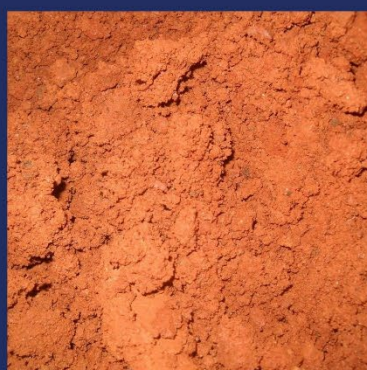
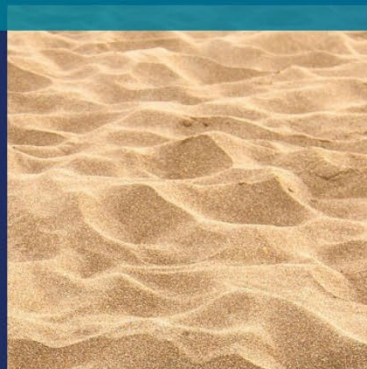


Industry insights- Soils

Supporting document

NSW PI Schools Program



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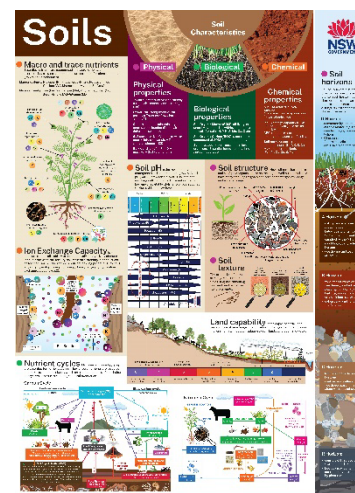
Overview

Soil is a term used to describe the thin layer of mineral and organic material, that is usually biologically active and covers the earth's land surface.

Soils are dynamic systems, providing plants with support, water, nutrients and air. They support many macro- and microorganisms that recycle nutrients essential to life. They support all ecosystems on land, including the entire human population, providing food, fibre, water, building materials and sites for construction and waste disposal. We rely on them to protect the groundwater by filtering wastewater.

Understanding and managing soils is essential to all primary production, earth ecosystems and human existence.

The following resource has been developed to cover all soils and related soil sustainability syllabus content from the Agriculture Stage 6 Syllabus (2013). It covers both Preliminary and HSC content. It has also been mapped to the Agriculture Technology 7-10 Syllabus (2019). Access the accompanying soils poster at: [Industry Insights: Soils](#)



This supporting document has been developed as a digital resource and to access the large number of hyperlinks which it contains it should be used in this format.

Questions and sample answers

A sample answer guide has been developed to assist teachers and students' complete activities throughout the document. These sample answers are not necessarily the very best answer, nor are they the only possible answers. Find them at: [Industry Insights: soils](#)

The end of the document includes a compilation of past NESA Agriculture Stage 6 HSC questions surrounding soils and sustainability. These questions can be used to revise Stage 6 learning throughout this booklet.

Teachers, students and markers can view [past HSC examinations](#) and Sample [HSC Examination Questions](#) on the NSW Board of Studies, Teaching and Educational Standards website.

Soil practical activities- teacher notes:

Ideally all suggested practical activities will be carried out using soil samples from different sites. At each site multiple samples should be collected to various depths (e.g. Sample 1-A 0-5cm; sample 1-D 15-20cm). Samples collected to depth (either dug out or using a core sampler), allow for a comprehensive analysis for soil at each site to be determined.

Watch: [How to test your soil - site selection](#)



A soil laboratory test is recommended so that all field test results can be compared to accurate results. Laboratory analysis results also allow for ‘real world’ management decisions to be formulated such as selecting amendments, calculating application rates and understanding plant growth implications etc. Find out more tips at [soil sampling techniques for laboratory analysis](#).

HSC Verbs and Key Words

It is important that students address the following key terms and verbs when answering questions. The following glossary developed by the NSW Education Standards Authority is provided to assist with the answering of activities throughout this booklet.

Key Word	Definition
Account	Account for: state reasons for, report on Give an account of; narrate a series of events or transactions
Analyse	Identify components and the relationship between them; draw out and relate implications
Apply	Use, utilise, employ in a particular situation
Appreciate	Make a judgement about the value of
Assess	Make a judgement of value, quality, outcomes, results or size
Calculate	Ascertain/determine from given facts, figures or information
Clarify	Make clear or plain
Classify	Arrange or include in classes/categories
Compare	Show how things are similar or different
Construct	Make; build; put together items or arguments
Contrast	Show how things are different or opposite
Critically (analyse/evaluate)	Add a degree or level of accuracy depth, knowledge and understanding, logic, questioning, reflection and quality to (analyse/evaluate)
Deduce	Draw conclusions
Define	State meaning and identify essential qualities
Demonstrate	Show by example
Describe	Provide characteristics and features
Discuss	Identify issues and provide points for and/or against
Distinguish	Recognise or note/indicate as being distinct or different from; to note differences between
Evaluate	Make a judgement based on criteria; determine the value of
Examine	Inquire into
Explain	Relate cause and effect; make the relationships between things evident; provide why and/or how
Extract	Choose relevant and/or appropriate details
Extrapolate	Infer from what is known
Identify	Recognise and name
Interpret	Draw meaning from
Investigate	Plan, inquire into and draw conclusions about
Justify	Support an argument or conclusion
Outline	Sketch in general terms; indicate the main features of
Predict	Suggest what may happen based on available information
Propose	Put forward (for example a point of view, idea, argument, suggestion) for consideration or action
Recall	Present remembered ideas, facts or experiences
Recommend	Provide reasons in favour
Recount	Retell a series of events
Summarise	Express, concisely, the relevant details

Source: [NSW Education Standards Authority, 2025](#)

Soils

Glossary:

Soil term	Definition
Anion Exchange Capacity (AEC)	The Anion Exchange Capacity (AEC) is a measure of the positive charge of the soil and therefore that soil's ability to attract, exchange and hold negatively charged anions by electrostatic attraction.
Bulk Density	Bulk density is an indicator of soil compaction and is dependent on soil structure and texture (proportion and arrangement of sand, silt and clay components). <i>Bulk Density (g/cm³) = Dry soil mass (g) ÷ Soil volume (cm³)</i> Ideally, a medium textured soil with about 50 percent pore space will have a bulk density of 1.33 g/cm³. Well structured, loose, porous soils and those rich in organic matter have lower bulk density.
Humus	Decomposed organic matter that is dark brown/black in colour. It is a colloid and reactive, cementing soil particles together and improving a soil's structure. It has a negative surface charge, high water holding capacity (WHC), high cation exchange capacity (CEC) and encourages microbial activity.
Cation Exchange Capacity (CEC)	The Cation Exchange Capacity (CEC) is a measure of the negative charge of the soil and therefore that soil's ability to attract, exchange and hold positively charged cations by electrostatic attraction
Ion Exchange Capacity (IEC)	Ion exchange capacity (IEC) is a measure of the soil's ability to hold positively or negatively charged ions. It is the most important chemical property of a soil as it directly controls soil fertility. Ion exchange capacity also influences soil structural stability, plant nutrient absorption, soil pH, the soil's reaction to fertilisers and nutrient holding ability, Soil may be considered as a weak electrical system consisting of positively charged ions, called cations (+) and negatively charged ions, called anions (-).
Macro and micronutrients	Nutrients are essential for plant growth and living organisms in the soil. Macronutrients are required in large quantities and micronutrients are required in small amounts for growth, development and function. Macronutrients include: Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), and Sulfur (S). Micronutrients include: Boron (B), Chlorine (Cl), Manganese (Mn), Molybdenum (Mo), Iron (Fe), Zinc (Zn), Copper (Cu), Nickel (Ni)
Organic matter	Organic matter is any carbon -based living or dead animal and plant material. It includes living plant roots and animals, plant and animal remains at various stages of decomposition, and microorganisms and their excretions.
Parent material	The material that soil develops from. It may be rock that has decomposed in place, or eroded material that has been deposited by wind, water, or ice. The nature of the parent material strongly influences soil properties such as texture, pH, fertility, and mineralogy. For example, coarse-grained, quartz-rich parent material such as glacial outwash generates gravelly soils with a coarse (sandy) texture.
pH	pH (potential of hydrogen) is a scale of acidity from 0 to 14. It indicates how acidic or alkaline a substance is. More acidic solutions have lower pH while more alkaline solutions have higher pH. Substances that are not acidic or alkaline have a pH of 7 and are termed neutral. Each one-unit change in the pH scale corresponds to a ten-fold (logarithmic) change in hydrogen ion concentration.

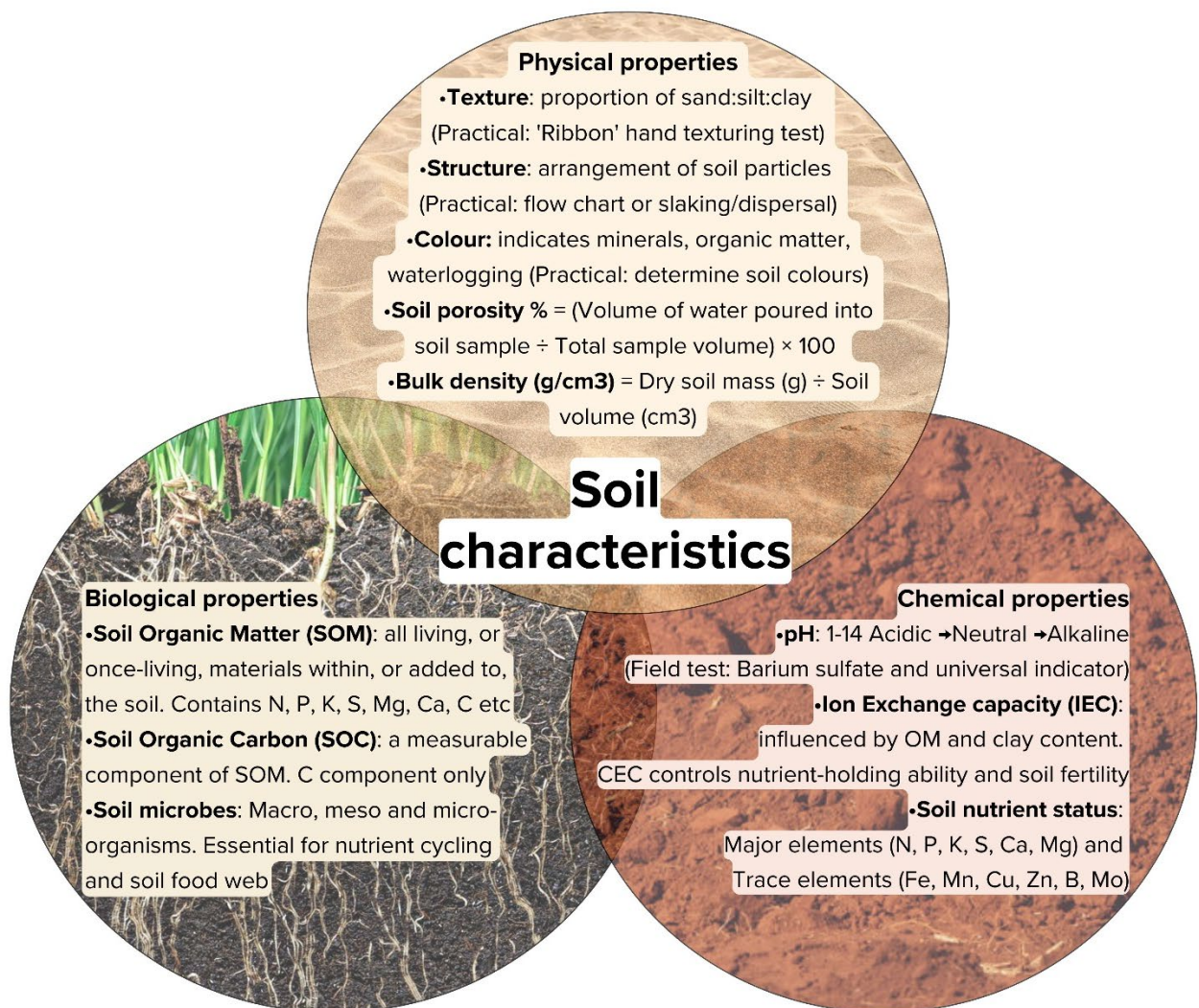
Soil term	Definition
Porosity	Pore space is that part of the bulk volume that is not occupied by either mineral or organic matter but is open space occupied by either air or water. Ideally, the total pore space should be about 50% of the soil volume. The air space is needed to supply oxygen to plant roots and soil organisms. Pore space also allows the movement and storage of water and dissolved nutrients.
Soil	The thin outer layer covering the earth (lithosphere). Made up of five components: • Mineral particles (sand, silt and clay); • Organic Matter- dead and decaying plants animals and animal products • Water • Gas- this fills the spaces (pores) between soil particles • Organisms- living organisms such as macro and micro invertebrates, bacteria, fungi and protozoa.
Soil colour	Is caused by the minerals present and by the organic matter content. Soil can exhibit a wide range of colour; grey, black, white, reds, browns, yellows and under the right conditions green. Soil colour is described by using general terms such as “dark brown” but can also be described more technically using Munsell soil colour charts.
Soil horizon	A soil horizon makes up a layer of soil. The horizon runs roughly parallel to the soil surface and has different properties and characteristics than the adjacent layers above and below. Characteristics used to distinguish between horizons are obvious physical features, such as soil particles, colour and texture. Horizons are obvious in some soils, because changes in soil appearance are abrupt, however, in many soils the change is more gradual, and horizons are hard to distinguish. Horizons are categorised as the following: • O horizon (surface organic litter) This is the layer of organic matter sitting on top of the soil. It tends to be deepest in undisturbed forest environments. • A1 horizon (topsoil). This is the surface soil, referred to as topsoil. It has the most organic matter and biological activity of any of the horizons. The decayed organic matter (humus) darkens the soil colour. • A2 horizon (topsoil). This layer is not present in all profiles. It frequently has a pale, bleached appearance and is poorly structured. Bleaching is an indication of periodic waterlogging often due to formation of a ‘perched’ watertable above a relatively impermeable subsoil. • B horizon (subsoil). This horizon frequently has more clay than topsoil. In clay soils, the difference in clay content between the A and B horizons is less than those for other soils, such as the Red Brown earths, where the topsoil is loamy or sandy. C horizon (weathering rock). This layer may be very deep and may not be present in the root zone of many vegetable-growing soils.
Soil Organic Carbon (SOC)	Soil organic carbon (SOC) refers only to the carbon component of soil organic matter (SOM). SOC is the measurable component of SOM.
Soil Organic Matter (SOM)	Soil Organic Matter (SOM) is the term used for all living, or once-living, materials within, or added to, the soil. All organic matter contains carbon (C), but it also contains nitrogen (N), phosphorus (P), sulfur (S), potassium (K), magnesium (Mg), calcium (Ca) and a whole range of micronutrients (e.g. copper, (Cu) and zinc (Zn). SOM improves the physical, chemical and biological properties of the soil, it increases the cation exchange capacity (CEC) and the water-holding capacity and it contributes to the structural stability of soils by helping to bind (glue) particles into aggregates. It also holds a great proportion of nutrients, cations and trace elements that are important to plant growth. It prevents nutrient leaching and produces organic acids that make minerals available to plants. It also buffers soil from strong changes in pH. It provides a food source for soils microbes and invertebrates essential for nutrient cycling.

