SOIL SMART NOTES

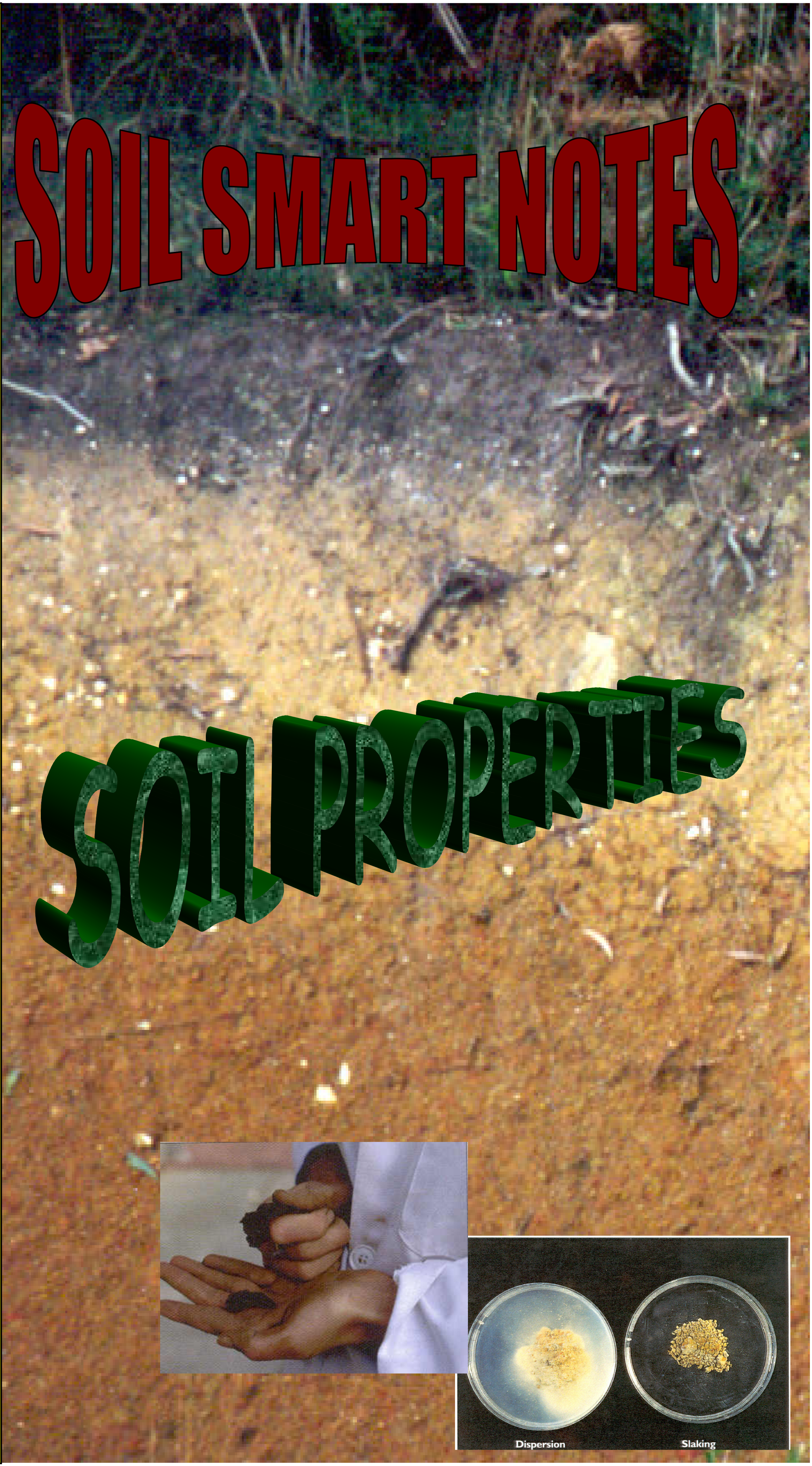
SOIL PROPERTIES

A HANDBOOK
FOR
LANDHOLDERS

TROY CLARKSON

SW REGION

DEPARTMENT OF
PRIMARY
INDUSTRIES



SOIL SMART NOTE 1.

WHAT IS SOIL?

Main Components of Soil

Soil is a highly variable medium. There are four main ingredients (fractions) that are consistent with all types of soil: minerals, organic matter, water and air. These four fractions fall into two categories: *solid* (minerals and organic matter) and *non-solid* (water and air) (Fig. 1).

The solid section makes up approximately 50-70% by volume of the total soil. Combined, the mineral and organic matter fractions give the soil a characteristic known as texture (see Note 4) (Baxter & Williams 2001).

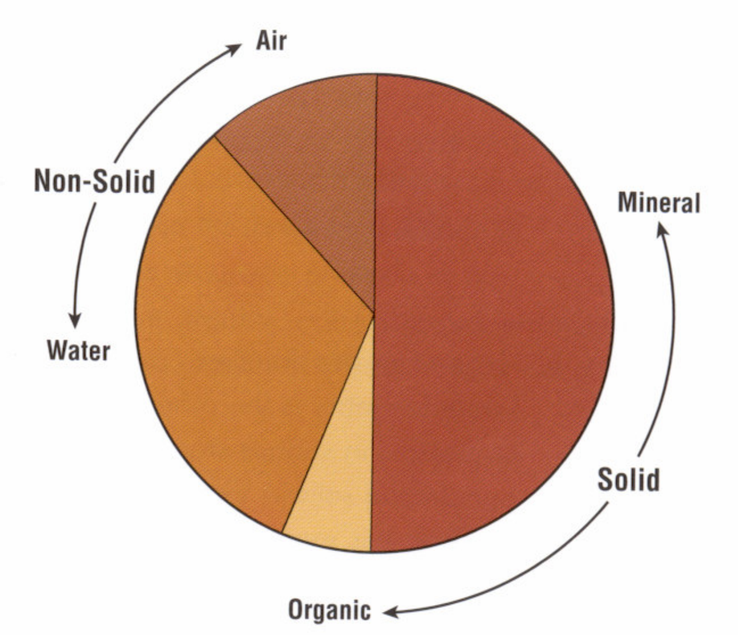


Figure 1: Approximate proportions of the four soil fractions in a typical soil (Baxter & Williams 2001).

The mineral fraction is comprised of four main particles that are defined by their diameters;

Gravel	> 2 mm
Sand	0.02-2 mm
Silt	0.002-0.02 mm
Clay	< 0.002 mm

The relative proportions of these particles play an important role in the fertility of the soil and its response to management.

Clay particles are the smallest particles of the mineral fraction. They are an important component of soil as they have a negative electrical charge. This enables them to hold and exchange nutrients (which also have an electrical charge). Clay particles in soil provide an exchange site for plant nutrients. Clay soils are normally more fertile than sandy soils.

The type and quantity of clay in the soil can affect the amount of nutrients held for plant use and the ease with which these nutrients are release to the plant. The electrical charge on clay particles enables them to stick to other clay particles and also to sand and silt particles (this is why clays are sticky).

Gravel, sand and silt particles do not have an electrical charge and therefore do not have the ability to hold and exchange plant nutrients. They do however have important roles such as aeration of the soil. Gravel and coarse sand particles are larger than clay, silt and fine sand particles, and they have bigger gaps between them. Therefore more space is available for movement of water and air through the soil (see Note 5).

A good mix of sand, silt and clay particles will allow the soil to hold sufficient nutrients as well as allowing adequate exchange of air and water essential for plant growth.

Organic matter is the other part of the solid soil category. It consists of the remains of living organisms in various stages of decomposition. In agriculture soils in Victoria, organic matter can comprise up to 6% of the solid soil fraction however it is more common for agricultural soils to have 0.5 to 3.0% organic matter. In forest soils, organic matter can comprise up to 20%.

Organic matter occurs in various forms from undecomposed to completely decomposed (humus), and all forms provide benefits for the soil. Like clay particles, humus is also electrically charged and is able to store and release nutrients. Humus is also able to increase the water holding capacity of the soil. This is particularly important for a sandy soil, which have low water holding capacity.

Micro-organisms, and often macro-organism, form the living component of the organic fraction. They feed on organic matter decomposing it to humus. Micro-organisms also live on products of living plants, some providing benefits to the plant, others creating disease. Most soil organisms decompose organic matter, release nutrients for plant growth, improve soil structure and overall are important for soil health (Baxter & Williams 2001).

Characteristics of Soil

There are three characteristics of soil that are important for plant growth and productivity: physical, chemical and biological. A change in one characteristic is likely to affect another.

Physical

These are the aspects of the soil that you can see and touch. Physical characteristics include soil texture, colour, depth, structure, porosity and stone content. The role physical properties plays in soil health are to:

- supply water and air to plant roots and allow adequate water and air movement into and through the soil profile;
- store water for plant growth;
- support machine and animal traffic; and
- stabilise vegetation.

Chemical

This determines the soil's ability to supply nutrients for plant and store nutrients in the profile without loss by leaching. The soil chemistry also stabilises clay aggregates, which impacts on soil structure.

