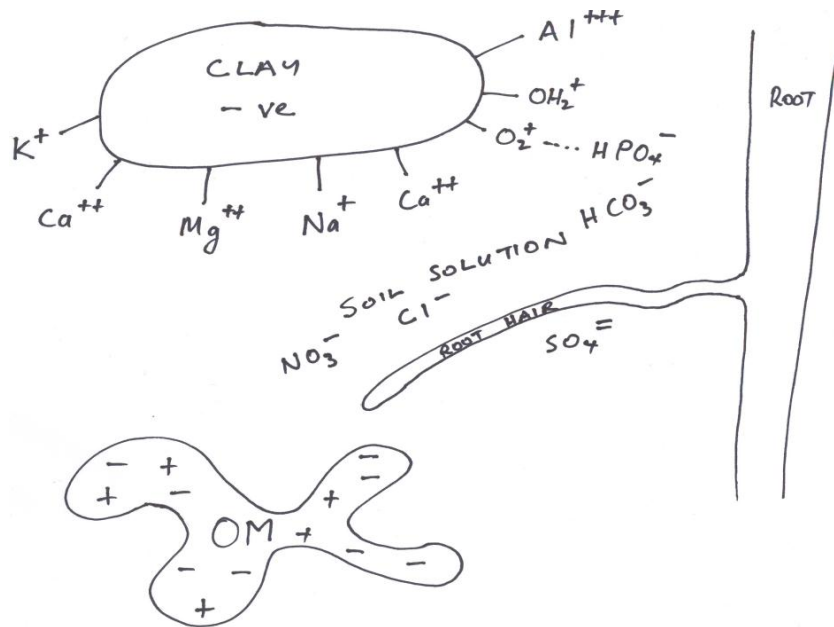


Figure 8. Soil nutrients and their common form around a plant root

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.

5.3 Ion exchange properties

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**.

5.3.1 Exchangeable Cations

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)

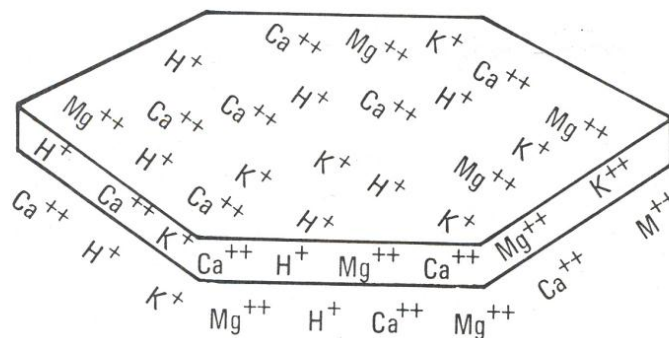


Figure 9. A clay particle with its surface store of negative charges and balancing swarm of adsorbed positive ions (cations)

5.3.2 Cation Exchange Capacity (CEC)

The CEC is a measure of the soils ability to attract, hold and exchange cations (a measure of the total negative charge of the soil). 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 10: Range of CEC values commonly found in soils of different textural classes.

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

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

The ratios of cations can be important for soil structure. High levels of sodium, potassium and magnesium relative to calcium may indicate a structural issue. If the ratio of calcium: magnesium is <2, or the exchangeable sodium % is >6 structural problems may occur in some soils.

Table 11: Desirable proportions of different cations in soil

Exchangeable Calcium	65-75 %
Exchangeable Magnesium	10-15 %
Exchangeable Sodium	0-4 %
Exchangeable Potassium	3-8 %
Exchangeable Aluminium	0-5 %

The presence of salts, gypsum or carbonate can lead to over estimation of exchangeable cations resulting in CEC values that are high than in other soils in the same texture class. Different methods of measuring CEC can lead also give different results, particularly when using tests developed in other countries that have not been effectively calibrated for Australian soils.

6. Critical Values for Major Nutrients for Dryland Agriculture

6.1 Colwell Phosphorus, Potassium and Sulphur

Table 12: Critical values for major nutrients in dryland agricultural production

	High	Adequate	Marginal	Low	Very low
Phosphorus (Colwell test) mg/kg					
Non-calcareous	>45	30-45	20-30	10-20	<10
Calcareous	>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	
Extractable Sulphur mg/kg					
Permanent pasture and dryland cropping		>10	5-10	<5	

Colwell phosphorus figures are a guide only. Actual phosphorus requirements will be based on crop yield, stocking rate, production targets as well as soil phosphorus status. On sandy soils, adequate levels can be considerably lower or difficult to reach if on leaching sandy soils. On highly calcareous soils, Colwell P is considered less accurate due to high levels of P fixation compared to non-calcareous soils.