Soil term	Definition
Soil organisms (biota)	Soil organisms represent a large fraction of global terrestrial biodiversity. Some examples include macro-organisms, earthworms, millipedes, fungi and microorganisms such as bacteria and protozoa. Soil organisms play a big role in: breaking down organic matter, recycling nutrients, creating humus, improving soil structure, nitrogen fixation, promoting plant growth, and controlling pests and disease.
Soil porosity	Soil porosity refers to the arrangement and distribution of pores (air spaces) within the soil. Pore spaces are filled with either air or water. The number, size and shape and continuity of soil pores determine soil fertility, water infiltration rates, gas exchange and overall soil health. <i>Soil Porosity % = (Volume of water poured into soil sample ÷ Total sample volume) × 100</i>
Soil profile	A soil profile is a vertical section of the soil that depicts all of its horizons. It allows you to examine the layers of the soil from the surface down to the rock or sediment from which the soil was formed (parent material).
Soil salinity	Both soil salinity and sodicity are caused by accumulation of too much salt in the soil. Salinity is the presence of soluble salts in the soil solution. Elements contributing to salinity include cations: Sodium (Na⁺), Magnesium (Mg²⁺), Potassium (K⁺), Calcium (Ca²⁺), Ammonium (NH₄⁺) and anions Chloride (Cl⁻), Sulfate (SO₄²⁻), Carbonate (CO₃²⁻), Bicarbonate (HCO₃⁻) and Nitrate (NO₃⁻). Soluble salts occur naturally in Australian soils; however, the accumulation of these salts can be amplified through inefficient irrigation and fertiliser use, or land clearing practices. Excess soluble salts in the root zone reduce plant growth.
Soil sodicity	Caused by the presence of excess sodium (Na⁺) (cation) attached to clay in soil. A soil is sodic when the sodium reaches a concentration where it begins to affect soil structure. The sodium weakens the bonds between soil particles. When the soil is wetted the clay particles become detached and spread out (disperse). The soil solution will appear cloudy and the soil structure will be poor. Water infiltration, gas exchange and drainage can be negatively affected by dispersed clay particles. Sodic soils are very prone to erosion.
Soil structure	Structure refers to the arrangements of soil particles. It describes the way which the sand, silt and clay peds are arranged or aggregated. Structure influences the amount and nature of porosity, affects tilling capability, nutrient retention, drainage, water holding capacity (WHC) and root penetration. Structure can be degraded or improved through farming practice.
Soil texture	Texture refers to the proportion of sand, silt and clay sized particles that make up the mineral fraction of the soil. Texture influences the soils mineralogy, ability for draining, WHC, nutrient retention and CEC, tilling workability and root penetration. Soil texture cannot easily be naturally altered.
Water Infiltration	Infiltration is the downward entry of water into the soil. Infiltration indicates the soil's ability to allow water movement into and through the soil profile. Soil temporarily stores water, making it available for root uptake, plant growth and habitat for soil organisms.

Introduction to soils

Soils are essential to all land based primary industries. They supply nutrients, water and oxygen to plants, they support machinery and animal traffic and assist the decomposition of crop and pasture residues. Soil management affects land productivity and environmental sustainability. Maintaining soil health for productivity requires knowledge of soil features and how they should be managed. Poor management practices can lead to soil degradation, which can reduce productivity. Soil is not a renewable resource. The loss of 1 mm of topsoil can take 3000 years to replace ([Evans et.al, 2020](#)).

Soils features fall into three groups: physical, chemical and biological. It is important to understand each of these , as they determine the success or failure of any agricultural crop or pasture . This document will explore these categories in greater detail.



Composition of soils

Soils are made up of three components:

- soil solid
- soil liquid and
- soil gas

Soil solids: comprise

- Inorganic materials (contain no carbon) including:
 - Residual minerals from rock
 - Minerals formed as rock are broken down (crystalline substances, mostly compounds of oxygen (O), silicon (Si) and aluminium (Al), sometimes with significant amounts of iron (Fe) calcium (Ca), potassium (K) or magnesium (Mg).
- Organic matter (material, both living and dead, containing carbon) including:
- Humus - completely decomposed organic matter, it cannot be further decomposed by microbes
 - Fresh and decomposing plant and animal material
 - Living macro-organisms (e.g. nematodes, earthworms, arthropods, rodents) and micro-organisms (protozoa, bacteria, fungi, algae, nematodes)

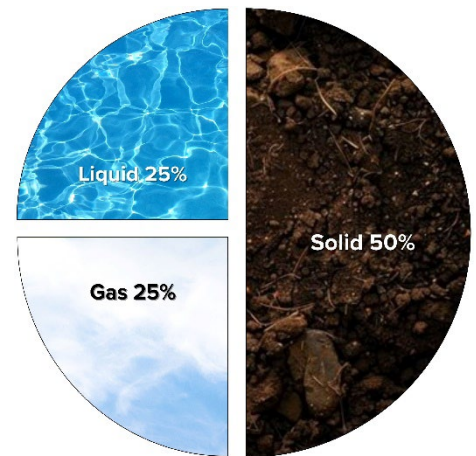


Figure 1 Components of soils- approximate proportions

Soil solution: the liquid phase (or soil solution) fraction consists of:

- Water which is held in the pores or holes in soil (like a sponge); and
- Contains dissolved materials including nutrients

Soil gas: the gas phase contains:

- Nitrogen gas (N₂)
- Oxygen (O₂) and
- Carbon dioxide (CO₂)

Soil gases are present in similar concentrations to the atmosphere, except CO₂ is normally higher and O₂ is slightly lower in soils.

Soil formation

Soils vary due to the original parent material; rock or sediment they develop from and different environmental conditions which control soil formation.

Types of rocks

Out of all the naturally occurring elements on earth, only eight elements Oxygen (O), Silicon (Si), Aluminium (Al) Iron (Fe), Magnesium (Mg), Calcium (Ca), Potassium (K) and Sodium (Na) make up 98% of the earth's crust. These elements combine in chemical compounds called minerals.

Primary minerals are formed by the cooling of molten materials. Secondary minerals originate from the chemical weathering of primary minerals. Rocks are mixtures of minerals.

There are three main rock groups: igneous, sedimentary and metamorphic.

- **Igneous rocks** originate from molten magma. Examples include Granite, Diorite, Gabbro, Peridotite, Hornblende, Rhyolite, Andesite, Basalt, Felsite.
- **Sedimentary rocks** originate from deposits of sediment on the floor of oceans or lakes. Over millions of years the deposits move above the water through earth crust movement. The resultant rocks have distinctive bands of deposited material cemented together. Examples include mudstone/shale (which form clays), siltstone (which forms silt), sandstone (forms sand), conglomerates (which form cemented gravels).
- **Metamorphic rocks** form when igneous or sedimentary rocks are melted by heat or pressure near a volcano, or as the earth's crust moves. Metamorphic rocks often have irregular, broken layers that contain crystals. Examples include schist, marble, hornfels, slate, quartzite and gneiss.

Once rocks are formed, they immediately start breaking down (weathering) forming soils.

To learn more about rocks, the rock formation process and how to identify them go to [Deakin University, 'Ideas for teaching science: Rocks and Soil'](#).

Parent material

A soil develops from the breakdown of parent rock (parent material). Parent materials include bedrock (sedentary parent material), unconsolidated rock deposited by wind, water, gravity or ice (transported parent material) and decomposed plant and animal material (organic matter).

The two main types of parent material are:

Sedentary parent material overlying soils are formed from the breakdown of underlying rocks, formed from rock at that site, or

Transported parent material parent rock was transported from elsewhere. Rocks are deposited then break down to form new soils. Mechanisms for transporting the parent rock are gravity, water, wind and ice (glacial).

Parent material influences soil physical properties (soil colour, texture, structure and porosity), all soil chemical properties (pH, cation exchange capacity, soil salinity etc) and soil biology. For example, soils developed from basalt are high in phosphorous (P) and fine textured, high in nutrients and have a high water holding capacity. Soils derived from granite are low in phosphorous (P) and coarse textured with low nutrients and have a low water holding capacity.

How are soils formed?

From the moment rocks are formed or transported parent materials deposited, the soil formation process begins.

To form a soil, parent materials are altered by:

- **Weathering** (transforming minerals to different sizes and composition).
Weathering is either physical (caused by temperature, water, wind and plant roots physically breaking apart or wearing down parent rock); or chemical weathering which is a result of rock minerals chemically reacting with water molecules.
- **Leaching** Moving soluble minerals of clay particles through a developing soil profile. Transported material accumulates in the subsoil.
- **Accumulation** of organic matter or newly formed crystals in the surface layers and topsoil

Watch [The Five soil forming factors](#)

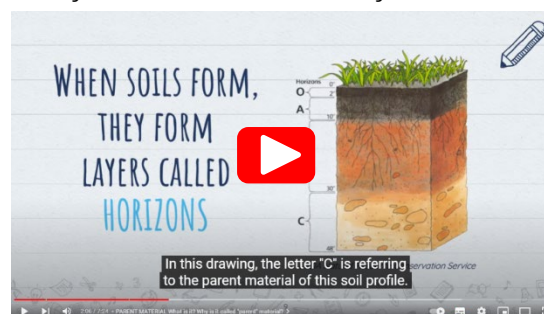
The five soil forming factors are:

- Parent material,
- Climate
- Biological factors
- Topography and
- Time

Where any of these soil forming factors change, the properties of the soil change.

Soil profile and soil horizons.

The product of these processes is the formation of vastly different soils with differing chemical, physical and biological features. As parent material breaks down it forms in different layers (called horizons) at various depths throughout the soil (soil profile).



Soil horizons are approximately parallel to the soil surface. Each horizon has different physical, chemical and biological characteristics.

Watch [Soils webinar: soil profiles and soils of NSW](#) to learn more.

1. List and describe the three main rock groups.

2. Define parent material.

3. Explain how soils are formed. Include the three processes involved.

4. List the five soil forming factors.

Soil physical properties

Soil horizons

Soil horizons are the most distinctive feature of a soil profile. Each horizon has differences in colour, texture and structure that distinguish it from those lying above or beneath.

Australian soil horizons are named according to the '[Australian Soil Horizon System](#)' using combinations of letters and numbers.

Five common horizons occur in Australian soil profiles. They are named with the capital letters A, B, C, O and R. These are called master horizons. Soils rarely have more than three master horizons within a soil profile. See Table 1.

As the soil often changes within master horizons, they are further classified into subordinate horizons using numbers for example A₁, A₂, B₁, B₂, B₃. etc.

Practical activity- edible soil horizons

Activity adapted from [DIY edible soil layers](#)

Background: Students use edible ingredients to model the common Master horizons.

Aim: model the common master horizons (O, A, B, C and R) in Australian soils.

Materials: (materials to be substituted dependant on allergies, preferences etc.)

- Teaspoon
- Transparent glass (plastic or glass)
- Shredded coconut died green with food colouring (organic material- O horizon)
- Sour worm lollies (decomposers- O horizon)
- Crumbled choc chip biscuits (A horizon)
- Chocolate mousse or chocolate yoghurt (subsoil-B horizon)
- Choc chip pieces (parent material- C horizon)
- Whole choc-chip biscuits (bedrock parent material – R horizon)

Method

1. Students take all materials and construct an edible soil profile consisting of master horizons O , A, B, C and R into a glass in their correct order (see Table 1).
2. Students complete the results table identifying and describing the characteristics of each Master horizon in your model (use Table 1 for assistance)



Figure 2 Source [DIY Edible soil layers](#)

Results table

Soil profile	Master horizon	Soil horizon characteristics	Model ingredient/s
	O (rarely present in Australian soils)		
	A		
	B		
	C		
	R		

Soil Profile	Master Horizon	Subordinate horizon
	O horizon: dominated by organic debris in various states of decomposition such as leaves pine needles, twigs, moss and lichens; accumulated on the soil surface. O horizons are quite rare in Australian soils as they normally only occur in alpine peat soils.	O₁ Original form of organic matter visible to the naked eye O₂ Organic matter partly decomposed. Visible to the naked eye
	A horizon: the natural surface layer. The A horizon is characterised by having a darker colour than horizons below due to organic matter and humus accumulation from decaying animal and plant residues. A Horizon structure has greatest influence of water and air infiltration. About 90% of the nutrients required by plants for growth are found in the A Horizon (therefore most laboratory soil tests are conducted on samples from the A Horizon). The A Horizon is the most biologically active horizon in the soil profile. Layer where weathering and leaching is most pronounced. Usually has a coarser texture than horizons below.	A₁ Normally present • High organic matter content (black/dark colours) • Zone of maximum biological activity • Low clay content • Normally low salt content
		A₂ May be absent • Low organic matter content • Lower clay content • Normally low salt content
	B horizon: zone of accumulation. Made up from one or more mineral layers consisting of either considerably more clay layers, iron or aluminium hydroxides or of a structure different to the A horizon above. Typically colours in B horizons are more pronounced (e.g. greater hue or colour than the horizon above).	B₁ Sometimes absent. Transitional horizon – More like B than A horizon
		B₂ Usually deeper/strongest coloured. Maximum accumulation of clay minerals and organic matter from A.
		B₃ Transitional to C
	C horizon: are layers beneath the A and B horizons containing partly altered and weathered bedrock parent material, along with clay minerals.	C Occasionally absent.
	R horizon: These consist of hard bedrock (parent material) underlying the soil. Granite, basalt, quartzite and hardened limestone or sandstone are examples of bedrock in the R horizon. The bedrock may contain cracks, but these are so few and so small that few roots can penetrate.	R Consolidated Bed Rock (Parent material)

Table 1 Common Master Horizons in Australian soils

Practical activity- identifying horizons in soil monoliths

This activity focuses on identifying master horizons.

Students identify soil horizons in a range of soil profiles using soil monoliths, soil pits or digital images.

Answer the following questions when identifying each master soil horizon within a soil profile.

Part A - Identify soil parent material (C and R Horizons)

Focus your attention at the bottom of the soil monolith (or profile if you are in the field) and try to determine type of parent material. Consider the following questions:

Is the parent material coarse or fine-textured?	
---	--

Are there any coarse fragments (with diam. > 2 mm) present? If so, what is their degree of rounding (angular, sub-rounded, rounded)?	
--	--

What is the degree of sorting (are particles all the same size, or do they range in size)?	
--	--

What was the mode of transportation and deposition for the parent material?	
---	--

Part B - Master horizon identification (A, B and O Horizons)

After you have identified the parent material, focus your attention to the soil above it and try to identify soil horizons. For each horizon identified, answer the following questions:

Is the horizon mineral (A horizon and B horizons) or organic? (O horizon)	
---	--

What is the horizon thickness?	
--------------------------------	--

What is the horizon colour?	
-----------------------------	--

What is the type of soil structure?	
-------------------------------------	--

Is there any mottling present? (Indicating water logging)	
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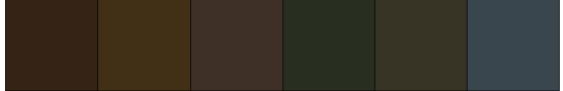
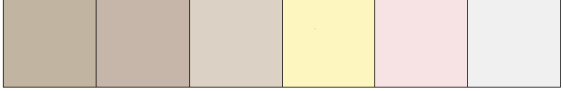
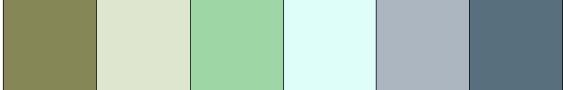
How does this horizon differ from overlying and underlying horizons? Note differences in colour, texture, structure, rooting depth, etc	
--	--

What is the most dominant soil formation process in this horizon?	
---	--

Sites to source images of monoliths to alternatively carry out this activity, include: Victorian Monolith Collection and [Soils of Tocal](#).