Biological

This characteristic is important as a healthy microbial population is necessary for organic matter breakdown (faeces and crop and pasture residues), nutrient cycling and the growth of nitrogen fixing bacteria (Baxter & Williams 2001).

SOIL SMART NOTE 2.

HORIZONS

Soil Components

Soil solids are a combination of weathered minerals and organic matter. The topsoil is usually a different colour and texture from the subsoil due to the presence of organic matter and leaching processes. The organic matter is decomposing plant and animal matter and provides important nutrients and structure for the soil. Numerous micro-organisms are responsible for decomposing the organic matter into a form that can be used by plants. The weathered mineral particles are made up of many chemical compounds, in particular oxides and silicates of elements such as calcium, magnesium, potassium, sodium, iron, aluminium, sulphur and phosphorus. Australian soils are generally low in sulphur, phosphorus and nitrogen (Laffan 1992).

Soil Horizon Classification

A soil horizon is a layer within the soil profile that has different characteristics from those layers that occur below and above it.

The first task for a person is assessing his/her soil (once the soil profile is exposed) is to assign horizons and their depths. The initial decisions should be reviewed before the task. Major soil horizons are described in Table 1 and illustrated in Fig 2 (Walker *et al.* 1994).

Depth & Boundaries

In the column for depth in the soil profile description sheet, record the upper and lower limits (in cm) of the different soil horizons within the profile.

The boundary between soil horizons defines the nature of the change from one horizon to that below. This can be achieved by measuring the thickness or width of the transition zone between horizons, which can be classified as follows:

a) **Sharp or Abrupt** = boundary is less than 2 cm wide.
b) **Clear** = boundary is 2 cm to 5 cm wide.
c) **Gradual** = boundary is 5 cm to 10 cm wide.
d) **Diffuse** = boundary is more than 10 cm wide.

(McDonald et al. 1990)

Table 1: Summary of properties for different soil horizons in a profile (Walker *et al.* 1994).

- **A1** mineral horizon at or near the surface with organic matter accumulation.
- **A2** mineral horizon with less organic matter than either the A1 or B horizons, and generally of paler colour.
- **A3** transitional horizon between A and B but having properties more like the A.
- **B1** transitional horizon between A and B but having properties more like the B.
- **B2** horizon with relatively high contents of one or more of clay, iron, humus; there may be a maximum of soil structure or an intensification of colour.
- **B3** transitional between B and C horizons but has properties more like the B2.
- **C** horizon below the solum (or totally weathered soil profile), partially weathered.
- **D** horizon of soil material unlike the overlying C horizon (buried soil).
- **R** bedrock.

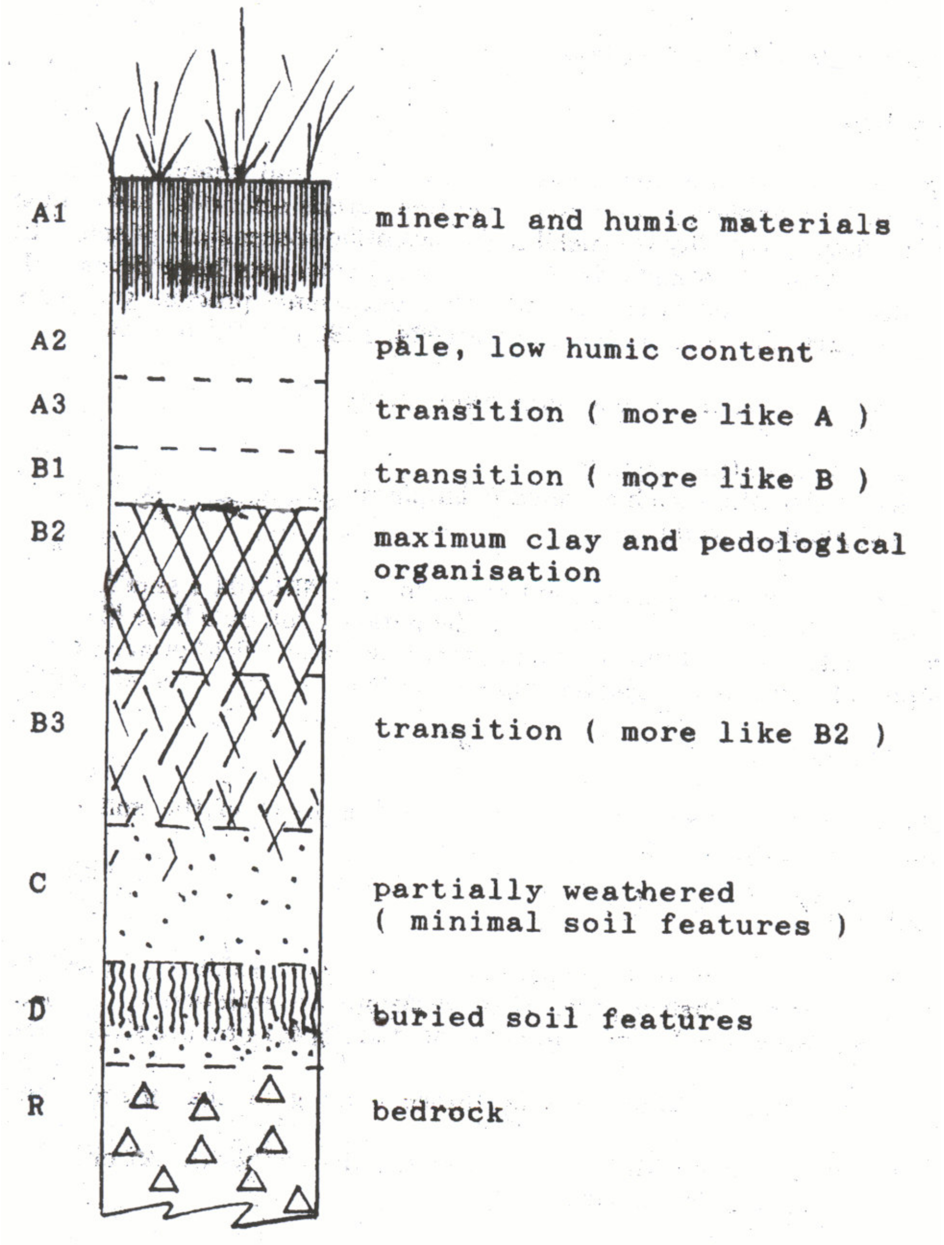


Figure 2: Main mineral horizons of the soil profile (Walker *et al.* 1994).

SOIL SMART NOTE 3

COLOUR

What is Soil Colour?

Colour is an important descriptive characteristic of soil. Colour also provides an indication of soil drainage properties, degree of leaching and organic matter content.

Colour is generally determined by organic matter and the iron compounds in the soil. Decayed organic matter gives the soil a dark colour. In well drained soil, colour can be attributed to: humus (black), iron (red) and silicates and salts (white). The colours of poorly drained soils tend to be bluey-green. Soils with low iron in them are pale grey in colour (Corbett 1969) (Table 2).

Table 2: Summary of soil colour and its implications (Corbett 1969).

Soil Colour	Interpretation
Topsoil	
Dark brown surface layer	Indicates presence of organic matter (cultivation can disturb this feature in cropping soils).
A2 horizon (pale middle horizon between topsoils and subsoil)	The pale colour indicates the strong leaching of iron, aluminium and manganese compounds into the subsoil. This layer tends to be poorly structured and becomes waterlogged in winter, sets hard in summer and is acidic.
Subsoil	
Bright red or yellow.	Well drained and aerated soils. The presence of iron oxides gives the soil its red colour. The redness tends to disappear from waterlogged soils.
Pale grey, olive or blue	Poorly drained soils, that lack oxygen.
Mottled red, yellow and/or grey.	Mott1ing is often common in high rainfall zones. The mottles result from seasonal waterlogging. During waterlogged, poorly drained conditions the iron in the soil turns a grey\blue\green pigment 'gleying'. This iron can be leached out of a soil, leaving bleached areas with no pigment at all. The redder and yellower areas found in the poorly drained grey soils indicate the drier zones where more oxygen has become available to cause a reaction with the clay minerals, causing them to turn bright red or yellow.
Dark brown and black	The dark brown and black soils are rich in humus, but the colour of the soil does not necessarily indicate fertility, although the lighter colour soils do lack organic matter.

Classifying Soil Colour

Figure 3 is a colour chart, which can be used to classify a soil’s colour. Classifying soil colour helps identify the fertility and drainage properties of a soil.

Figure 3: Soil classification colour chart (From Baxter & Williamson 2001).

SOIL SMART NOTE 4.

TEXTURE

What is Soil Texture?

Soil texture is based on the relative proportions of the different particles in the soil (ie. sand, silt, clay and organic matter) (Fig. 4). Texture influences many soil physical properties such as water holding capacity and drainage.