6.2 PHOSPHORUS BUFFERING INDEX (PBI)

When applied as granular fertiliser, P dissolves rapidly and is then subject to a range of processes including 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 “tie up” and leaching potential.

Higher PBI levels (greater than 150-200) indicate a stronger potential for “tie up” and a significant proportion of P applied will be unavailable to plants. A very low PBI (below 40) indicates that there may be potential for phosphorus to leach (these soils generally have low Colwell P levels as well).

6.2.1 Making decisions on P fertiliser

Colwell P, PBI and the forecast needs of the crop for P all need to be taken into account when deciding on fertiliser application. Where PBI levels are low-moderate (40-200) soil P levels detailed in table 13 is an appropriate benchmark and there may be potential to cut back P applications where levels are above recommended minimums. Where PBI levels are greater than 200, Colwell P levels need to be higher than the minimums in the table above. There is also less opportunity to reduce phosphorus applications on these soils as “tie up” of phosphorus will continue to reduce availability.

If the intent is to build up soil Phosphorus levels, higher fertiliser rates above maintenance are required to increase the Soil P if the soil’s PBI is high.

Table 13: Critical values for Colwell P when combined with the PBI figures for grazed pastures

PBI Category		Critical Colwell P value (mg/kg) for mid point of PBI category (Range)
<15	Extremely Low	23 (20-24)
15 – 35	Very very Low	26 (24-27)
36 -70	Very Low	29 (27-31)
71 - 140	Low	34 (31-36)
141 - 280	Moderate	40 (36-44)
281 - 840	High	55 (44-64)
> 840	Very High	Insufficient data to derive a response relationship

It is strongly recommended that the soil test results should be discussed with an agronomic consultant or fertiliser supplier when making decisions based on test results.

6.3 DGT Phosphorus- An emerging new Phosphorus test

DGT phosphorus measures the diffusion of available P sources in the soil towards a P sink in the form of a ferrhydrite (Iron Oxide) gel.

This new method of P measurement is being developed by Sean Mason at the University of Adelaide and has developed critical levels for 4 crops at this stage but no calibration has yet been made for pasture species. The DGT method measures the soil water available P under field soil conditions and has a better relationship with yield responses than Colwell P, particularly non calcareous soils.

Table 14: Categories by Crop for DGT tests (from Mason), levels are still being developed and revised as more information become available

Category	Wheat	Barley	Field and Chickpeas	Canola
Very Low	0 – 20	0 – 20	0 – 20	0 – 20
Low	20 – 45	20 – 45	20 – 35	
Marginal	45 – 56	45 – 73	35 – 50	20 – 25
High	56 – 100	> 73	> 50	> 25
Very High	> 100			

6.4 Nitrate Nitrogen (mg/kg)

Soil nitrogen figures should be used as a guide only. Nitrate is highly mobile in the soil profile, moving in soil solution and can change its form rapidly with mineralisation. Nitrogen applications should be determined by assessing yield expectations, crop type, soil type, rainfall, and past and present management factors. Deep soil nitrate testing is the preferred testing as nitrate is highly soluble and can be leached deeper into profiles.

6.5 Extractable trace elements (mg/kg)

Soil test interpretation is difficult as critical concentrations vary between soil types and plants. Availability also 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 noted for manganese and copper.

Table 15: Critical values for trace elements for broad acre dryland agriculture production

Trace element	DTPA Adequate (mg/kg)
Ext. Copper	0.2
Ext. Zinc	0.5
Ext. Manganese	1.0

7. “Nasties” (Toxicities)

7.1 Salinity

There are two forms of salinity commonly referred to in dryland agriculture in South Australia. These are;

- Dryland Salinity or “Water table induced salinity” – this type of salinity is induced by rising ground water tables, often the result of the clearance of deep rooted perennial vegetation. Management of this type of salinity involves either using water before it reaches the water table (through revegetation or high water use crops or pastures) or lower the ground water table at the discharge point through improved drainage.
- Dry Saline Land or “Magnesia patch” is caused by the natural presence of high levels of salts in the soil profile. These salts 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 drying years where the wetting/leaching front is not as deep.

Salinity can be measured 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 EC conversion factor to give an estimate of electrical conductivity (ECe).

Table 16 : ECe values and their effect on plant growth

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

7.2 Boron

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

7.3 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.

7.4 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 for sands to 300 mg/kg for clays.

8. Calculating Fertiliser Requirements

To convert from mg/kg on a soil test to kg/ha of nutrient required is approximately 1 kg/ha of nutrient per mg/kg for cultivated soil can be used. However, soil bulk density will impact on this conversion.

Determining the nutrient required per hectare is based on soil test results, the nutrient removal by type and amount of crop grown (Table 18) and the amount of expected “tie up” depending on soil types. Fundamentally enough fertiliser should be supplied to meet the nutritional needs of the crop (based on a target yield) as well as add to the “soil nutrient bank” where the soil test identifies deficiencies.