Soil colour

Soil colour is one of the most obvious soil features. Soil colour may indicate the amount of organic matter, seasonal waterlogging or dry periods. Soil colour can indicate potential plant growth.

Main colour groups	Examples of some soil colours
Black- in surface soil, black colours are associated with organic matter accumulation. In sub soils black stains may be associated with waterlogging or organic matter content in buried horizons	
Brown colours- black/dark brown soil usually indicates the presence of decaying organic matter. Soils will be generally fertile.	
Red colour - is due to presence of oxidised iron (Fe^{3+}) minerals produced during weathering. Red colours dominate in dry environments. Yellow - soils often have poorer drainage than red soils. The iron compounds in these soils are in a hydrated form and therefore do not have the 'rusty, red' colour.	Some red soil colours  Some yellow soil colours 
White or pale colours – associated with iron removal from soil, predominance of silica (quartz) or the presence of salts. Pale bleached layers found throughout a soil profile indicate past waterlogging.	
Blue/green (gleyed) – soil is permanently anaerobic (no oxygen) e.g. waterlogged soil where the red (Fe^{3+}) has been reduced to a bluish green form (Fe^{2+}). Plant residues buried in wet soil may create a bluish colour in the soil; decomposing organic matter uses up oxygen and creates an anaerobic zone for a short time.	
Mottled colours – e.g. red, orange or yellow patches in a grey background. This indicates historic intermittent anaerobic conditions such as fluctuating water table and periodic water logging.	Example of mottling 

Whenever possible use a [Munsell soil colour chart](#) to identify soil colour. The Munsell system divides colour into: hue; value; and chroma. Hue is based on the primary and secondary colour base (red, yellow, blue); value is the tone (from dark to light); and chroma is the colour saturation.

Watch: [Soil pit Lab with Professor Ray Weil – soil colour and classification](#)

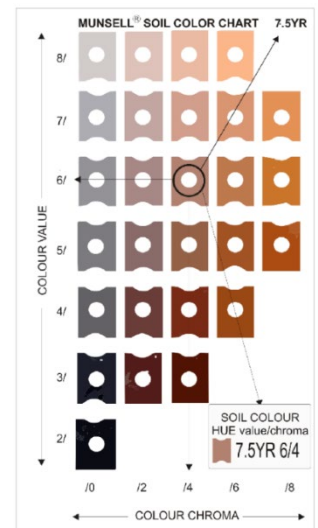
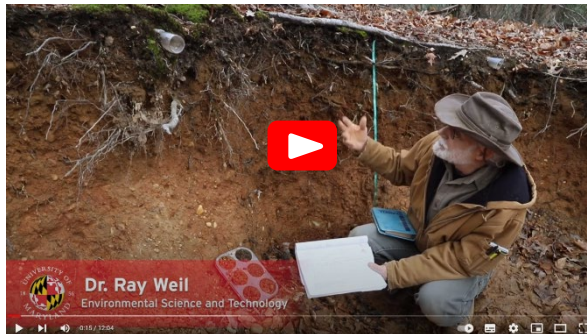


Figure 3 Example of Munsell soil colour chart

If a Munsell colour chart is not available, use simple colour names as shown in Figure 4.

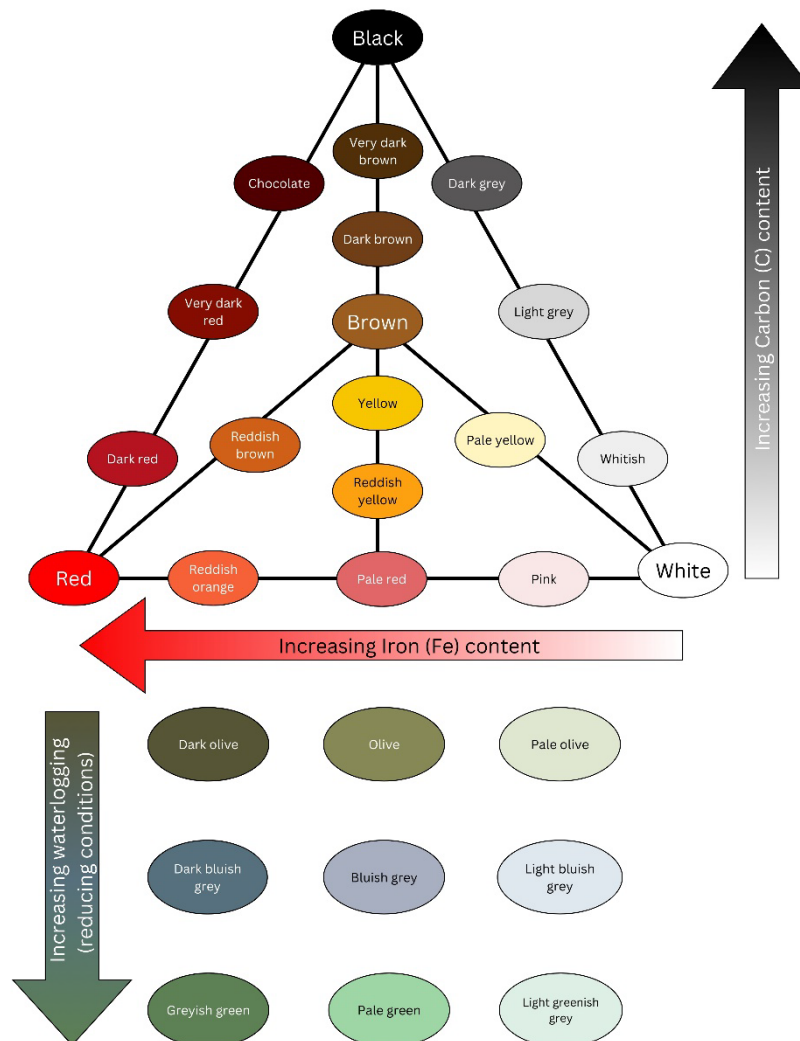


Figure 4 Relationship between soil colour and influencing factors/conditions. Source: Adapted from Better Soils, Agricultural Bureau of South Australia

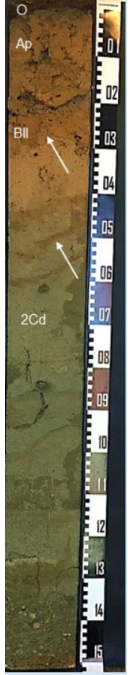
5. Describe how soil colour is an indicator of soil fertility. Give examples.

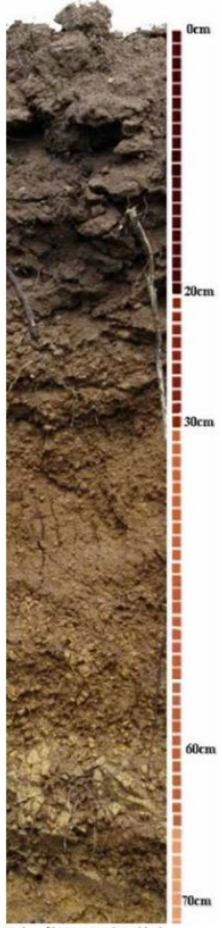
6. Apply your understanding of soil colour to identify the colour/s present and characteristics of the soils in each monolith image. A monolith is a mounted soil core which shows the undisturbed soil in profile.

For each monolith image:

- Label the depth of each soil colour interval
- Comment on any problems with drainage

The first has been completed for you.

Monolith image	Description
	0-3cm black, organic topsoil
	3-20cm dull brown indicates organic matter present and good drainage
	20-50cm brown indicates good drainage and some iron present
	50-150cm green indicates reducing conditions caused by waterlogging

Practical activity- measuring soil colour

Teachers to adapt the following activity dependant on resources available. Monolith images can be found at [Soils of Tocal](#) (Australian) and [Soil Monoliths, Ku Leuven](#).

Aim: to identify soil characteristics by identify soil colours.

Materials:

- Images of soil profile monoliths or a range of soil samples from different depths
- [Munsell soil colour chart](#) or Figure 4 'Relationship between soil colour and influencing conditions'

Method:

1. Assess a range of soil samples (or images) to determine the soil colour using the [Munsell soil colour chart](#). If you do not have access to a Munsell chart, use Figure 5.
2. Record your results. Comment on soil drainage based on the samples colour/s.

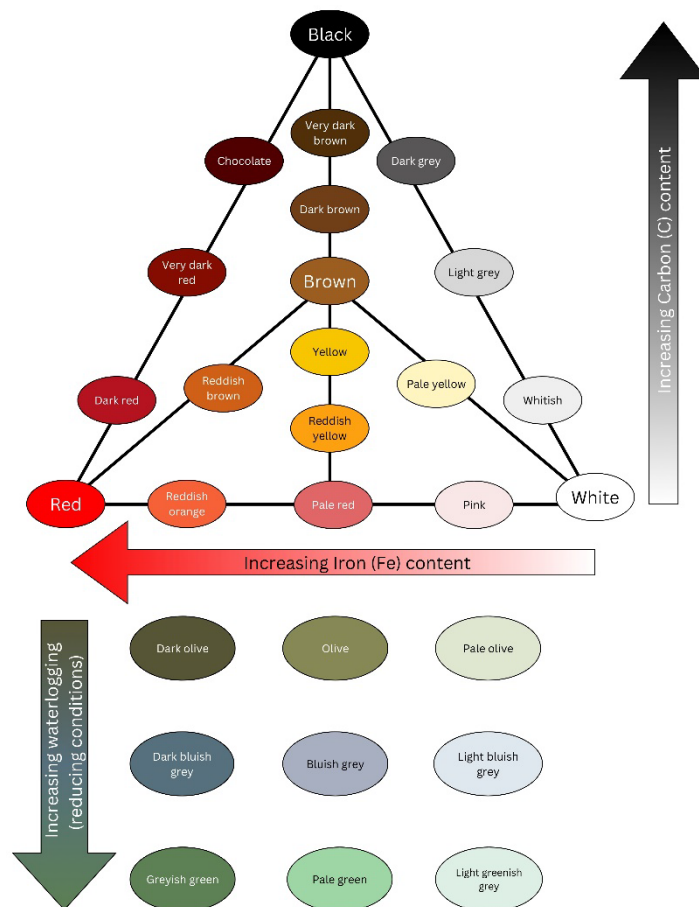


Figure 5 Relationship between soil colour and influencing factors/conditions. Source: Adapted from [Better Soils, Agricultural Bureau of South Australia](#)

Discussion: Explain how soil colour influences plant growth and soil management using specific examples.

Soil texture

Soil texture is a physical soil property and measures the proportion of the various sizes of the individual soil particles (sand, silt and clay).

Soil texture often changes with depth and across a paddock or landscape. Clay content in a soil often increases with depth. Soils with a high clay content are called 'heavier' textured soils. Understanding the texture changes throughout the soil profile and across a paddock or landscape helps to explain how different soils behave, influence plant growth and can be managed. Therefore, when investigating soils, it is important to obtain samples to depth throughout a soil profile and from multiple sites within a paddock.

The basic texture classes are sand, loam and clay. These are further divided into about 12 more sub-divisions e.g. silty clay (SC), clay loam (CL), sandy clay loam (SCL) etc dependant on the proportions of sand, silt and clay.

Characteristics of sand, silt and clay

Sand

- Large particles 0.02-2 mm
- Large air (pore) spaces between particles
- Sand is inert, so doesn't hold nutrients, or water and drains freely
- Warms up quickly and cools down quickly (extends growing season early in Spring)
- Are easy to cultivate but wear equipment quickly
- Easily eroded by wind and water as particles don't hold together (weak structure)
- More likely to be water-repellent compared to clay and silt

Silt

- Mid-sized particles 0.002-0.02 mm
- Fairly inactive, being composed mostly from broken down grains of quartz
- Fertile, adequate drainage, adequate moisture holding capacity compared to sandy soils
- Easy to cultivate (except in dry conditions), but easily compacted
- Damaged when worked or grazed in wet conditions

Clay

- Very small particles < 0.002 mm
- Restricted air and water movement (can easily become waterlogged for long periods)
- Have a high surface area and negative surface charge allowing them to hold together particles and nutrients
- May hold high levels of nutrients if drainage is adequate
- Easily compacted if worked or grazed when wet

- Bakes hard in dry conditions
- May crack in dry frosted conditions (which may reduce compaction)

The ideal soil is a loam, which is a relatively even mixture of sand, silt and clay. Loams are highly fertile with good water retention, high nutrient holding capability and high porosity for root growth and air circulation. They are also generally easy to work. Any soil with high proportions of any one soil particle will have both limitations and benefits for management and plant growth.

Figure 6 size of different soil particles

Particle	Image	Diameter (mm)	Number of particles/g	Specific surface area (cm ² /g)
Clay		<0.002	90260000000	8000000
Silt		0.05-0.002	5776000	454
Very fine sand		0.1-0.05	722000	277
Fine sand		0.25-0.1	46000	91
Medium sand		0.5-0.25	5700	45
Coarse sand		1.0-0.5	720	23
Very coarse sand		2.0-1.0	90	11

Texture and plant growth

Texture cannot be changed through management* on a commercial scale; its qualities are inherited from parent material rock (time and weathering). Texture affects soil air and water spaces/pores (porosity), water infiltration (permeability) and the soils' ability to hold water and nutrients.

*Texture technically could be changed by adding e.g. sand to a heavy clay and mechanically working it into the existing soil, but this will not change texture to depth and is impractical and uneconomic for most production systems.

Soil Water Holding Capacity (WHC)

Soil Water Holding Capacity (WHC) refers to the ability of a soil to physically hold water in its [soil pores](#) against the force of gravity. Water molecules are held in soil pores by cohesion.

Along with soil depth and structure, the texture of a soil will determine the potential water and nutrient holding capacity (Learn more about soil nutrient holding ability in the soil [Ion Exchange Capacity](#) section of this document).

Water-holding capacity is controlled mainly by soil texture and organic matter content.

Soils with smaller particles (silt and clay) have a larger surface area than those with larger sand particles. A large surface area allows a soil to hold more water. In other words, a soil with a high percentage of silt and clay particles has a higher water-holding capacity.

The amount of water available to plants, known as Plant Available Water (PAW), depends on the texture and depth of the soil. Clay soils hold a lot of water, but they hold water molecules very tightly by cohesion. So, some of the water held in clay soils is unavailable to plants. Typically, in clays only 25% of total water held in the profile can be used by plants. In sands, approximately only 10% of the total water held is available to plants, because sands drain quickly (due to low surface area as sand particles are large).

7. Define Water Holding Capacity.

Measuring texture

Soil texture can be accurately measured with a [soil test laboratory analysis](#) which measures the total particle sizes present in the mineral fraction of the soil sample. The total proportions of sand, silt and clay are shown in Figure 7 Australian standard texture triangle to determine a soil texture grade.