How to Assess Soil Texture

Field texture is determined by measuring the behaviour of a small handful of soil (a bolus) when moistened and kneaded until it does not stick to the hand (1-2 minutes). It provides an estimate of the relative amounts of coarse sand, fine sand, silt and clay size particles, as well as organic matter (McDonald *et al.* 1990) (Fig. 4 & Table 3).

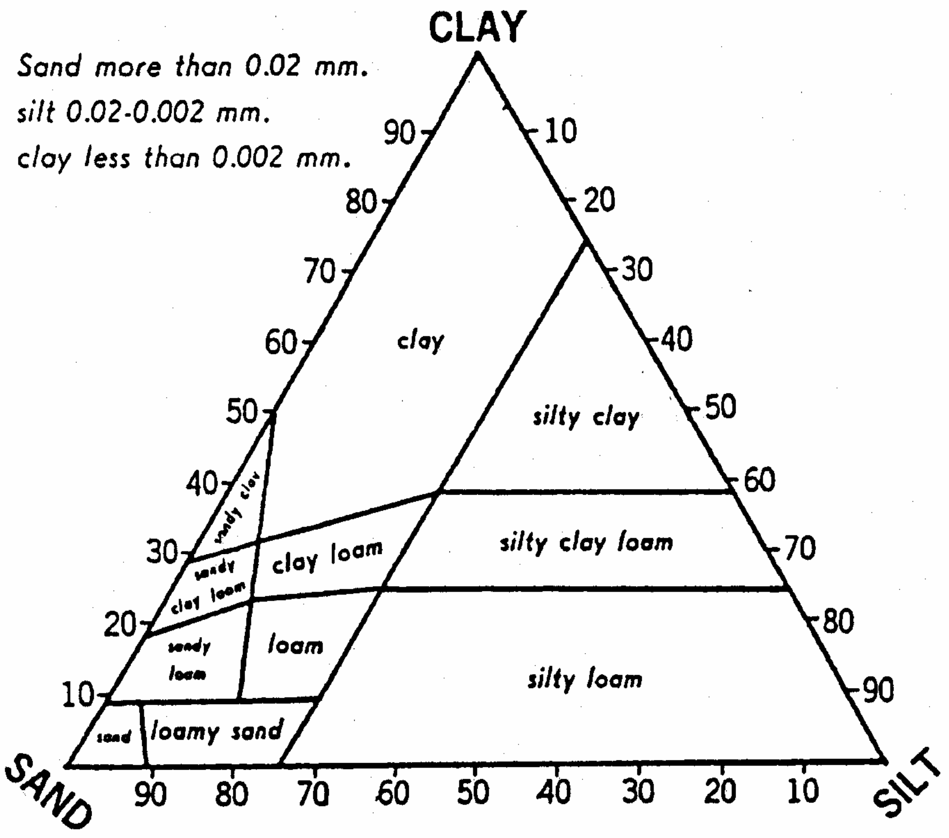


Figure 4: Soil texture triangle, explaining the different proportions of clay, silt and sand in soils (Northcote 1979).

Table 3: The different texture types and properties found in soils (Northcote 1979).

Texture symbol	Field texture grade	Behaviour of moist bolus	Approx. clay content (%)
S	Sand	Coherence nil to very slight, cannot be moulded; sand grains of medium size; single sand grains stick to fingers.	Less than 5%
LS	Loamy Sand	Slight coherence; sand grains of medium size can be sheared between thumb and forefinger to give minimal ribbon of 5 mm.	Approx. 5%
CS	Clayey sand	Slight coherence; sand grains of medium size; sticky when wet; many sand grains stick to fingers; will form a minimal ribbon of 5-15 mm; discolours fingers with clay stain.	5-10%
SL	Sandy loam	Bolus coherent but very sandy to touch; will form a ribbon of 15-25 mm; dominant sand grains are of medium size and are readily visible.	10-20%
FSL	Fine sandy loam	Bolus coherent; fine sand can be felt and heard when manipulated; will form a ribbon of 13-25mm; sand grains are clearly evident under a hand lens.	10-20%
SCL	Light sandy clay loam	Bolus strongly coherent but sandy to touch; and sandy to touch; sand grains dominantly medium sized and easily visible; will form a ribbon of 2-2.5cm.	15-20%
L	Loam	Bolus coherent and rather spongy; smooth feel when manipulated but with no obvious sandiness or 'silkiness', may be somewhat greasy to the touch if much organic matter present; will form ribbon of 25 mm.	About 25%
Lfsy	Loam, fine sandy	Bolus coherent and slightly spongy; fine sand can be felt and heard when manipulated; will form a ribbon of about 25 mm.	Approx. 25%
ZL	Silty Loam	Coherent bolus; very smooth to often silky when manipulated; will form a ribbon of approx. 25 mm.	Approx. 25% and with silt approx 25% or more
SCL	Sandy clay loam	Strongly coherent bolus, sandy to the touch; medium sized sand grains visible in finer matrix; will form a ribbon of 25-40 mm.	20-30%
CL	Clay loam	Coherent plastic bolus; smooth to manipulate; will form a ribbon of 40-50 mm.	30-35%
CLS	Clay loam, sandy	Coherent plastic bolus; medium sized sand grains visible in finer matrix; will form a ribbon of 40-50 mm.	30-35%
ZCL	Silty clay loam	Coherent smooth bolus, plastic and often silky to the touch; will form a ribbon of 40-50 mm.	30-35% and with silt 25% or more.
SC	Sandy clay	Plastic bolus; fine to medium sands can be seen, felt or heard in clayey matrix; will form a ribbon of 50-75 mm.	35-40%
ZC	Silty clay	Plastic bolus; smooth and silky to manipulate, will form a ribbon of 50-75 mm.	35-40%
LC	Light clay	Plastic bolus; smooth to touch; slight resistance to shearing; will form a ribbon of 50-75 mm.	Clay: 35-40% Silt: 25%+
LMC	Light medium clay	Plastic bolus; smooth to touch; slight to moderate resistance to forming a ribbon; will form a ribbon of 75 mm.	40-45%
MC	Medium clay	Smooth plastic bolus; can be moulded into a rod without fracturing; has moderate resistance to forming a ribbon; will form a ribbon of 75 mm +.	45-55%
MHC	Medium heavy clay	Smooth plastic bolus; can be moulded into a rod without fracturing; has a moderate to firm resistance to forming a ribbon; will form a ribbon of 75 mm or more.	50%+
HC	Heavy clay	Smooth plastic bolus; can be moulded into rods without fracturing; has firm resistance to forming a ribbon; will form a ribbon of 75 mm +.	50%+

SOIL SMART NOTE 5.

STRUCTURE / POROSITY

What is Soil Structure?

Soil solids, ie. individual particles of sand, silt, clay and organic matter, can cement together to form *aggregates* (also known as peds) (Fig. 5).

The electrical attraction properties of clay and organic matter cement all soil matter together. Aggregates are units of soil structure of varying size and shapes. They differ from clods, which are formed as a result of soil disturbances such as ploughing (Cornforth 2000).

Organic matter and clay bind aggregates together (Fig. 6). The arrangement of aggregates along with their size and shape, gives soil a characteristic known as soil structure (Baxter & Williams 2001).

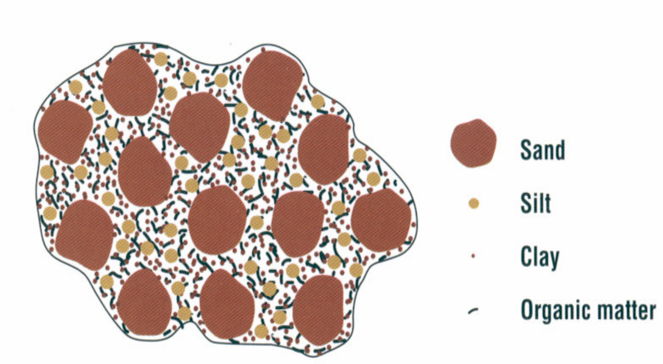


Figure 5: Soil aggregate (Baxter & Williams 2001).

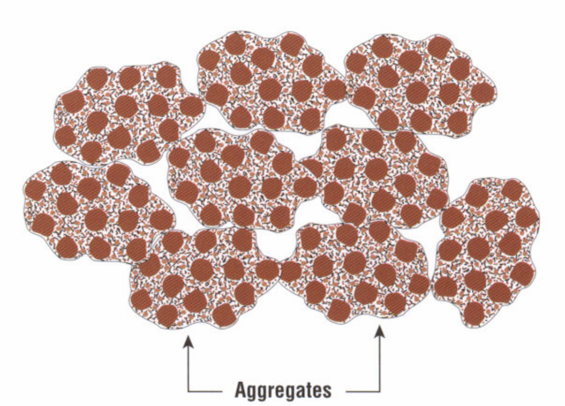


Figure 6: Aggregates join together to give soil a characteristic known as structure (Baxter & Williams 2001).

What is Soil Porosity?