Table 18: Nutrient removal by one tonne of various crops

n/a, not available.

Crop type	N (kg)	P (kg)	K (kg)	S (kg)	Ca (kg)	Mg (kg)	Cu (g)	Zn (g)	Mn (g)
Cereals									
Wheat	23	3.0	4	1.5	0.4	1.2	5	20	40
Barley	23	2.7	5	1.5	0.3	1.1	3	14	11
Oats	17	3.0	5	1.6	0.5	1.1	3	17	40
Grain legumes									
Chickpeas (Desi)	33	3.2	9	2.0	1.6	1.4	7	34	34
Chickpeas (Kabuli)	36	3.4	9	2.0	1.0	1.2	8	33	22
Faba beans	41	4.0	10	1.5	1.3	1.2	10	28	30
Lentils	40	3.9	8	1.8	0.7	0.9	7	28	14
Lupins (sweet)	53	3.0	8	2.3	2.2	1.6	5	35	18
Lupins (white)	60	3.6	10	2.4	2.0	1.4	5	30	60
Peas (field)	38	3.4	9	1.8	0.9	1.3	5	35	14
Mung beans	45	5.1	11	n/a	1.1	1.6	n/a	n/a	n/a
Soy beans	70	4.8	17	n/a	n/a	n/a	n/a	n/a	n/a
Oilseeds									
Canola	41	7.0	9	10.0	4.0	3.8	4	40	40
Linola	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Safflower	25	4.3	9	4.0	2.0	n/a	14	26	13
Pastures									
Lucerne hay	33	3.3	28	2.4	11.0	2.1	6	21	56
Lucerne seed	60	2.9	n/a	n/a	10.0	n/a	n/a	n/a	n/a
Medic hay	30	3.0	25	2.0	9.0	n/a	8	20	15
Medic seed	64	8.4	12	5.0	2.0	n/a	7	23	13

Source: Hyland (1995).

Common fertiliser products

- Single superphosphate/ goldfos/ MAP: sulphur coated – principally applied for phosphorus but also contains sulphur and calcium
- Triple superphosphate– more concentrated form of phosphorus
- MAP/DAP- High analysis fertilisers. Both N and P supplied.
- Muriate of potash – cheapest form of potassium if required, can get in super blends
- Generally speaking trace elements where required can be blended in or applied as liquids
- Urea – cheapest form of N

The particular fertiliser product used will be the one that can provide the required amounts of nutrient most cost effectively. To calculate kg/ha of the product required, decide on the amount of kg of each nutrient required to be supplied and multiply by the percentage of that nutrient in the selected product. E.g. Require 18 kg/ha P, Single super contains 8.6% P. So $18 \times 100/8.6 = 210$ kg/ha single superphosphate (Table 19).

Table 19: Compositon of soil common fertilisers and soil amendments

Fertilizer	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 sulfate	20-21	--	--	24	--
Ammonium phosphate sulfate	14-18	7-12	--	12-17	--
Mono-ammonium phosphate (MAP)	10-12	22	--	1-2	--
Sulfur-coated MAP	9	19	--	12	1.7
Di-ammonium phosphate (DAP)	18	20	--	1-3	--
Sulfur-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
Sulfur-fortified single superphosphate	--	5-8	--	25-45	12-17
Double/triple superphosphate	--	17-20	--	1-4	15-16
Sulfur-coated triple superphosphate	--	16	--	20	11.8
Powdered sulfur	--	--	--	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 sulfate (sulfate of potash)	--	--	40-42	16	--
Blood and bone	4-7	3-9	--	--	8-15

9. Estimating Water Holding Capacity

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

Table 20 provides a guide to the available water holding capacities for a range of texture classes.

Table 20: Water holding capacities of texture groups

Texture Group	Total Available Water (8 – 1500 kPa) mm / cm soil
Medium to coarse sand	0.4 – 0.8
Fine sand	0.6 – 1.0
Loamy sand	0.8 – 1.2
Sandy loam	1.0 – 1.4
Light sandy clay loam	1.1 – 1.7
Loam	1.4 – 2.0
Sandy clay loam	1.3 – 1.8
Clay loam	1.5 – 2.2
Clay	1.2 – 2.2

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 – 40 cm is a light clay and from 40 – 60 cm is a medium clay with 25% gravel. The amount of available water is estimated as:

15 cm (depth) x 1.2 mm/cm (from Table 20 Sandy loam)	=	18 mm
25 cm x 1.6 mm/cm	=	40 mm
20 cm x 1.8 mm/cm x (100-25)% (gravel content)	=	<u>27 mm</u>
Total Root Zone	=	<u>85 mm</u>

10. Key References

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