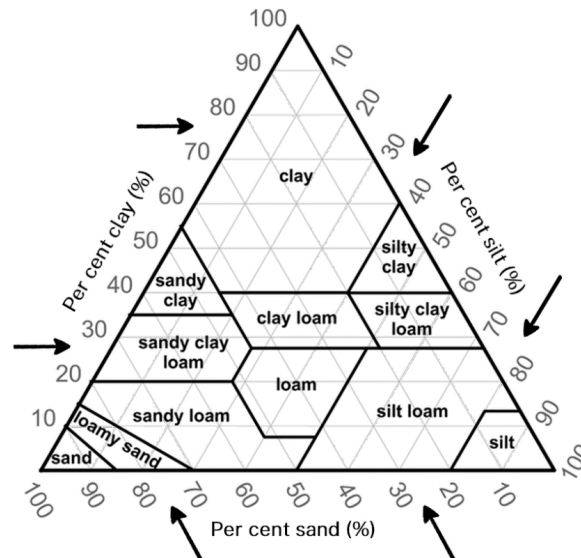


Figure 7 Australian soil texture triangle

Read the texture triangle graph by following the axis lines for each of the components as indicated by the arrows (see Figure 8). Where the axis transect is the soil texture grade. For example, a soil with 15% sand; 70% silt; and 15% clay is a silt loam (See Figure 8).

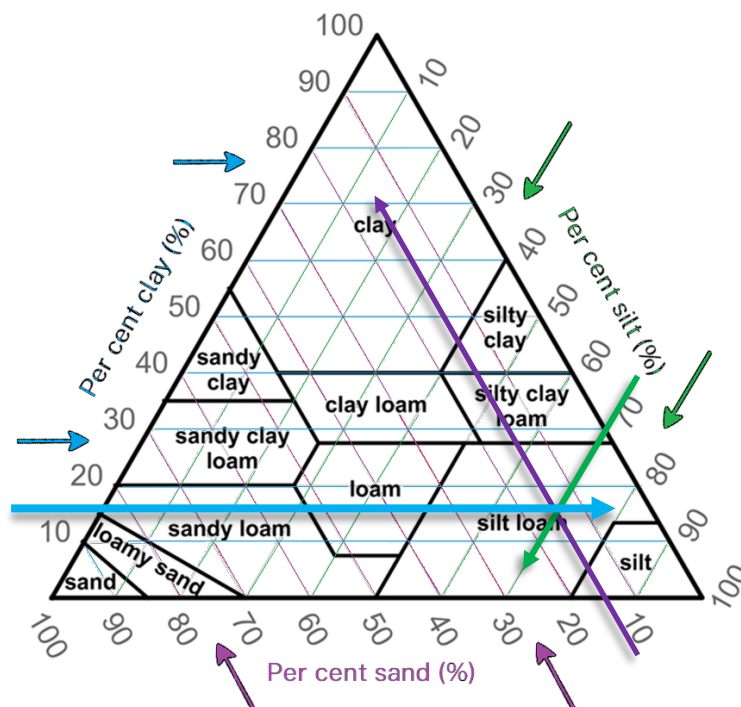


Figure 8 Reading a texture triangle

Soil texture can also be approximately determined in the field by carrying out a '[hand texturing test](#)' or a '[jar test](#)' (Figure 9). Hand texturing involves identifying how the soil feels, reacts and sounds when a small handful of soil is moistened and kneaded into a ball (or bolus) then ribboned between forefinger and thumb. Observations from hand texturing allow a texture class to be determined by observing the approximate proportions of sand, silt and clay. Clay is the smallest or finest of the soil particles in a bolus, sand is the largest and coarsest, and silt is between the two.

Watch: [How to test your soil- texture \(sand, silt and clay composition\)](#)

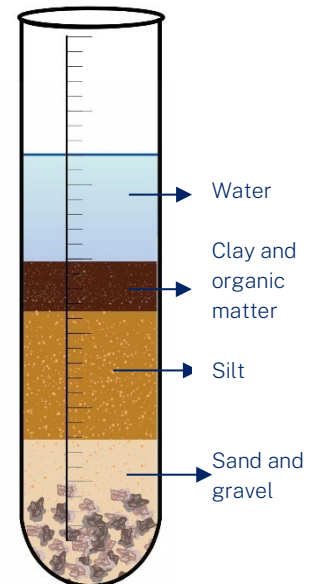


Figure 9 Jar test concept-
measure soil components.

8. Define soil texture

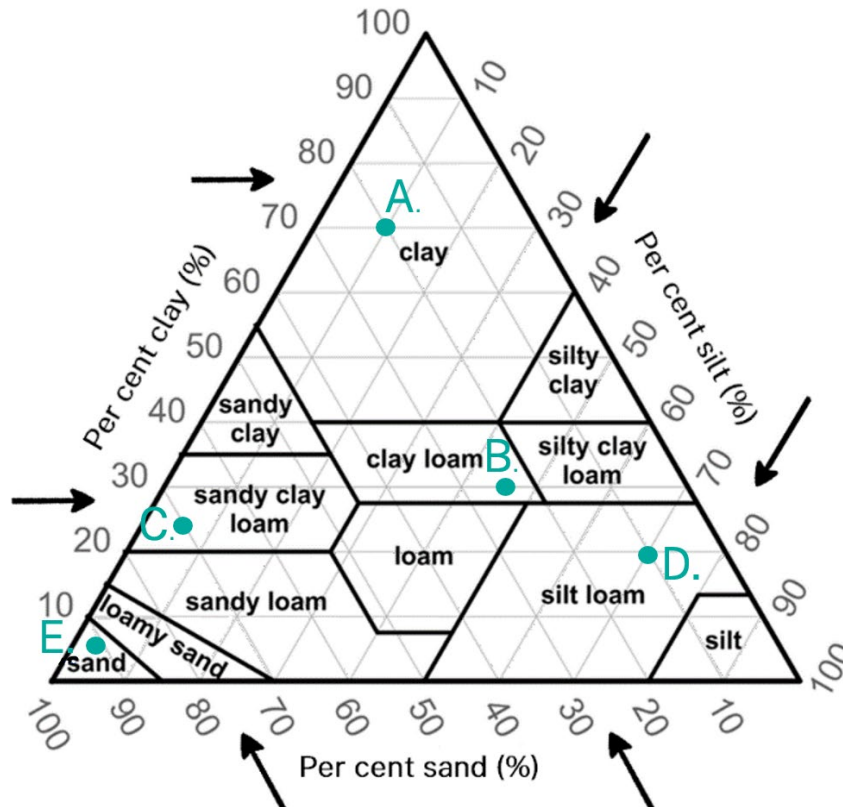
9. Describe how soil texture affects plant growth

10. Can soil texture be altered through management?

11. Use the texture triangle (Figure 7) to identify the texture class of a soil with:

- a) 40% sand; 30% silt; 30% clay _____
- b) 5% sand; 95% silt; 5% clay _____
- c) 85% sand; 5% silt; 12% clay _____
- d) 49% sand; 14% silt; 39% clay _____
- e) 23% sand; 23% silt; 76% clay _____

12. Label the components of sand: silt: clay for soils A-E in the diagram.



Label	Components sand: silt: clay
A	
B	
C	
D	
E	

Practical activity – soil texture, ribboning test

Aim: to conduct a hand texturing (soil ribboning) test to determine the approximate texture class for a range of soils.

Materials:

- Range of soil samples from different sites and different soil profile depths
- Water
- Access to texture triangle (Figure 7)
- Soap and cloth to wash/dry hands
- Ruler

Method:

1. Take a small handful of a soil sample. (Remember to collect samples to depth at the sample site).
2. Remove any coarse organic matter i.e. roots and any stony material (larger than 2 mm diameter). Crumble the soil in your hand, especially if it is clayey.
3. Wet the soil until it is moist enough to mould and roll it into a ball (bolus). Stop adding water when the ball starts to stick to your hand. If you can't make a ball the soil is very sandy.
4. Use Figure 10 to determine the texture class and carry out steps 5-7.
5. To determine the texture class, you need to manipulate the ball in your hands and feel whether the soil is:
 - sandy - feels and sounds very gritty
 - silty - feels very smooth and silky
 - clayey - feels like plasticine and is sticky.
6. The texture class is also determined by ribboning the soil. Roll the ball into a sausage shape and then press the 'sausage' out between your thumb and forefinger to form a 'ribbon' until it breaks.
7. Measure the length of the ribbon using a ruler.
8. Record results into the results table
9. Wash and dry hands using water and towel
10. Repeat steps 1-9 for each sample



Figure 10 Guide to determining soil texture- hand texturing test

Feel	Ball coherence	Other features	Ribbon length (mm)	% clay	Texture grade	Field texture class
Sandy	Nil	Single sand grains stick to fingers	Nil	< 5	Sand (S)	Sands
Sandy	Slight	Discolours fingers with organic stain	5	5	Loamy sand (LS)	
Sticky	Slight	Sandy grains stick to fingers and discolours with clay stain	5 to 15	5 to 15	Clayey sand (CS)	
Sandy	Just coherent	Medium sand readily felt	15 to 25	10 to 25	Sandy loam (SL)	Sandy loams
Sandy	Just coherent	Fine sand can be felt	15 to 25	10 to 25	Fine sandy loam	
Spongy, greasy	Coherent	No obvious sandiness or silkiness	25	25	Loam	Loams
Smooth, silky	Coherent	Silky; very smooth when manipulated	25	25	Silt loam (SiL)	
Sandy	Strong	Medium sand in a fine matrix	25 to 40	20 to 30	Sandy clay loam (SCL)	Clay loams
Smooth, sandy	Coherent	Fine sand, can be felt and heard	40 to 50	20 to 30	Fine sandy clay loam (FSCL)	
Smooth	Strong	No obvious sand grains	40 to 50	30 to 35	Clay loam (CL)	
Smooth, silky	Coherent	Silky	40 to 50	30 to 40	Silty clay loam (SiCL)	
Plastic	Coherent	Fine to medium sand	50 to 75	30 to 40	Sandy clay (SC)	Light clays
Plastic, silky	Coherent	Smooth and silky	50 to 75	35 to 40	Silty clay (SIC)	
Plastic	Coherent	Smooth with slight resistance to shearing	50 to 75	35 to 40	Light clay (LC)	
Plastic	Coherent	Smooth; handles like plasticine; moderate resistance to shearing	75+	45 to 55	Medium clay (MC)	Medium and heavy clays
Plastic	Coherent	Smooth; handles like plasticine; firm resistance to shearing	75+	> 50	Heavy clay (HC)	

Glossary of terms

Coherence The ability of the ball to hold together.

Sandy Feels gritty, and you can see coarser sand grains. Very fine sand grains (too small to see and feel a bit like silt) make a grating sound as you rub the soil between your fingers.

Spongy Typical of loams; also, a high organic matter content creates a spongy feel.

Silky The smooth, soapy, slippery feel of silt.

Plastic The ball can be deformed (reshaped) and it holds its new shape strongly. Typical of clays.

Resistance to breaking How firm the soil feels as you form a ribbon. (Place the ball of soil between your thumb and forefinger and squeeze, sliding your thumb across the soil.) The firmness is a good way to distinguish light, medium and heavy clays. A light clay breaks easily, a medium clay is stiff, and a heavy clay is very stiff, usually needing two hands to form a ribbon.

Ribbon Make a ribbon by kneading the ball of soil with your thumb, gently pressing it out over your forefinger. The longer the ribbon you can make before it breaks, the more clay is in your soil.

Results table:

Sample	Form a ball (yes/no)	Feel of sand (yes/no)	Ribbon length (mm)	Plasticity (high/low)	Approx. clay %	Texture grade	Field texture class
1							
2							
3							
4							
5							

Add more rows as required

Soil structure

Structure refers to how soil particles (sand, silt and clay) plus organic matter group together to form aggregates (or peds).

Individual soil particles and organic matter usually stick together to form peds, leaving air spaces or pores between the aggregates. It is rare for soil particles to exist as single units in the soil (except in sands). The size and shape of aggregates varies. The arrangement and size of the aggregates, along with the pores or spaces between the aggregates, is known as structure.

A well-structured soil, along with having many small aggregates, has ample space within and between the aggregates to allow good penetration of water, air (gas exchange) and plant roots (transmission pores). It also has adequate small pores to store water for use by plants (water storage pores). See Figure 11.

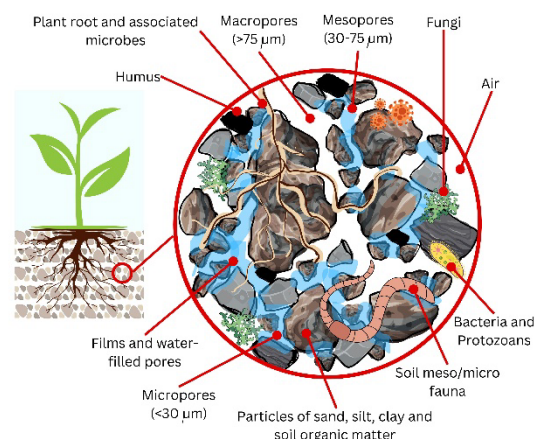
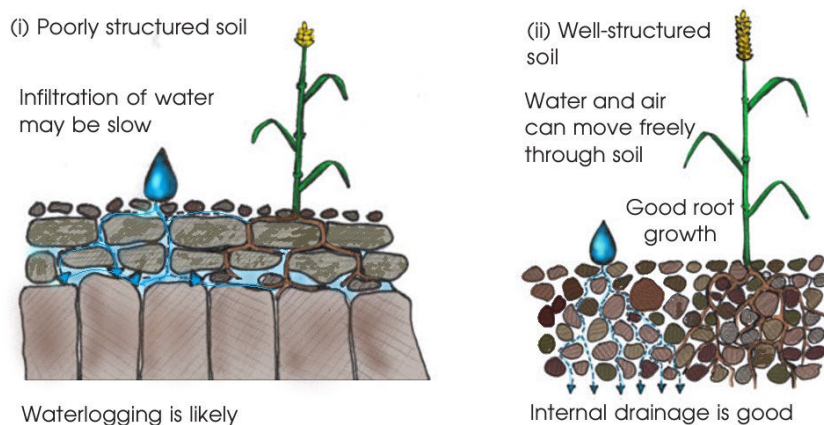


Figure 11 Soil pores and peds

If structural aggregates are not present, the soil mass is said to be structureless.

Individual soil aggregates may have differing shapes. Some aggregate shapes indicate better soil structure for plant growth. Platy structures can restrict air and water movement and reduce plant growth, because a platy structure is made up of soil particles aggregated in thin plates or sheets piled horizontally on one another. Crumb-type aggregates allow good plant growth because there is good water and air movement. Soils with a crumb structure allow good root growth (for example for vegetables and root crops), as the soil is less compact than other structure types. Blocky structures are generally less favourable for plant growth and production. (See soil structure flow-chart in [Practical: Determining the soil structure qualitatively](#))

Figure 12 Water infiltration, gas exchange and root growth in poorly structured vs. well-structured soils



Managing structure and plant growth

Structure can be rated as good or bad for plant growth. Poor structure does not allow water infiltration and air circulation, and hence plant growth and root development is poor. Soil that consists of large blocks with few pores or air spaces in the soil is said to have a 'massive' structure. Massive, structured soils are unsuited to plant growth. See Figure 12.

Characteristics of a soil with poor structure include:

- crusted or hard-setting topsoil (massive structure)
- pugged topsoil (damage from stock)
- slaking and/or dispersion
- compacted zones, such as those under wheel tracks or plough pans
- poor establishment or stunted plant growth.