Spaces or pores within and between aggregates can be either filled with air or water. The number, size and shape of the pores determines the amount and rate at which air and water can drain in and through the soil. Porosity also determines the amount of water held in the soil. Pores can be divided into two main classes based on their size.

1. Macropores occur between the soil aggregates. They are needed to allow rapid movement of air and water into and through the soil but are not filled with water at low to moderate moisture contents. Because of their size, roots grow through macropores. These pores are normally greater than 0.1 mm in diameter (Baxter & Williams 2001) (Fig. 7).

2. Micropores occur within the soil aggregates. They are the spaces formed between the sand, silt, clay and organic matter particles. Micropores are responsible for the water holding capacity of the soil and are the principal site for water extracted by roots. These pores are normally less than 0.1 mm in diameter (Fig 8.).

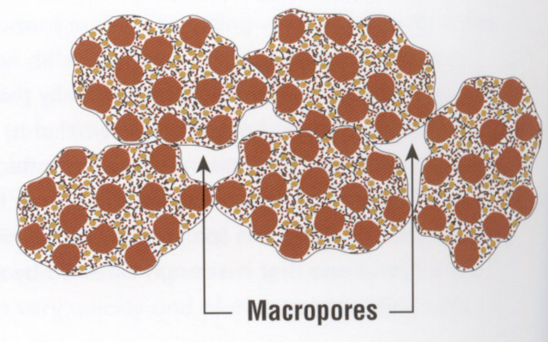


Figure 7: Macropores between soil aggregates (Baxter & Williams 2001).

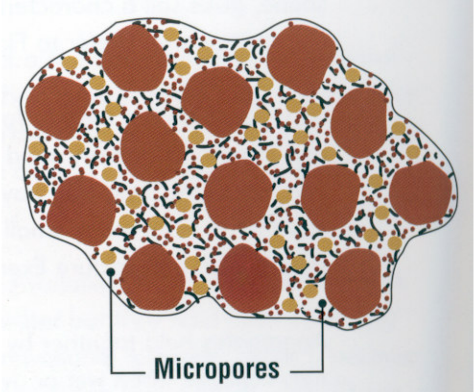


Figure 8: Micropores within a soil aggregate (Baxter & Williams 2001).

How to Assess Friability

Testing for friability is a method used to assess soil structure. Friability is determined by the proportion of macropores present in a particular soil sample. Friable soils have a large proportion of macropores and are likely to have plenty of air available to the plants. They are well drained and provide channels through which plant roots grow deep within the soil to tap into valuable water and nutrient storage (Baxter & Williams 2001).

Firstly remove a clump of soil (large handful) and gently try to prise the soil into individual aggregates (Fig. 9). According to Table 4, decide which friable classification best suits the soil (Baxter & Williams 2001).

Figure 9: The soil on the top is friable, ie. it will fall naturally into individual aggregates. The bottom soil is hardsetting ie. it will not naturally fall apart into individual aggregates (Baxter & Williams 2001).

Table 4: Soil friability classifications (Baxter & Williams 2001)

Classification	Description
Friable	The soil breaks easily with little force into small individual aggregates. There should be obvious cracks where the soil will naturally break apart.
Hardsetting	The soil does not naturally break into individual particles and remains solid unless strong force is applied. The soil does not necessarily have to be 'hard'. When moist a hardsettting soil tends to 'stick' together and it is difficult to break it apart.
Loose	The soil is loose and granular like beach sand. There may be some aggregates that are held together with organic matter but the majority of the soil is loose.

Management Impacts on Soil Structure

Soil structure is roughly determined by the texture of the soil although land management also has an important role to play. If a clay soil becomes waterlogged due to poor drainage, not enough air will exchange between the soil and the atmosphere. Plants may suffer as a consequence of lack of oxygen to their roots. In comparison, plants growing in well drained sandy soil will generally show water stress faster than similar plants growing in clayey soil (Figures 10-12).

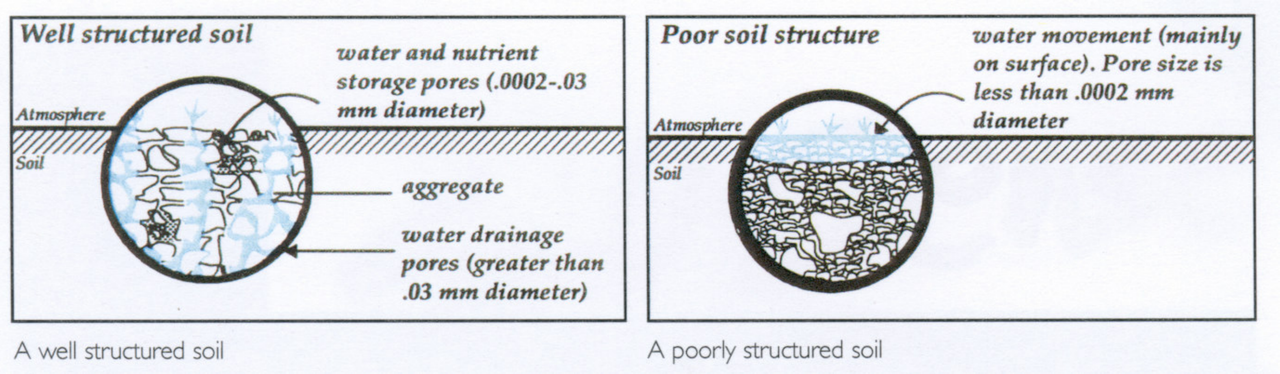


Figure 10: The difference in drainage and nutrient movement between well structure soil and poorly structure soil (Hollier & Hall 1997).

Figure 11: Poorly structured soils resulting in waterlogging (Hollier & Hall 1997).

Figure 12: Poorly structured soil profile (left) compared with a well structured soil profile (right) (McGuiness 1993).

SOIL SMART NOTE 6.

SLAKING AND DISPERSION

What are Slaking and Dispersion?

Slaking and dispersion are two processes, which degrade the soil's structure. When the soil is wet slaking occurs within minutes and causes the breakdown of aggregates into smaller sizes. Dispersion can take hours and causes the breakdown of aggregates into individual clay, silt and sand particles (Fig. 13.) (Rengasamy & Bourne 1992).

Dispersion occurs when clay particles form a cloud around an aggregate placed in water. An example of this on a larger scale is muddy water in a dam, which occurs as a result of dispersed clay. Dispersive soils have a high *Exchangeable Sodium Percentage (ESP).* Excessive sodium forces the clay particles apart (dispersion) when in water. The fine clay particles that have dispersed, clog up the small pores in the soil, degrading soil structure, and restricting root growth and water movement.

Slaking is when soil aggregates break down when immersed in water into smaller sized micro-aggregates. These aggregates may subsequently disperse (Nagambie Landcare Group 1995).

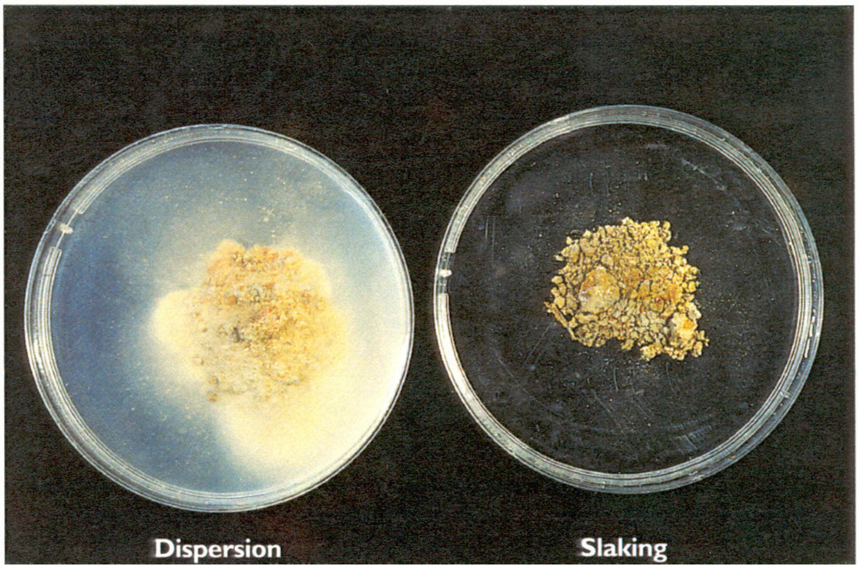


Figure 13: The Emerson Test, illustrating soil aggregates dispersing and slaking in petrie dishes (Hollier & Hall 1997).

The high sodium levels in many Australian soils have resulted from weathered parent materials such as basalt, granite and marine sediments. Bore water can be sodic and when used for irrigation or stock watering purposes, sodium is added to the soil, causing the soils to become sodic. Manure may also contain sodium, depending on the diet of the animal, and if spread over the paddock this can increase the sodium content of the soil.

A soil becomes sodic through the leaching of salt (eg. sodium chloride). As salt is washed down through the profile, some insoluble sodium is left behind, attached to clay particles. This displaces more useful substances such as calcium. This process may have occurred recently (eg. in the last 20 years) or up to 10 000 years ago (Hollier & Hall 1997).