Some soil structural problems occur naturally, for example, sodicity (which is caused by the presence of sodium (Na^+) ions attached to clay particles in soil and results in soils dispersing).

Unfortunately, most problems are caused by, or made worse by, human activity.

Inappropriate use of cultivation is a major cause of soil structural decline.

Soil structure can be managed and improved. Management practices which improve soil structure include:

- Incorporation of organic matter into a soil. For example, through green manuring, or incorporating animal manure etc. Organic matter has a negatively charged, high surface area which allows organic matter to act like a 'glue' binding soil particles together to form stable aggregates. Organic matter also holds nutrients for plant and microbial growth and increases the water holding capacity of soils.
- Pasture phases in crop rotations which allow for the buildup of organic matter content (e.g. pasture ley phases and long-term pastures).
- Conservation tillage methods such as the use of direct drill, zero-till and cover crops in cropping rotations.
- Use of tramlines and roads when using implements in paddocks to reduce soil compaction.
- Livestock management practices including no over stocking, over grazing or pugging of soils through compaction.
- Growing deep rooted perennial species which incorporate organic matter deep into the soil profile and encourage biological activity to greater depth than shallow rooted annual plant species.
- Addition and incorporation of agricultural lime (Calcium carbonate- CaCO_3). Calcium carbonate displaces hydrogen and aluminium ions located around clay

particles with calcium. Calcium then strongly holds (bonds) the clay particles together thus improving soil structural stability and increasing pH.

- Addition and incorporation of gypsum (Calcium sulfate, CaSO_4). Gypsum improves soil structure by displacing sodium ions on the surface of clay particles with calcium. Calcium then strongly holds (bonds) the clay particles together thus improving soil structural stability and decreasing soil dispersion.

13. Define soil structure

14. Describe characteristics of a well- structured soil

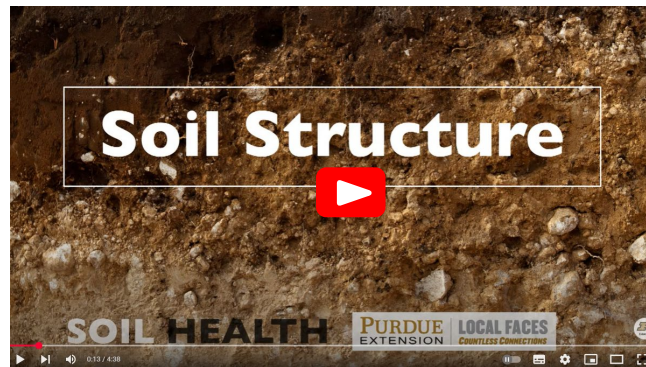
15. Describe characteristics of a poorly structured soil

16. Describe two management practices which improve soil structure

17. Construct and label a diagram to contrast plant growth, water infiltration and gaseous exchange in a well-structured and poorly structured soil

Well-structured soil	Poorly structured soil

Practical activity - Determining soil structure qualitatively

Background: [Watch: Soil basics: structure](#)

Aim: to determine the level of soil structure for a range of samples.

Materials:

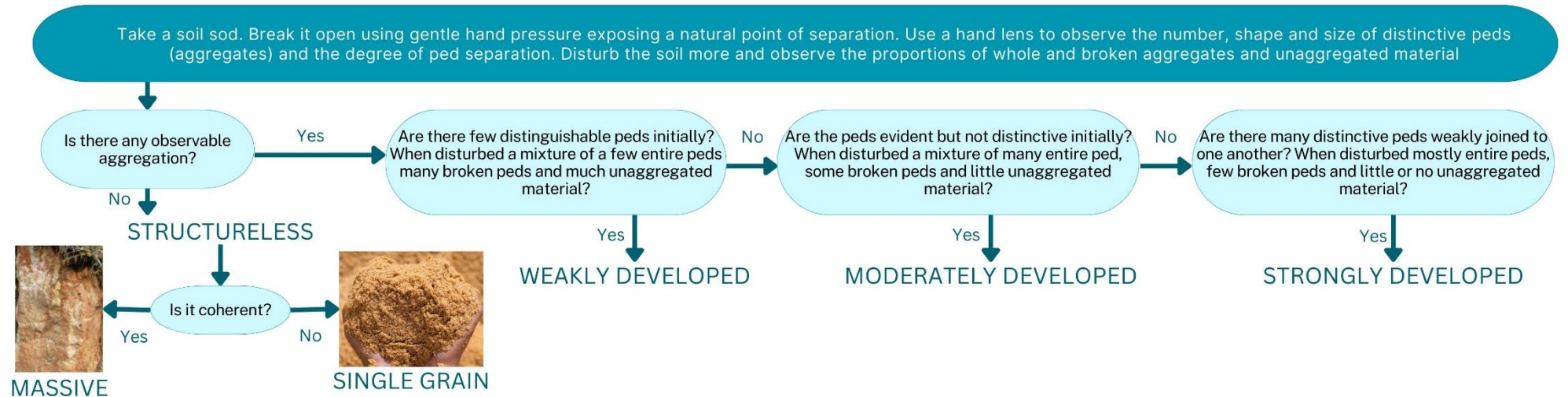
- A range of soil sod samples, each approximately the diameter of a dinner plate. Samples collected at different sites (Soil sod is a 'clump' of soil)
- Hand lens (optional)
- Ruler
- Water and towel to wash/dry hands

Method:

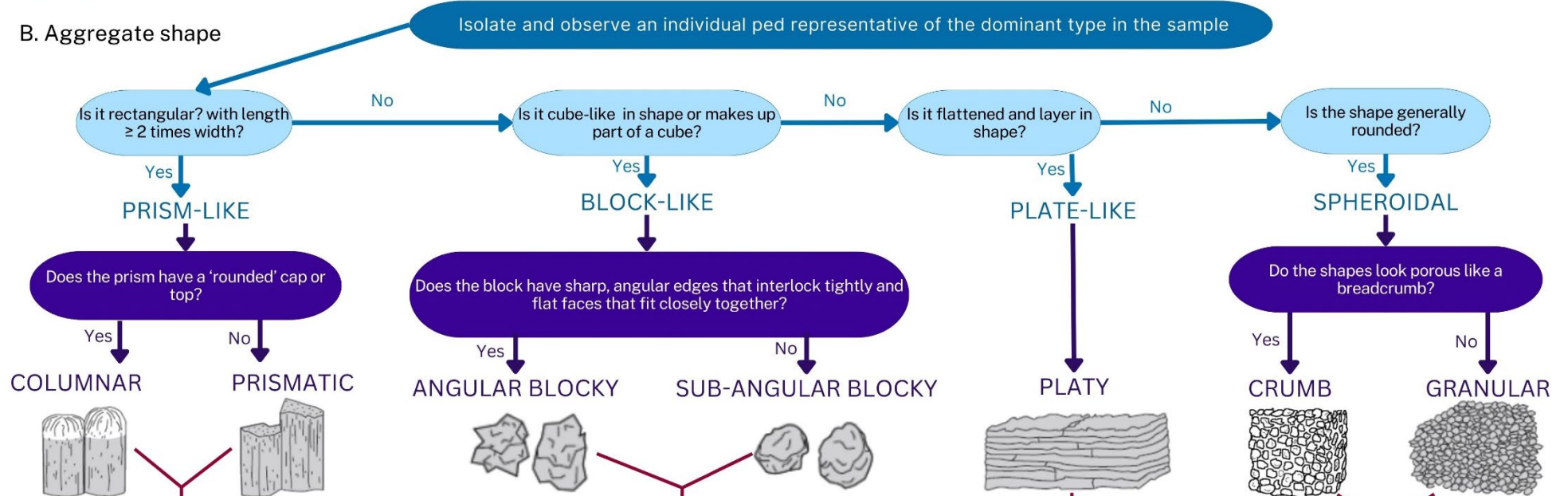
1. Take a soil sod
2. Break it open using gentle hand pressure exposing a natural point of separation
3. Use a hand lens to observe the number, shape and size of distinctive peds (aggregates) and the degree of ped separation
4. Disturb the soil more and observe the proportions of whole and broken aggregates and unaggregated material
5. Use the 'Soil structure determination flow chart' to identify the structure of your soil sample
6. Record results in the results table
7. Wash hands
8. Complete steps 1-7 for each sample

Soil structure determination flow chart

A. Aggregate distinctness (Structure grade)



B. Aggregate shape



C. Aggregate dimensions (type)

<10mm very fine
10-20mm fine
20-50mm medium
50-100mm coarse
>100mm very coarse

<5mm very fine
5-10mm fine
10-20mm medium
20-50mm coarse
>50mm very coarse

<1mm very thin
1-2mm thin
2-5mm medium
5-10mm thick
>10mm very thick

<1mm very fine
1-2mm fine
2-5mm medium
5-10mm coarse
>10mm very coarse

Results table:

Sample	A.) Structure grade	B.) Aggregate shape (class)	C.) Aggregate dimensions (type)

Add rows as required

Discussion activity

Complete the table to identify the expected water infiltration rate (fast, medium or slow) for each soil sample. Justify your answer with reasons.

Sample	Structure grade and class	Infiltration rate	Reasons

Add rows as required

Extension activity- if you have access to soil monoliths, a soil pit, riverbank or road cutting; describe and observe the structure of soil in each horizon through the soil profile using the 'Soil structure determination flow chart'.

Practical Activity- Aggregate structural stability - Slaking and dispersion (structure quantitative test)

Background:

Soil structural examination (qualitative test) indicates soil structure in terms of water and air filtration. An alternative and quantitative test for structural stability is the simple slaking and dispersion test. It measures aggregate stability. Soils with good structure have aggregates that are porous and stable.

Soil aggregate stability is the ability of a soil to regulate the movement and storage of water and air throughout a soil profile. Soils which have stable aggregates are more productive.

Soil structure influences:

- soil porosity
- tilling capability
- nutrient retention
- drainage
- water holding capacity (WHC)
- root penetration
- air and water movement to plant roots.

Slaking

Slaking is the breakdown of large, air-dry soil aggregates (>2-5 mm) into smaller sized microaggregates (<0.25 mm) when they are immersed in water. Slaking occurs when aggregates are not structurally strong enough to withstand internal stresses. Internal stresses result from irregular swelling of clay particles, trapped and escaping air in soil pores and rapid release of heat during wetting. Organic matter reduces slaking by binding mineral particles and by slowing the rate of wetting.

Most cultivated soils in Australia are prone to slaking. Slaked soil particles block soil pores, form a soil crust which can reduce seedling germination/emergence, reduce infiltration and water movement through the soil and increase runoff and erosion.

Dispersion

A soil that disperses on wetting has a very unstable structure. In a dispersive soil, the soil aggregates (small clods) collapse when the soil gets wet, because the individual clay particles disperse into solution. This collapse of structure causes the soil to slump, lose porosity and become denser, thus restricting root growth of most plants.

Dispersion is affected by soil texture, clay type, soil organic matter content, soil salinity and types of exchangeable cations (nutrients) present.

Dispersive soils are highly vulnerable to erosion via water. Dispersive soils are structurally unstable when wet and often lack structure when dry. Movement of air and water into dispersive soils is poor, making them prone to waterlogging and compaction.

Managing slaking and dispersive soils

Conventional tillage methods that disturb soil, cause soil compaction and hasten organic matter decomposition increase slaking and dispersion in soils. They also remove ground cover which increases the impact of raindrops and infiltration. Increasing the organic matter content of soil will also significantly improve the stability of a soil to resist slaking and dispersion.

Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is a rock mineral which, when incorporated into dispersive alkaline soils, can improve soil structural stability by making clay particles flocculate (stick together). In dispersive acidic soils, agricultural lime (CaCO_3) should be incorporated. Read more at [Managing dispersive soils](#).



Watch: [How to test soil structure](#)

Aim: to determine soil aggregate structural stability through testing for slaking and dispersion

Materials:

- *Aggregates must be air dried for a minimum of 5 days prior to the practical.*
- Soil aggregate samples from a range of sites. Soil aggregate size approximately 3-5mm.
- Petri dish (1 per sample)
- Distilled water or deionised water (substitute-rainwater)
- Watch/ clock/ timer

Method:

1. Fill a petri dish with distilled water within a few mm of the top
2. Take a soil aggregate
 - a. Observe the colour/s and structure
 - b. Gently place the aggregate into the distilled or deionised water filled petri dish
 - c. Do not agitate or mix the petri dish
3. Start timer
4. Observe the following at stated times
 - a. Immediately- Does the aggregates swell? If a soil is prone to swelling, it happens nearly immediately as the soil wets up

- b. 5 minutes- Does the aggregates slake? Slaking is observed as collapse of the original aggregate. The aggregate appears to crumble into smaller particles. (see Figure 13).
 - c. 10 minutes- Does the aggregate disperse? If dispersion occurred, was it complete or partial? (see Figure 14).
 - d. (OPTIONAL) 2 hours - Leave petri dish and observe at 2hrs or more if there was moderate dispersion. Some soils take a lot of time to disperse.
5. Record results into results table
 6. Repeat steps 1-5 for each aggregate sample.

Figure 13 Slaking

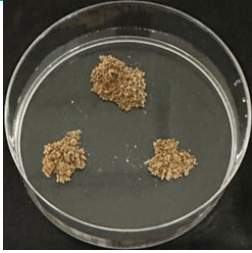
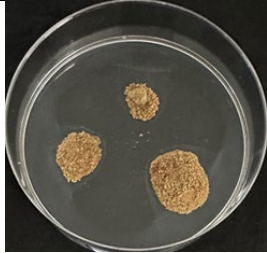
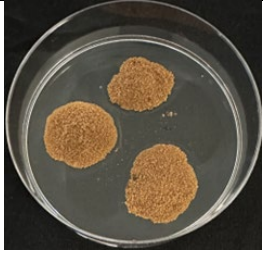
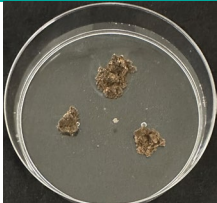
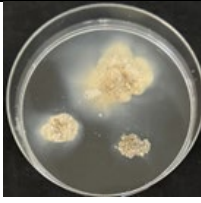
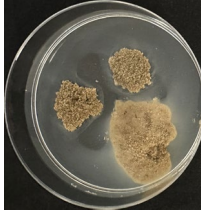
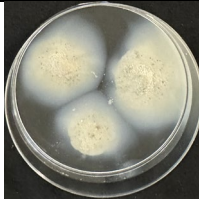
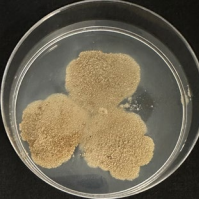
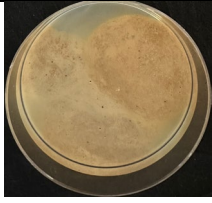
Slight slaking	Moderate slaking	Complete slaking
		
Aggregate remains intact, or only slightly collapses around the edges. Some oxygen gas given off as bubbles.	Moderate oxygen gas given off. Structure collapses but medium- large aggregates still present. Low Organic Matter content. Organic matter holds soil particles together.	Oxygen gas rapidly given off Compressed air in pores rapidly fills with water which breaks aggregates apart. Structure completely collapses to individual soil particles (sand, silt, clay)

Figure 14 Dispersion

Nil dispersion	Moderate dispersion	Strong dispersion	Complete dispersion
 	 	 	 
Nil dispersion – no cloudiness surrounding aggregate	Moderate dispersion with obvious cloudiness/milkeness	Strong dispersion with considerable cloudiness/milkeness and about half of the original volume of the aggregate dispersed outward	Complete dispersion leaving only sand particles in a cloud of dispersed clay

Results:

Sample	Observable features of dry soil (e.g. colour, pores, organic matter presents, structure)	Aggregate behaviour in water	Slaking or dispersal (or both)
Add more rows as required			

Soil density and porosity

Soil porosity

Soil porosity refers to the arrangement and distribution of pores (spaces) within the soil. Pore space is the part of the total volume of a soil which is not occupied by either mineral or organic matter but is open space inside and between soil particles and aggregates. Pore spaces are filled with either air or water. The number, size, shape and continuity of soil pores determine soil fertility, water infiltration rates, gas exchange and overall soil health.