Dispersive soils present significant problems. Dispersive subsoils are particularly prone to gully and tunnel erosion. Repair works may be costly and perhaps ineffective due to high maintenance requirements. These soils are often best undisturbed.

SOIL SMART NOTE 7.

FABRIC

What is Soil Fabric?

Differences in fabric are defined by the presence or absence of aggregates (ped), aggregate surface characteristics, and the presence, size and arrangement of pores in the soil mass.

SANDY FABRIC – the soil material is coherent with few, if any, aggregates. The closely packed sand grains provide the characteristic appearance of the soil mass.

SMOOTH-PED FABRIC – aggregates are evident, and characteristically more than 50 percent of them are smooth-faced. They have a degree of shininess on their surfaces. These aggregates are dense in comparison with rough-faced peds.

EARTHY (or porous) fabric – the soil material is coherent and characterised by the presence of pores, and few, if any, aggregates. Generally soil particles (eg. sand grains) are coated with oxides and/or clays and arranged clumped around the pores.

ROUGH-PED FABRIC – aggregates are evident, and characteristically more than 50 percent of the aggregates are rough-faced. Rough-faced peds generally have less clearly defined faces than smooth-faced peds.

Figure 14: Different fabric types classified for soils (Northcotte, 1979).

SOIL SMART NOTE 8.

CONSISTENCE

What is Consistence?

Consistence relates to the texture and structure of a soil and is a measure of its workability and stability (eg. Friable soils are easier to work than hard soils). Consistence is measured by resistance of an aggregate (ped) to deformation between the thumb and forefinger, measured on a scale of 1 (small force required) to 7 (rigid force required). This varies according to the soil water content.

Consistence comprises the attributes of soil material that are expressed by the degree and kind of cohesion and adhesion or by the resistance to deformation or rupture (McDonald *et al.*, 1997).

How Do I Measure Soil Consistence?

You measure consistence by simply testing the resistance of soil aggregates under physical pressure. This can be carried out according to Table 5.

Table 5: The different definitions and methods to measure for soil consistence (McDonald *et al.* 1997).

No.	Name	Characteristics
0	= Loose	➢ No force required, separate particles such as loose sand.
1	= Very weak	➢ Small force.
2	= Weak	➢ Small but significant force.
3	= Firm	➢ Moderate to firm force.
4	= Very Firm	➢ Strong force but within the power of the thumb and forefinger.
5	= Strong	➢ Beyond power of thumb and forefinger but crushes underfoot on hard flat surface with small force.
6	= Very Strong	➢ Crushes underfoot on hard flat surface with full body weight applied slowly.
7	= Rigid	➢ Cannot be crushed underfoot by fully body weight applied slowly.

SOIL SMART NOTE 9.

pH

What is Soil pH?

Soil pH is a measure of soil acidity and soil alkalinity on a scale 0 (extremely acidic) to 14 (extremely alkaline), with a pH of 7 being neutral (Table 6). Soil pH is measured by the concentration of H+ ions of soil in a neutral solution of water of calcium chloride. The pH measured in water more readily reflects current soil conditions whereas the calcium chloride method is less sensitive to seasonal changes.

It gives an indication of the availability of plant nutrients and relates to the growth requirements of particular crops. Acid soils are usually deficient in necessary nutrients eg. calcium and magnesium (Walker *et al.* 1994). Most field crops and pastures prefer soils within the pH(w) range of 6 – 8.

Table 6: The pH scale (Walker *et al.* 1994).

PH reaction	pH value
Strongly acid	Less than 5.5
Acid	5.5 - 6.5
Neutral	6.5 - 7.5
Alkaline	7.5 - 8.5
Strongly alkaline	Greater than 8.5

On the pH scale each unit decrease is 10 times more acidic than the one before it (eg. a pH of 5 is ten times as acidic as a pH of 6).

Soils with high levels of exchangeable hydrogen are called acid soils. Soil acidity is most commonly associated with the replacement of cations such as calcium, magnesium, potassium and sodium by hydrogen (Fig. 15). Replaced cations may subsequently be leached through the soil profile and lost from the system into groundwaters and river systems (Hollier & Hall 1997).

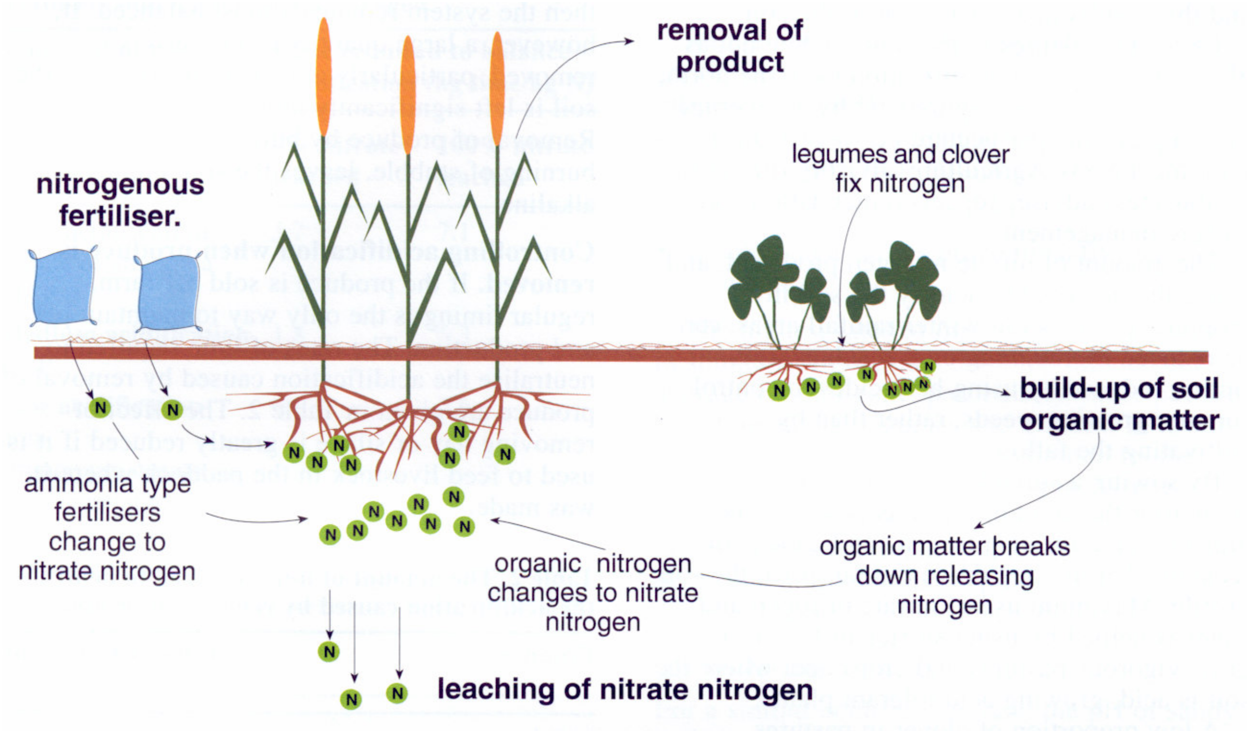
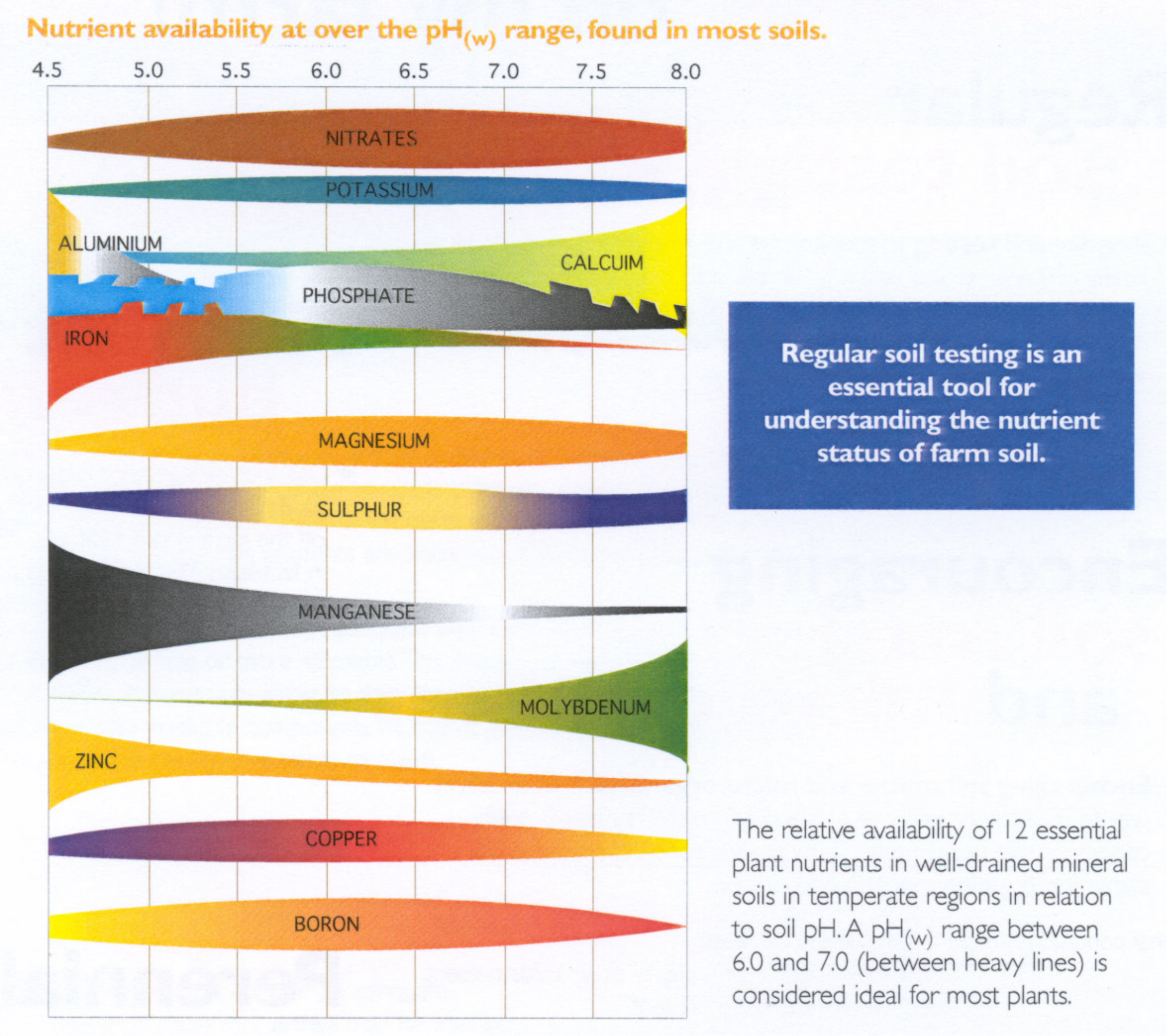