Pore space is essential for allowing gas exchange to plant roots and soil organisms. Gases exchanged include oxygen (O_2), carbon dioxide (CO_2) and nitrogen (N_2) gases. Pore space is essential for the movement and storage of water and dissolved nutrients. Pores can be divided into three main classes (Micropores, Mesopores and Macropores), based on their diameter. See Figure 15.

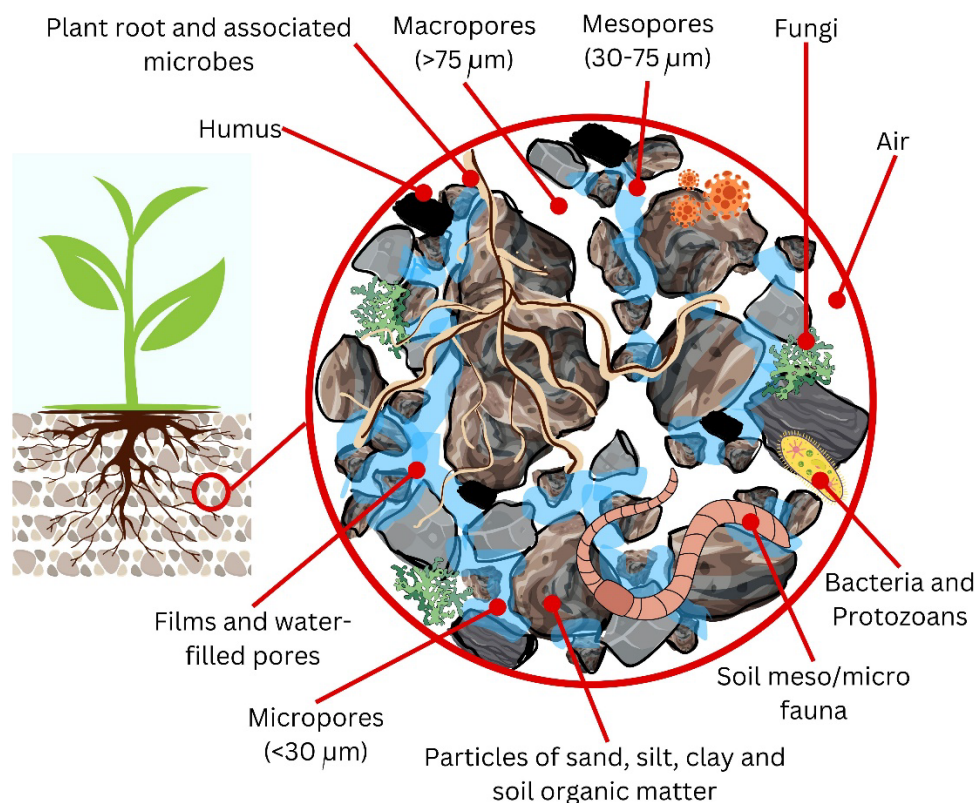


Figure 15 Soil pores

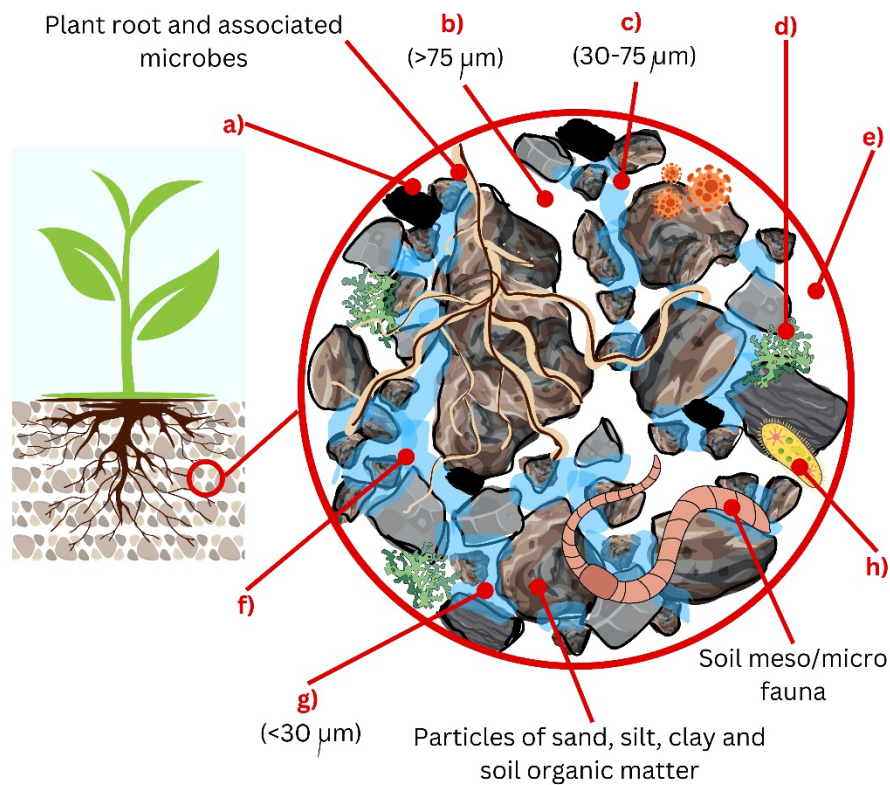
In a well-structured soil, the porosity of the top 10-15cm of soil will be 50%. A well-structured soil requires a combination of both macropores, mesopores and micropores. A high proportion of macropores allows for high levels of gas and water movement (high permeability) through the soil, but a lower water holding capacity for plant use as soil water easily moves (infiltrates and drains) through the soil pores. Sandy soils frequently

have a greater percentage of macropores. Silty and clay soils have a greater proportion of micropores and mesopores.

Water infiltration is the movement of water from the soil surface into the soil profile. Soil texture, soil structure, and slope have the largest impact on infiltration rate. Water moves by gravity through the pore spaces in the soil. Soil porosity can be degraded through tillage and improved by adding organic matter.

18. Define soil porosity

19. Complete the table to label the missing parts of the soil pore diagram



Soil pore labels	
a)	e)
b)	f)
c)	g)
d)	h)

[illegible]

Practical activity - Measuring soil porosity through saturation

Aim: To measure the soil porosity for a soil.

Materials:

- Soil sample/s
- Bucket (substitute with extra-large beaker)
- Large measuring cylinder
- Mallet/ hammer
- Secateurs
- Spade
- Steel pipe e.g. steel soup can with top and bottom removed,
- Tap water
- Wooden block (length = > diameter of steel pipe)

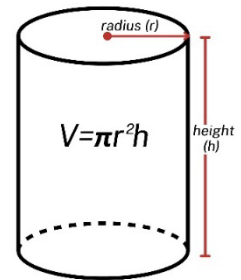


Figure 16 Collect a soil core sample.

Method:

1. Collect a soil core sample by driving the steel ring into the soil using the wooden block and mallet. Hammer the ring until the top is level with the soil surface. See Figure 16.
2. Use the spade to dig out the steel ring. Be careful not to disturb the soil inside the ring, cut away any roots at the bottom of the ring.
3. Measure and record the volume of your sample either directly or calculate mathematically using the volume of a cylinder equation, $V = \pi r^2 h$
4. Carefully transfer the soil core sample to a bucket. Take care to not disturb the soil structure.
5. Fill measuring cylinder to known amount e.g. 1000 mL (volume of water must be greater than the soil sample volume). Record the initial water volume in the results table.
6. Saturate the sample with water- carefully add enough water to fill all soil pores, without excess water above the soil sample surface. See Figure 17.
7. Record the final volume of water (water used to bring soil sample to point of saturation). The volume of water used is approximately equal to the sample's total soil pore volume.
8. Calculate the **volume of water poured into the sample = initial water volume – final water volume**. See Figure 18. Record this into the results table.
9. Calculate the porosity using equation

$$\text{Soil Porosity \%} = (\text{Volume of water poured into soil sample} \div \text{Total sample volume}) \times 100$$
10. Repeat steps 1-9 for each soil sample.



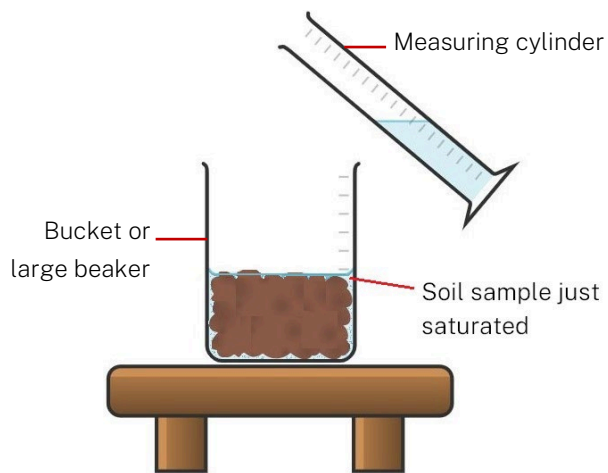


Figure 17 Saturating soil sample

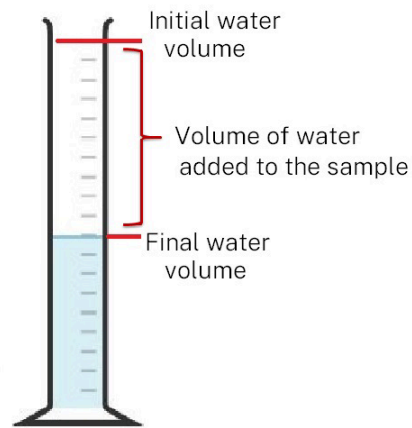


Figure 18 Volume of water added to the soil sample

Results table

Soil sample	Total sample volume (g/cm ³) ($Volume = \pi r^2 h$)	Initial H ₂ O volume	Final H ₂ O volume	Volume H ₂ O added to sample	Porosity % = (Volume of water poured into soil sample ÷ Total sample volume) × 100
1					
2					
3					
4					
5					
Add extra rows as required					

Discussion question

- Ideally, the total pore space (porosity %) should be about 50% of the total soil volume in a topsoil. Discuss the Porosity % of your soil sample/s in reference to plant growth, soil water retention (water holding capacity); gas exchange and ideal soil porosity %.

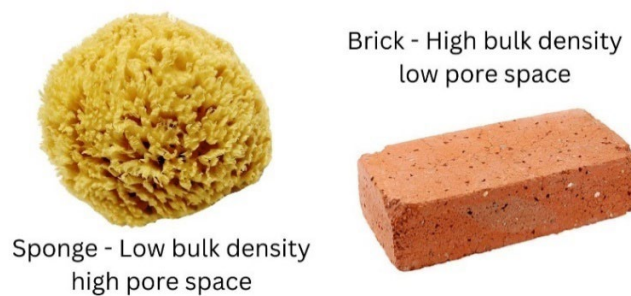
Bulk density

Bulk density is an indicator of soil compaction and is dependent on soil structure and texture (proportion and arrangement of sand, silt and clay components).

It is calculated as the dry weight of soil divided by its volume and is measured in g/cm^3 . This volume includes the volume of soil particles and the volume of pores among soil particles.

$$\text{Bulk Density (g/cm}^3\text{)} = \text{Dry soil mass (g)} \div \text{Soil volume (cm}^3\text{)}$$

Bulk density and total porosity have an inverse relationship. Soils with a low bulk density have a high total porosity %; whereas soils with a high bulk density have a low total soil porosity %. Think of the sponge and brick.



As a rule of thumb, most rocks have a bulk density of 2.65 g/cm^3 . A medium textured soil with about 50% pore space will have a bulk density of 1.33 g/cm^3 which would support good plant growth.

Generally, well structured, loose, porous soils which are rich in organic matter have a lower bulk density. Sandy soils have a relatively high bulk density than fine silts and clays because they have larger, but fewer, pore spaces.

Bulk density typically increases with soil depth because subsurface layers have reduced organic matter content, aggregation, and root penetration compared to surface layers and therefore, contain less pore space. Subsurface layers are also subject to the compacting weight of the soil above them.

General relationship between soil bulk density to root growth based on soil texture.

Soil texture	Ideal bulk densities for plant growth (g/cm^3)	Bulk densities that can restrict root growth (g/cm^3)
Sand, loamy sand	<1.6	>1.8
Sandy loam, loam	<1.4	>1.8
Sandy clay loam, clay loam	<1.4	>1.75
Silt, silt loam	<1.4	>1.75
Silty clay loam	<1.4	>1.65
Sandy clay, silty clay	<1.1	>1.58
Clay	<1.1	>1.47

Managing Bulk Density

Management practices which can lead to poor bulk density:

- Continually carrying out conventional tillage methods such as ploughing or discing to the same depth (creating a clay pan, compaction layer)
- Compaction through livestock hooves or equipment traffic (especially on wet soils)
- Using a limited crop rotation without incorporation of perennial tap rooted (dicotyledon) species, which vary in root structures and depths that break up soil and create structure
- Burning or removing crop residues (loss of organic matter)
- Overgrazing pastures
- Overstocking paddocks

Management practices that maintain or improve soil bulk density include:

- Controlled traffic farming (using established traffic lines and laneways across a property)
- Having lower tyre inflation pressure in heavy equipment/implements
- Using equipment with wider tyres or multiple axles, which distributes the weight over a larger area, reducing compaction
- Using laneways and never overstocking or over grazing with livestock
- Increase soil organic carbon and organic matter
- Inclusion of deep-rooted perennial plant species into crop rotations and pasture systems which improve soil structure and adds organic matter
- Inclusion of cover crops in cropping systems
- Reduced and minimum tillage cultivation
- Minimise traditional cultivation methods
- Retaining ground cover
- Retaining stubble in cropping systems

21. Define bulk density

22. Write the bulk density equation and describe how it is calculated

23. Contrast bulk density and soil porosity

24. List 5 management practices which maintain or improve soil bulk density

Practical activity – Measuring and calculating bulk density

Aim: To measure the bulk density for a soil.