Figure 15: The process of how acid can be formed in soil (Hollier & Hall 1997).

The pH of a soil affects the availability of soil nutrients to plants. Most plants grow best when the soil pH is between 5.5 and 7.5. If the soil has a pH of less than 4.5 (very acid) aluminium and manganese become available in the soil in large quantities that are toxic to many plants. If the pH is greater than 7, trace elements such as zinc, iron, copper and boron become less available and can lead to deficiencies in plants. Figure 16 illustrates the nutrient availability over the pH range, found in most soils. Figure 17 illustrates the pH range suitable for fungi, bacteria and worms (Hollier & Hall 1997).


Nutrient availability at over the $pH_{(w)}$ range, found in most soils.

Regular soil testing is an essential tool for understanding the nutrient status of farm soil.

The relative availability of 12 essential plant nutrients in well-drained mineral soils in temperate regions in relation to soil pH. A $pH_{(w)}$ range between 6.0 and 7.0 (between heavy lines) is considered ideal for most plants.

Figure 16: Nutrient availability to plants at different pH levels in soil (Hollier & Hall 1997).

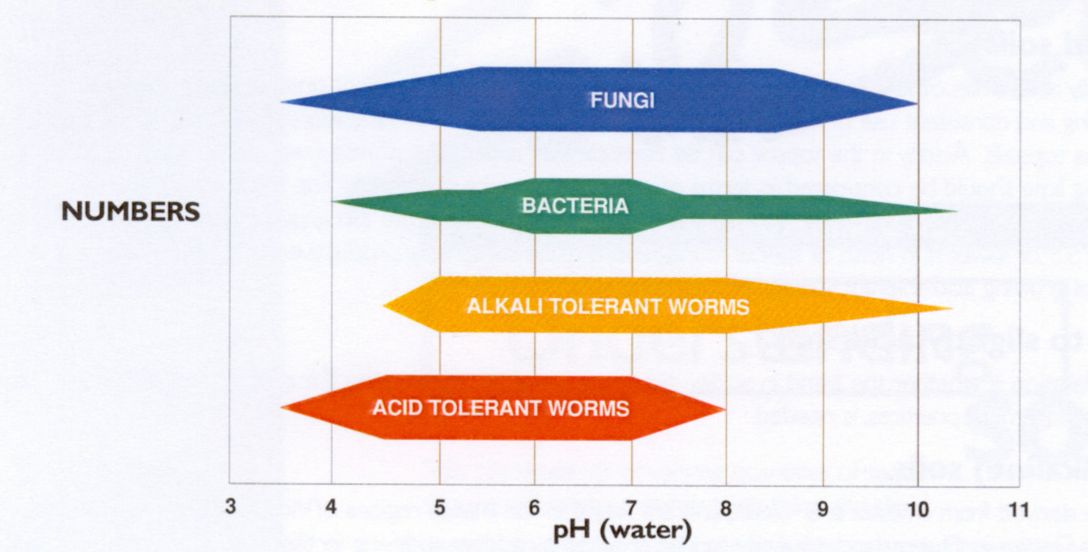


Figure 17: pH levels suitable for worms, bacteria and fungi (Hollier & Hall 1997).

SOIL SMART NOTE 10

HOW TO INTERPRET A SOIL CHEMICAL TEST

Phosphorous (P)-(Colwell Extractable mg/kg)

Extractable P tests measure P which is potentially available to plant uptake. The P test is used to predict the likelihood of a response to applied fertiliser P.

	Seep Acid Sands (sand over Sand pH 7.5) (mg/kg)	Sands, Sandy Loam and Loam (mg/kg)	Clay Loam and Clays (mg/kg)	Lateritic Ironstone's (mg/kg)	Calcareous sands (Sands pH>8+ high fizz test (mg/kg)	Peats (mg/kg)
Low	<15	<20	<20	<25	<25	<25
Marginal	16-20	21-30	21-30	26-35	26-40	26-35
Moderate	21-36	31-60	31-60	36-65	41-70	36-65
Adequate	>35	>60	>60	>65	>70	>65

* A fizz test employs dilute acid to determine the presence of free calcium carbonate (limestone).

Phosphorous (P)-(Olsen Extractable mg/kg)

Soil samples from Victorian pastures are also analysed by the Olsen method. A general guide to Olsen P test results for dryland and irrigated pastures and crops follows.

Dryland Pasture Olsen P mg.kg	Irrigated Pasture Olsen P mg/kg	Comment	Response to applied P fertiliser
<6	<15	Very low	Large
6-12	15-25	Low	Good
12-18	25-40	Moderate	Moderate
>18	>40	Adequate	Only slight

Kilograms of P required per tonne of potential yield.

Soil test results	High	Medium	Low
Wheat	3.0	4.0	5.0
Legumes	5.0	6.0	7.0
Canola	7.0	8.5	10.0

Example: Soil test result of 22 mg/kg Colwell P = Medium
Potential yield wheat = 5 t/ha
Required Phosphorous rate = (5 x 4) = 20 kg/ha

Rates in the high range relate P removal in each tonne of grain.

Rates in the medium and low ranges for removal per tonne of grain plus some additional to build up soil P levels to optimal levels.

Potassium (K) – (Colwell Extractable mg/kg)

Extractable K tests measure potassium, which is potentially available to plants for uptake. The potassium test is used to predict the likelihood of a response to applied fertiliser potassium.

For cropping, pasture and general horticultural situations, the descriptive terms used for the different soil types are as follows:

	Sands, Sandy Loams, Calcareous sands (mg/kg)	**Loams, Clay Loam, Clay, Peats, Lateritic, Ironstone (mg/kg)**	**Response to applied K fertiliser**
Low	<80	<120	Large
Marginal	81-150	121-200	Good
Adequate	151-250	201-500	Slight
High	>250	>500	Unlikely

Sulphur (KCl mg/kg)

Sulphur is also more abundant in heavier type soils with good levels of organic matter.

The descriptive terms used for sulphur ranges are as follows.

Sulphur	**Fertility status**
<6	Low
6-10	Marginal
11-100	Moderate
>100	Adequate

Structure

Exchangeable Cations (meq/100gm soil)

An exchangeable cations is a positively charged ion which can be found on a clay particle or on the humus (broken down organic matter) of the soil.

The exchangeable cations of importance are Na+, K+, Mg++, Ca++ and Al+++.

NB: + monovalent
++ divalent
+++ trivalent

In general the monovalent cations (especially Na) are less favourable to soil structure because they have a low affinity for the clay particle, therefore the overwhelming negative charges on the clay particles repel each other, causing dispersion.

The divalent cations, Ca more than Mg have a strong affinity for the clay particles, therefore the bond is tighter between the clay particles which forms water stable aggregates.

Al+++, and Na+ are not plant nutrients, so are not wanted by the plant. Therefore the lower levels of these nutrients the better, especially when growing sensitive varieties eg. lucerne sensitive to Al.