Materials:

- Digital scales
- Soil sample/s
- Incubator or oven
- Mallet/ hammer
- Oven proof tray
- Secateurs
- Spade
- Steel pipe e.g. steel soup can with top and bottom removed,
- Wooden block (length = > diameter of steel pipe)
- PPE- to prevent burn risk e.g. gloves

Method:

1. Collect a soil core sample by driving the steel ring into the soil using the wooden block and mallet. Hammer the ring until the top is level with the soil surface. See Figure 19.
2. Use a spade to dig out the steel ring. Be careful not to disturb the soil inside the ring, cut away any roots at the bottom of the ring.
3. Measure and record the volume of your sample either directly or calculate mathematically using the volume of a cylinder equation,
 $V = \pi r^2 h$
4. Transfer the soil core sample to an oven proof tray and label the soil sample
5. Weigh and record the wet mass (g) of your soil sample using digital scales (minus weight of oven proof tray)
6. Place sample into oven or incubator at 60 °C.
7. Reweigh sample every 24 hrs. Leave sample in incubator until three constant, consecutive dry weights are measured (Up to 72 hours). Record the final dry soil mass (g) in the results table.
8. Calculate the Bulk density using the equation and record results into results table.

$$\text{Bulk Density (g/cm}^3\text{)} = \text{Dry soil mass (g)} \div \text{Soil volume (cm}^3\text{)}$$

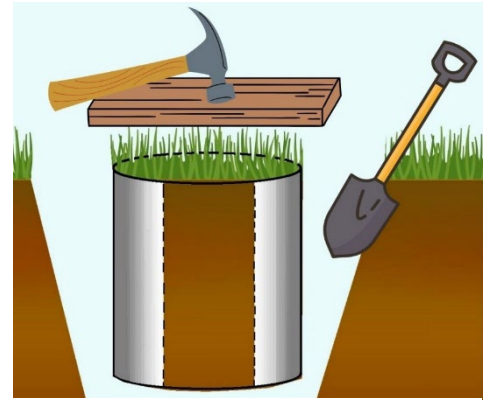
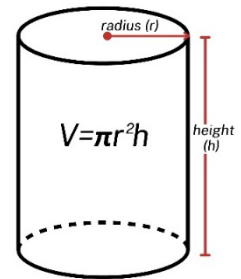


Figure 19 Collect a soil core sample.



9. Repeat steps 1-12 for each soil sample

Results table:

[illegible]

Soil chemical properties

Soil pH

pH (potential of hydrogen) is a universal scale measuring how acidic or alkaline a substance is, ranging from 1 to 14. More acidic solutions have lower pH while more alkaline or basic solutions have higher pH (see Figure 20). A pH of 7 is termed neutral (neither acidic nor alkaline). Each one-unit change in the pH scale corresponds to a large ten-fold (logarithmic) change in hydrogen ion concentration.

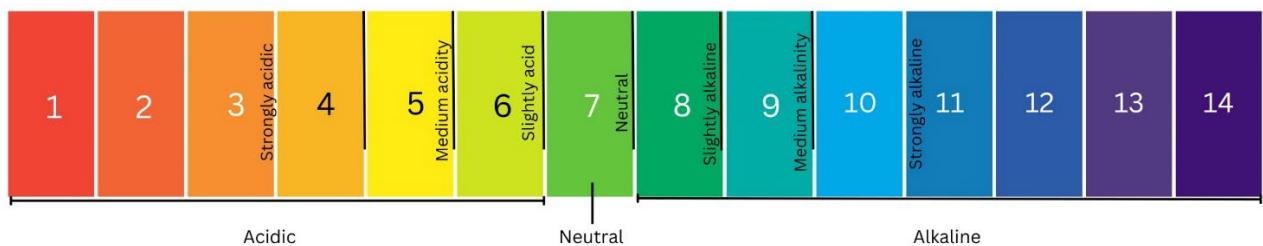


Figure 20 pH scale

Different plants can tolerate different pH levels. Some plants prefer to grow in slightly acidic soils (e.g. lupins), others can tolerate a wide pH range, but most plants prefer a pH between 6.0 and 7.5. See Table 2.

Table 2 The soil pH sensitivity of some commonly grown NSW crops and pasture.

Soil acidity tolerance	Species
Highly sensitive	Durum wheat, Schooner barley, Yerong barley, faba beans, chickpeas, Lucerne, medics, strawberry, Berseem and Persian clovers, Buffel grass, tall wheatgrass
Sensitive	Canola, Rosella and Janz wheat, O'Conner and Skiff barley, Albus lupins, red grass, phalaris, red and Balansa clovers, Caucasian and Kenya white clovers, common couch
Tolerant	Brindabella barley, Swift and Sunstar wheat, Diamondbird wheat- (most acid tolerant wheat), annual and perennial ryegrass, tall fescue, Haifa white and subterranean clovers, Wallaby grass (<i>Danthonia linkii</i>),
Highly tolerant	Narrow leaf lupins, oats, Tahara triticale, cereal rye, cocksfoot, kikuyu, paspalum, yellow and slender serradella, Biserrula, Maku lotus, Consul love grass

Soil pH outside the neutral range can influence the availability of specific nutrients to plants, as well as the activities of both beneficial and pathogenic microorganisms in the soil and plant root development. If pH is too acidic or too alkaline some nutrients becoming locked up (immobilised) or reach toxic levels, because they are available to the plants at concentrations too high for the plant's needs (e.g. Aluminium and Manganese

toxicities). See Figure 21. This results in plant deficiencies in macro and/or micronutrients (trace elements). *Soil pH is the most limiting manageable soil factor in plant growth.*

Plants need larger concentrations of macro nutrients than trace elements for growth and development. However, if any single nutrient is lacking (or in an insoluble form) it can affect the availability and uptake of all nutrients (see [The law of the minimum](#)).

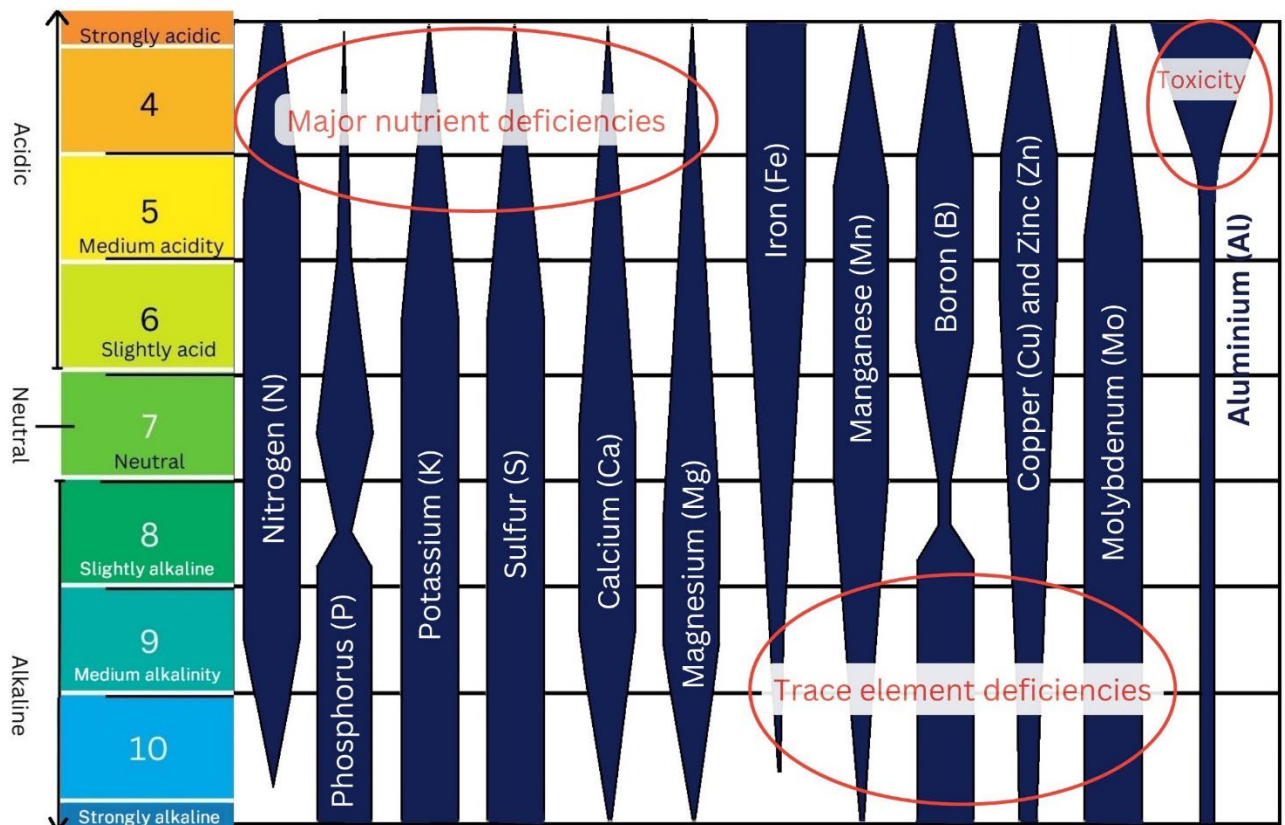


Figure 21 Effect of pH (CaCl₂) on the availability of soil nutrients

Measuring Soil pH

Soil pH can be measured in the field using a test kit, pH probe or by sending a sample to a laboratory for accurate results. The standard depth of sampling is 10 cm.

pH is measured using water or CaCl₂ extractions. Be aware that the soil pH field kit provides a pH measure similar to that measured in water (soil solution). Laboratories may provide pH results in calcium chloride (pH_{CaCl}) and/or water (pH_w). Be aware of this before comparing results.

Soil pH in the field can be conveniently measured using a simple test kit based on a colour-card method, available from agricultural or gardening supply stores called the [Raupach soil pH kit](#) (an Australian, CSIRO invention). The kit gives the soil pH on the water scale (pH_w) and should be *used only as a guide* for measuring soil pH. Results are qualitative and can be more than +/-0.5 pH out.

pH analysis in a laboratory provides the most accurate measurement of soil pH. Laboratory testing involves using glass electrodes. Glass electrodes often measure both pH and EC (electroconductivity, which indicates [soil salinity](#)) and are calibrated to ensure accurate results. Watch the laboratory pH testing method at: [Soil, water and plant tissue testing- NSW DPI Wollongbar environmental Lab](#)



Portable handheld and automated pH probes can be used on farm but should only be used to give an indication of soil pH. These devices are very convenient but generally not very accurate, with cheaper models being the most inaccurate. However technological improvements with time will hopefully improve the accuracy of these portable commercial devices.



Find out more about acidity in the section [Land degradation issues: Soil acidity](#).

Watch: [Working out your soil pH](#)

25. Identify what does pH stands for?

26. Describe the following pH values

a) pH 1-6 -----

b) pH 7 -----

c) pH 8-14 -----

27. List the pH range most plants prefer

28. Complete the table and list at least two examples of agricultural crops/pastures that tolerate the following pH levels

Soil acidity tolerance	Species

a) At <4 pH list all macro and/or micronutrient deficiencies

b) At 8> pH list all macro and/or micronutrient deficiencies

30. Identify the most accurate pH testing method

31. Describe the effect pH has on nutrient uptake in plants



Practical activity – Measuring soil pH using a field kit

Aim: To approximately measure soil pH_w using a soil pH kit.

Materials:

- Field pH kit:
 - Universal indicator solution
 - Barium sulfate (BaSO₄) powder
 - pH colour chart
 - Clean, dry stirrer or spatula
 - Clean, dry, non-porous mixing plate (e.g. ceramic tile)
- Soil sample/s (ideally a surface soil (10cm depth) and subsoil >10cm) for each sample location

Method:

1. Collect soil sample from an identified location
2. Thoroughly mix the soil sample, crush large aggregates and remove any gravel so that you have a fine, homogenous sample for testing.
3. Put half a teaspoon of soil on the plate/tile
4. Add approx. 10 drops of universal indicator dye (or until sample is saturated forming a slurry)
5. Thoroughly mix sample using the spatula
6. Sprinkle Barium sulfate onto the soil slurry, mix and allow the colour to develop (wait up to 5 minutes).
7. Compare the sample colour with the pH colour chart.
8. Record results.
9. Clean tile and spatula and dispose of soil sample
10. Repeats steps 1-9 for each sample

Results table:

Soil sample	Sample depth (cm) (optional)	Location	pH _w
1			
2			
3			
4			
5			
6			
Add more rows as required			

Discussion questions:

1. Did you identify differences in pH between surface soil and subsoil for each location?
2. If yes, what implications does that have for plant growth and nutrient availability for agricultural crops or pastures?
3. Use Table 2 to identify possible agricultural plants or pastures which would grow adequately at your site/s.
4. Use Figure 21 to identify possible Macro or micro- nutrient deficiencies/toxicities at your site/s.
5. What amendment/s could you add to:
 - a. Increase pH?
 - b. Decrease pH?

Technology activity- Contrast lime strategies using the iLime app.

Background: Managing acid soils is essential for the long-term sustainability of farming systems and the soil sustainability. Management goals should aim for long term improvement of soil health and minimise soil acidification. (Read more about [soil acidity](#)).

Agricultural production is an acidifying process. Where soils are at risk of becoming acidic the future impact of soil acidity can be reduced, (but not eliminated), by slowing the rate of acidification. Management options available to minimise soil acidification include the types, rate, placement and timing of fertiliser applications.

The application of limestone (ag lime) or other alkali materials e.g. dolomite, that neutralises soil acidity is the only practical solution. Its effectiveness is determined by product quality, rate and application method.

Acid tolerant plants species can be used to maintain some production as you treat acidity. It is important to remember that acid-tolerant plants can also be responsive to increases in soil pH. In the case of legumes, it is important to consider not only plant impacts but also the possible effects of soil pH on nitrogen fixation. Historically lime was applied to achieve a soil pH of 5.2 (0-10 cm) to remove the effects of Aluminium toxicities on plant production. However, this will not stop acidification further down the soil profile nor is it optimal for most commercial rhizobia strains. There are significant plant production and soil fertility benefits when pH is maintained above pH5.5 (CaCl_2).

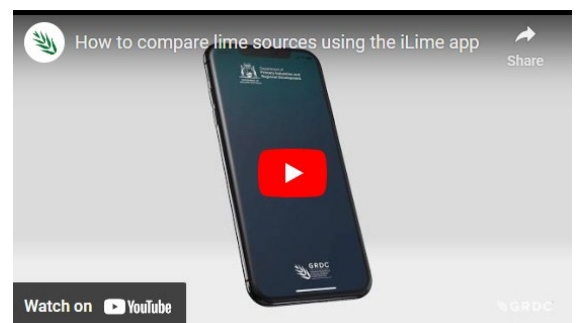
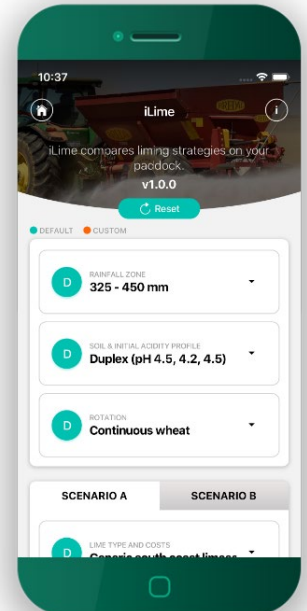
Any lime application needs to be done at least a season before sowing a sensitive plant for the effect of liming to occur. Liming to increase the pH(CaCl_2) of the 0-10 cm layer significantly above 6.0 should be avoided as it may induce deficiency of other plant nutrients such as zinc, boron and manganese in well-weathered soils.

In this activity students will use the application iLime developed by the GRDC and Government of WA, DPIRD. iLime allows for comparison of liming strategies. Users can specify crop, fertiliser and soil features specific to their farm. Different lime sources, rates of application and timing may be compared to estimate the optimum economic return for your paddock.