Desirable relationships between cations are as follows:

a) Sodium adsorption ratio (SAR)

SAR = [Na] / (square root of ([Ca] + [Mg]) /2)

If SAR:

<3 no real effect on structure
>3, <7 cultivation may cause dispersion, add gypsum
>7 soil will be dispersive, add gypsum.

b) Calcium / Magnesium ratio
A well structured soil has a calcium / magnesium ratio of at least 2:1

c) Potassium / Magnesium ratio
A well structured soil has a potassium / magnesium ratio of less than 1:1.

Cation Exchange Capacity (CEC meq/100 gm soil)

CEC is the capacity of a soil to hold the major cations ca, Mg, Na and K and is widely used in determination of soil fertility. Cations are held on the surface of charged soil minerals and organic matter and also within the crystal lattice of some clay minerals. The CEC is a measure of the general fertility of the soil and its ability to hold onto applied nutrients. These tests are primarily used for the diagnosis of soil structure problems. From the analytical data, the need or otherwise of gypsum can be estimated, since calcium and potassium are believed to aid soil structure and sodium and magnesium destroyed it.

Potential Fertility	**Cation Exchange Capacity (meq/100 gm)**
Poor	<5
Low	5-10
Fair	10-15
Moderate	15-25
High	>25

CEC varies depending on the soil type. It is closely related to the clay content, organic matter content and pH.

As soil pH increases, the number of negative charges on the colloid increases, thereby increasing CEC.

Humus has a very high CEC because of the large quantities of negative charges. Humus has a CEC two to five times greater than montmorillonite clay, so is important in improving soil fertility.

Organic Carbon

Organic carbon indicates the organic matter levels of the soil. It is a measure of the potential turnover of valuable plant nutrients such as nitrogen and sulphur.

Satisfactory levels of organic matter vary according to soil type.

	Sands, Sandy Loams, Calcareous Sands (%)	Loam, Clay Loam, Peat, Ironstone (%)
Very Low	<0.35	<0.75
Low	0.36-0.65	0.76-1.35
Moderate	0.66-0.95	1.36-1.85
Satisfactory	0.96-1.45	1.86-2.55
High	1.46-1.85	2.56-4.00
Very High	>1.85	>4.00

SOIL SMART NOTE 11

SOIL BIOLOGY

Introduction

Micro-organisms of the soil are of great importance as they recycle plant and animal remains back into the web of life via the soil. As these microbes feed they are able to break down organic matter into a useable form for plants. The two main groups of micro-organism in the soil that bring about chemical changes are bacteria and fungi. It has been estimated that one gram of fertile soils from a temperate climate contains one thousand million bacteria (National Soil Conservation Program 1989).

The living organism in the soil are sometimes known as the biomass. Most of the organisms, other than the roots of plants, get the energy they require for growth and reproduction by decomposing organic materials in the soil. They also get their mineral nutrients from decomposing organic matter and from the soil solution. A few specialised species of micro-organisms can get their energy requirements from chemical reactions in the soil, but the majority of micro-organisms require organic matter as a source of energy.

Most members of the soil population depend on one another for survival. While each group may be able to use a particular type of organic matter for food, they all fit in to a complex chain of growth, decomposition and the creation of new organic materials.

Organic matter provides food energy for micro-organism. In turn, the micro-organisms release nutrients from the organic matter, which can then be used by crop plants.

Other materials produced when microbes decompose organic matter help to form and stabilise soil structure (Laffan 1992).

Biology's Role in Soil Structure

Well structured soils allow plant roots to grow easily through the soil in search of water and nutrients. Roots further improve soil structure by making passages for oxygen to enter and water to drain. Micro-organisms and other small animals play a vital role in the structure of soil by producing secretions, which hold and bind mineral particles together into stable aggregates.

Earthworms also play a major role in improving the structure of soils. Worms eat an enormous amount of organic material and soil. One worm can eat as much as 40 grams per years and a population of 200 per square metre can eat 80 tonnes per hectare every year. This 'munching' process has direct benefits for soils as it:

- increases microbial activity;
- increases macropores; and
- hence, allows better penetration of plant roots, oxygen and water into soils.

(National Soil Conservation Program 1989).

Managing Soil Biology

In order to encourage useful microbes in your soil you need to be sure they have:

- air,
- appropriate pH,
- food and minerals,
- appropriate light,
- moisture,
- suitable companions, and
- appropriate temperature.

Air

Since most organism in the soil need air, they are restricted mainly to the upper 2-5 cm of the soil. This, in turn, means that most of their food will be in the same area. Most earthworms are found within the top 20 cm, although some may burrow as deeply as 1 m.

A well structured soil with good porosity will have plenty of air for organisms in the soil. Compacted soil is not well aerated because of the loss of pore or air spaces and so it does not favour most microbial activity.

Blue-green algae, some bacteria and water-moulds can grow in water logged conditions, which mean they do not need much air (anaerobic).

pH

Fungi seem to be largely unaffected by pH, whereas earthworms, algae, bacteria and actinmycetes (cross between a fungi and bacteria) grow poorly in acid soils.

Food for microbes

Soil microbes can feed on other organic material, which means they are heterotrophic, or they can make their own energy foods, which means they are autotrophic.

Heterotrophic organisms can grow where the foods are available, for example in the zone around the plant roots. As the roots grow they give out sugars and amino acids that stimulate the growth of microbes in the soil. The roots can also give out acids that help the microbes digest plant material. Dead roots are a source of food for many soil microbes. You are likely to have many more soil microbes in the zone near plant roots than in other parts of the soil.

When dead plant leaves, shoots and roots become mixed in with the soil, then insects, larvae and worms in the soil eat at it and reduce the size of the residues, and may also drag them through the soil. This action exposes more of the plant to microbial attack. Cultivation also stimulates microbial activity by letting air into the soil and shattering and mixing surface residues with soil.

Autotrophic organisms that need sunlight for photosynthesis (algae) will be very near the soil surface, whereas autotrophic organisms that can make energy foods from minerals in the soil can be found at greater depth.

Calcium and other elements

Most bacteria need plenty of exchangeable calcium. This is especially so for bacteria that fix nitrogen from the air. Molybdenum, boron and cobalt are also essential for effective nodulation.

Moisture

Algae are really tiny water plants. There are usually not many of them in cultivated land because there isn't enough moisture. Earthworms and actinomycetes also need moist soil.

Blue-green algae (really a type of bacteria) can fix atmospheric nitrogen. This makes these algae especially important where plants are grown under waterlogged conditions, for example in rice fields. The blue-green algae not only provide nitrogen that plants can use but they also provide oxygen to the submerged roots of the rice plants.

However, you can find algae in dry places when they combine with fungi and form lichens. You may have seen them as white or green crusts on wooden fences or gates. The algae can be use materials taken by the fungus, for example rotted wood or minerals from rock, and change them into foods for the fungus. In return, the fungus provides an environment that is moist enough for the algae to survive.

Most fungi need plenty of moisture. Those which form part of lichens are an exception.

Other Organisms

Some soil organisms are affected in some way by other soil organisms. In some cases the relationship is parasitic; one organism feeds off another and causes harm to its host. For example the nematode *Heterodera rostochiensis* is parasitic on tomatoes.

In some cases the relationship is *symbiotic* or *mutualistic*. In these relationships each organism helps the other survive. The fungal-algae association in lichens is an example of symbiosis.

Another one is *mycorrhiza*, the association between certain fungi and roots of plants. The fungus obtains most of its food from the roots. In return it absorbs nutrients from the soil and supplies then to the plant.

This type of association is particularly important when the fungus can absorb phosphorous from the soil and make it available to the plant. Examples of plants that benefit from this type of association include forest trees, especially conifers, eucalypts and some species of acacia.

Temperatures

Earthworms do not thrive where soils have high temperatures, whereas most bacteria grow best in a range of temperatures from 20-40^{o}C. Temperature above 25^{o}C are usually fatal for earthworms, and death is more rapid, the drier the soil (From Laffin 1992).

GLOSSARY OF SOIL TERMS

ACIDIFICATION: The process whereby a soils pH is lowered (becomes acidic) as a result of the parent material, age, and the soils exposure to acidification processes.

AEOLIAN: A geomorphic process whereby soil-forming material is transported and deposited by wind.

AEROBIC: Free oxygen is abundant and chemically oxidising processes prevail in the soil. This usually occurs in well-drained soils and good structure.

AGGREGATE (PED): The natural unit of soil structure formed by the soil's tendency to fracture along planes of weakness.

ANAEROBIC: These soils are deficient of free oxygen and the reducing processes are predominant. This generally occurs in poorly drained or waterlogged soils, where water has replaced the air in the soil resulting in a bluey-grey coloured soil.

APEDAL: None of the soil material occurs in the form of aggregate. It is massive or single grain and when disturbed separates into fragments or primary particles.

BOUNDARIES: The boundary between soil horizons defines the nature of the change from one horizon to that below. It is specified by two terms – one a measure of the thickness or width of the transition zone between horizons, the other measure of its shape (or departures from planar form) as expressed in the vertical section (profile).

BLEACHED: Horizons that are paler than adjacent horizons. A bleached generally occurs in the A2 horizon although it is not restricted to it. A conspicuously bleached horizon is one in which 80% or more of the horizon is bleached, whereas a sporadically bleached occurs irregularly throughout the horizon or as blotches at the interface of the A and B horizons (Northcote, 1979).

CEC (CATION EXCHANGEABLE CAPACITY): Is the measure of the capacity of a soil to hold the major cations: calcium, magnesium, sodium and potassium (including hydrogen, aluminium and magnesium in acid soils). It is a measure of the potential nutrient reserve in the soil and is therefore an indicator of inherent soil fertility. An imbalance in the ratio of cation can result in soil structural problems. High levels of individual cations (eg. Aluminium and magnesium) can also be toxic to plants.

COLLOIDS: Fine clay and organic material with a particle size of less than 0.002mm in diameter. These particles tend to remain permanently in suspension unless flocculation (aggregation of particles that settle out) occurs.

COLOUR: Colour provides a useful indication of a number of the other profile attributes. Dark surface soils for instance, indicate high contents of organic matter. In subsurface horizons (ie. A2) bleached colours indicate low levels of plant nutrients and that seasonal or periodic waterlogging occurs. In subsoils, the colour sequences from red to brown and yellow to grey colours, indicate a sequence from well-aerated and well-drained soils to poorly aerated and poorly drained soils.

DISPERSIBLE SOILS: Soils that are structurally unstable and disperse in water into basic particles ie. sand, clay silt and clay. Dispersible soils tend to be highly erodible and present problems for earth works.

DUPLEX PROFILE FORM: A Primary Profile form of the Northcote Factual Key (1979) classification. It describes a soil where there is a sharp contrast in the texture between the A and B horizons (often sandy or loamy surface horizons with a sharp to clear boundary to clay subsoils)

EARTHS: A great Soil Group (Stace *et al.* 1968) description defining a variable group of soils which are porous and sandy textured. They usually have an acidic trend (ie. the pH decreases with depth), weak profile differentiation, diffuse horizon boundaries, an increase in clay content with depth and no A2 horizon.

EC (ELECTRICAL CONDUCTIVITY): A measure of the conduction of electricity through water, or a water extract of soil. The value can reflect the amount of soluble salts in an extract and therefore provide an indication of soil salinity. Saline soils are defined as those with an EC greater than 1.5 dS/m for a 1:5 soil water extract and greater than 4 dS/m for a saturated extract. It can be interpreted in terms of the salinity tolerance of plants. Soil texture needs to be considered in this interpretation.

ESP (EXCHANGEABLE SODIUM PERCENTAGE): Is calculated as the proportion of the cation exchange capacity occupied by the sodium ions and is expressed as a percentage. Sodic soils are categorised as soils with an ESP of 6-14%, and strongly sodic soils have an ESP of greater than 15%.

FABRIC: Describes the appearance of the soil material. Differences in fabric are associated with the presence or absence of aggregates, and the lustre, or lack thereof, of the aggregate surfaces, and the presence, size and arrangement of pores (voids) in the soil mass. The fabric of soil can be put into four categories, which include earthy, sandy, rough-ped and smooth-ped.

FLUVIAL: A geomorphic process whereby soil-forming material is transported and deposited by flowing river water.

GRADATIONAL PROFILE FORM: It describes a soil with a gradual increase in texture (ie. more clayey) as the profile deepens. Gradational soils are given the notation “G”.

GYPSIC: These soils contain more than 20% visible gypsum that is of apparent pedogenic origin with a minimum thickness of 0.1m. If the upper boundary of the horizon occurs below the 1m depth it is disregarded in the classification. It is used as a definition for a number of Orders in the Australian Soil Classification (Isbell, 1995).

GYPSUM: A naturally occurring soft crystalline material, which is a hydrated form of calcium sulphate. Deposits occur naturally in inland Australia. Gypsum contains approximately 23% calcium and 18% sulphur. It is used to improve soil structure and reduce crusting in hard setting clayey soils.

HORIZONS: A layer within the soil profile having morphological characteristics and properties (eg. colour, texture, and structure) differing from the layer above and/or below it.

HUMOSE: The relatively resistant, usually dark brown or black fraction of soil organic matter, peat or compost which forms as a result of biological decomposition of organic material.

INFILTRATION: The movement of water through the soil surface. Soils with a high infiltration capacity allow more rain to enter the soil than soils with a low capacity. Runoff will occur when the rate of rainfall exceeds the soil’s infiltration capacity. Surface soil structure and texture are important determinants of the infiltration capacity of soils.

LATERITE: Indurated (becomes hard on exposure), iron-rich material that is associated with deeply weathered profiles.

LEACHING: The removal in solution of soluble minerals and salts as water moves through the profile.

LIME: A naturally occurring calcareous material used to raise the pH of an acidic soil and/or supply calcium for plant growth. It is effective for treating dispersible acidic soils.

MOTTLING: The presence of more than one soil colour in a horizon. Mottling occurs as blotches or streaks of subdominant colour throughout the main (ie. matrix) colour. It is often an indication of poor profile drainage but may be caused by the weathering of parent material.

MYCORRHIZAE: are soil fungi which acts as rootlets and increase the amount of nutrients (particularly phosphorous and zinc) available to plants.

NUTRIENT STATUS: This is calculated as the sum of exchangeable calcium, magnesium and potassium (in milliequivalents per 100g) as a guide to availability of nutrients in general. The categories used are: very low (0 – 3.9); low (4 – 7.9); moderate (8-17.9) and; high (>18) (Lorimer and Rowan, 1982).

ORGANIC MATERIALS: Plant derived organic accumulations.

PANS: hard or cemented layers interfering with water and root penetration.

PARENT MATERIAL: The rock from which a soil profile develops.

PED (AGGREGATE): The natural unit of soil structure formed by the soil's tendency to fracture along planes of weakness.

pH (SOIL): A measure of soil acidity and soil alkalinity on a scale 0 (extremely acidic) to 14 (extremely alkaline), with a pH of 7 being neutral. It gives an indication of the availability of plant nutrients and relates to the growth requirements of particular crops. Acid soils are usually deficient in necessary nutrients eg. calcium and magnesium.

POROSITY (SOIL): The degree of pore space in a soil (ie. the percentage of the total space between solid particles).

PROFILE: The vertical section of the soil from the soil surface down through the horizons including the parent material. It consists of two parts: the solum, and the parent material.

SALINITY: A measure of the total soluble salts in a soil. A saline soil is one with an accumulation of free salts at the soil surface and/or within the profile affecting plant growth and/or land use. It is generally attributed to changes in land use or natural changes in drainage or climate, which affects the movement of water through the landscape. Salinity levels of a soil or water can be tested using Electrical Conductivity.

SELF MULCHING: A structural condition of soils, where there is a high degree of pedality with the aggregates naturally falling apart as the soil dries to form a loose surface mulch.

SLAKING: The breaking down of soil aggregates when immersed in water into smaller sized micro-aggregates. These aggregates may subsequently disperse.

SODICITY: Is a measure of exchangeable sodium in relation to other exchangeable cations. It is expressed as the Exchangeable Sodium Percentage. A sodic soil contains sufficient exchangeable sodium to interfere with the growth of plants, including crops. A soil with an ESP greater than 6 is generally regarded as being a sodic soil in Australia (Northcote and Skene, 1972).

SOLUM: The horizons, that is the A and B horizons, which have developed from the parent material by the processes of soil formation.

STRUCTURE: Describes the way the soil particles are arranged to form soil aggregates. Aggregates are units of soil structure, which are separated from each other by natural planes of weakness. They differ from clods, which are formed as a result of soil disturbances such as ploughing.

SUBSOIL: The B horizon and their subdivisions, excluding the C horizon.

SURFACE CRUST: Soils with a massive or weakly structured surface crust, which is lighter in texture than the underlying, pedal clay. This condition should not be confused with self-mulching behaviour.

TEXTURE (FIELD TEXTURE): Field texture is determined by measuring the behaviour of a small handful of soil when moistened and kneaded (1-2 minutes) until it does not stick to the hand. It provides an estimate of the relative amounts of coarse sand, fine sand, silt and clay size particles. Soil texture influences many soil physical properties such as water holding capacity and hydraulic conductivity. Numerous soil properties affect the determination of texture such as type of clay minerals, organic matter, carbonates, etc.

UNIFORM PROFILE FORM: A primary Profile Form of the Factual Key Classification (Northcote, 1979). These soil profiles have limited, if any texture change throughout the profile. There is generally no textural boundaries found within the profile, except for possibly a surface crust. Uniform soils are given the notation “U”.

WATER REPELLENT: Soils that are fairly resistant to wetting (from a dry state). It is a condition usually associated with sandy surface horizons and is generally caused by organic coatings on sand grains.

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