Yield, soil pH, soil aluminium and cash flow responses are displayed for lime strategies compared to not applying lime, allowing a long-term strategic view to liming decisions to be made. It is available for Android and iOS.

[Download the app](#) before conducting this activity.

You will require [laboratory soil test results](#) to complete this activity.



Materials:

- Laboratory soil test results including: pH(CaCl₂) and soil texture, Exchangeable Al
- [iLime app](#)
- Smart device
- Average rainfall
- Details on paddock enterprises (cropping, rotation, continuous pasture etc.)
- Detail on different lime types and costs
- Lime rate and placement/incorporation strategy

Method:

1. Watch '[How to compare lime sources using the iLIME app](#)'
2. Input your data
3. Run calculations
4. Make comparisons with liming strategies
5. Contrast lime strategies and results for different enterprises
6. Download your results
7. Determine the most effective liming strategy (change graphs) in terms of:
 - a. Return on investment
 - b. Cash flow
 - c. Yield over time
 - d. 0-10 cm soil pH
 - e. 10-20 cm soil pH
 - f. 20-30 cm soil pH
 - g. 10-20 cm soil Al
 - h. 20-30 cm soil Al
 - i. Application rates

Ion Exchange Capacity

Ion exchange capacity (IEC) is a measure of the soil's ability to hold positively or negatively charged ions. It is the most important chemical property of a soil as it directly controls soil fertility. Ion exchange capacity also influences soil structural stability, plant nutrient absorption, soil pH, the soil's reaction to fertilisers and nutrient holding ability,

Soil may be considered as a weak electrical system consisting of positively charged ions, called cations (+) and negatively charged ions, called anions (-).

The **Cation Exchange Capacity (CEC)** is a measure of the negative charge of the soil and therefore that soil's ability to attract, exchange and hold positively charged cations by electrostatic attraction.

The **Anion Exchange Capacity (AEC)** is a measure of the positive charge of the soil and therefore that soil's ability to attract, exchange and hold negatively charged anions by electrostatic attraction.

CEC is generally much higher than AEC in soils due to clay and Organic Matter content.

The IEC of a soil is related to the type and amount of clay and organic matter present. Most clay types have a permanent negative surface charge. Soils containing highly weathered clays (e.g. kaolinite, gibbsite, goethite, and hematite) have a variably charged surface (negative and positive charge) and can hold both anions and cations.

Soils with greater clay and organic matter contents have a higher CEC than sandy, low-organic matter soils (See Table 3). Soil test results give the CEC as an indicator of soil nutrient holding ability as AEC is negligible. Soils with a high CEC have high fertility.

Negatively charged clay and humus (fully decomposed organic matter) are called colloids. They consist of thin flat plates which provide a large surface area (See Figure 22). This large surface area provides the capacity to hold a large number of cations or anions.

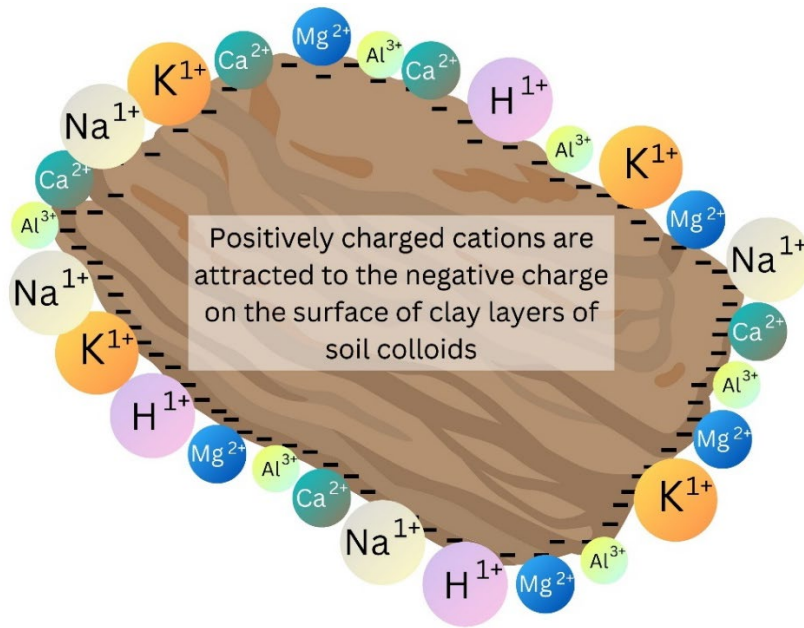


Figure 22 Clay and humus colloids have a negative surface charge

The dominant ions associated with the CEC are the exchangeable cations calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{1+}), Ammonium (NH_4^{1+}) and sodium (Na^{1+}). These are often referred to as the base forming cations. In acid soils the cations, hydrogen (H^{1+}) and aluminium (Al^{3+}) are more abundant. Common soil anions include hydroxide (OH^{1-}), chloride (Cl^{1-}), nitrate (NO_3^{1-}), sulfate (SO_4^{2-}) and phosphate (PO_4^{3-}).

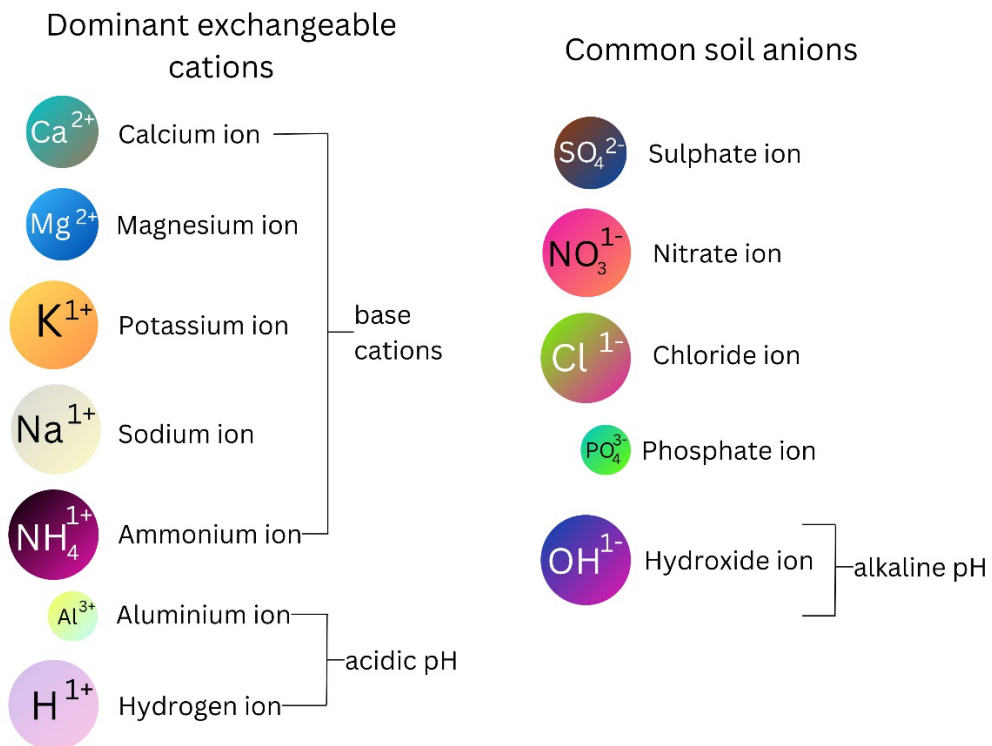


Figure 23 Common soil cations and anions

Measuring ion exchange capacity

The unit of measurement of the CEC is milliequivalents per 100 g of soil (meq/100 g) or centimoles of positive charge per kg soil (cmol⁺/kg).

Table 3 CEC of different soil components

Soil component	CEC (cmol ⁺ /kg)
Coarse sand	Negligible
Fine sand	Negligible
Silt	1-2 in some soils; usually negligible
Kaolinite clay	3-23
Illite clay	10-40
Smectite clay	80-150
Iron and Aluminium oxides	<4
Organic matter (individual fractions of the organic matter may be lower or higher)	150-500
Adapted from: McKenzie et.al (2004)	

IEC Management Implications

Nutrient holding, exchange and leaching

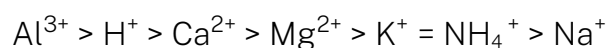
When fertilisers are applied, they mostly supply nutrients (cations and anions) to the soil in a plant available form, which (if applied correctly) dissolve into the soil solution. Ions in soil solution are electrostatically held to the surface of soil colloids (clays and humus) and plant roots (-ve surface charged particles such as clay and organic matter attract +ve charged cations).

The term 'exchangeable' in terms of cations describes the ability of cations or anions to be exchanged between colloid surfaces and the soil solution. If there is no ion exchange or adsorption, excess nutrients are leached down through the soil profile.

Soils with high CEC hold larger quantities of nutrients for longer. This is why high clay content soils have high fertility. Sandy soils require regular applications of fertilisers to meet plant requirements as they cannot hold large quantities of plant nutrients.

Cations and anions are adsorbed with different strengths. Cations/anions with a greater charge are more strongly adsorbed and held to a colloid.

The relative strength of adsorption of cations is:



(Aluminium > hydrogen > calcium > magnesium > potassium = ammonium > sodium)

The relative strength of adsorption of anions is:

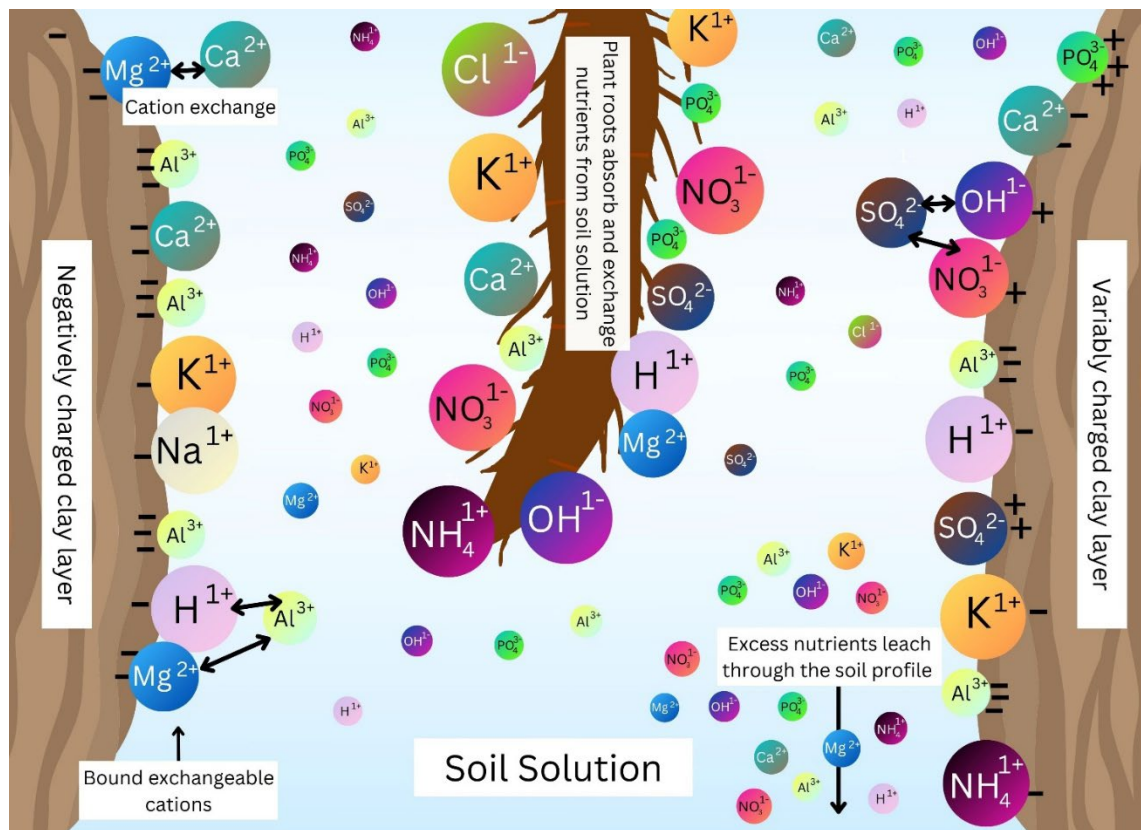
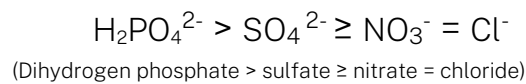


Figure 24 Plant adsorption, CEC and AEC of common nutrients.

Following photosynthesis, ion exchange is the most important reaction providing nutrients in food chains in living terrestrial things. Plants take up nutrients from the soil through ion exchange. Plant roots which are in contact with the soil solution exchange the nutrients from the soil solution for hydrogen ions present on the surfaces of root hairs.

Soil type and Ion exchange capacity

The CEC of soils varies according to the clay %, the type of clay, soil pH and amount of organic matter. Sand particles are inert, and the absence of electrical charge limits the capacity to exchange ions. The only option to improve CEC in sandy soil is with the addition of organic matter or clay. Adding clay to improve a sandy soil CEC is not practical or economic in commercial practice.

Soil pH and CEC

The fertility of soils decreases with lower pH. Acidification can be caused by acidifying nitrogen fertiliser, nitrate leaching, land clearing. Soil pH change can also be caused by natural processes such as decomposition of organic matter and leaching of cations. The

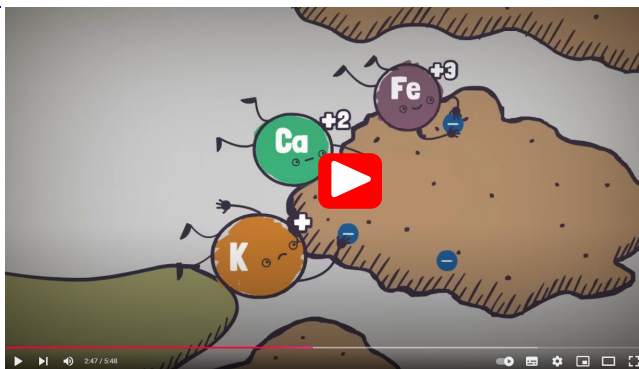
lower the CEC of a soil, the faster the soil pH will decrease with time. Liming soils to higher than pH 5.5 (CaCl_2) will maintain CEC. Alternatively, the addition of organic matter may increase the CEC. Deep rooted perennial pastures, green manure crops, addition of compost, mulch or manures are all effective management actions to increase soil organic matter but will take time to make an impact.

Nutrient availability and soil depth

Soils with a low CEC are more likely to develop deficiencies in potassium (K^+), magnesium (Mg^{2+}) and other cations while high CEC soils are less susceptible to leaching of these cations. Several factors may restrict the release of nutrients to plants. The addition of organic matter will increase the CEC of a soil but requires many years to take effect.

CEC can change with depth. Generally, 0-10cm depth (topsoil) has the highest organic matter content so will have high CEC (and AEC). At 10 – 30 cm depth, the organic content of the soil is usually much lower, hence the CEC will be low. The CEC of the subsoil layers are governed by clay content and clay type.

Watch [Cation Exchange](#)



32. Define CEC

33. Define AEC

34. Complete the table to list the common soil cations and anions. Include the chemical symbol and ionic charge

Common exchangeable soil cations		Common exchangeable soil anions	
Name	Symbol and charge	Name	Symbol and charge

35. Explain how nutrient leaching occurs in soils

36. List the relative strength of adsorption of common cations from highest to lowest:

37. List the relative strength of adsorption of common anions from highest to lowest:

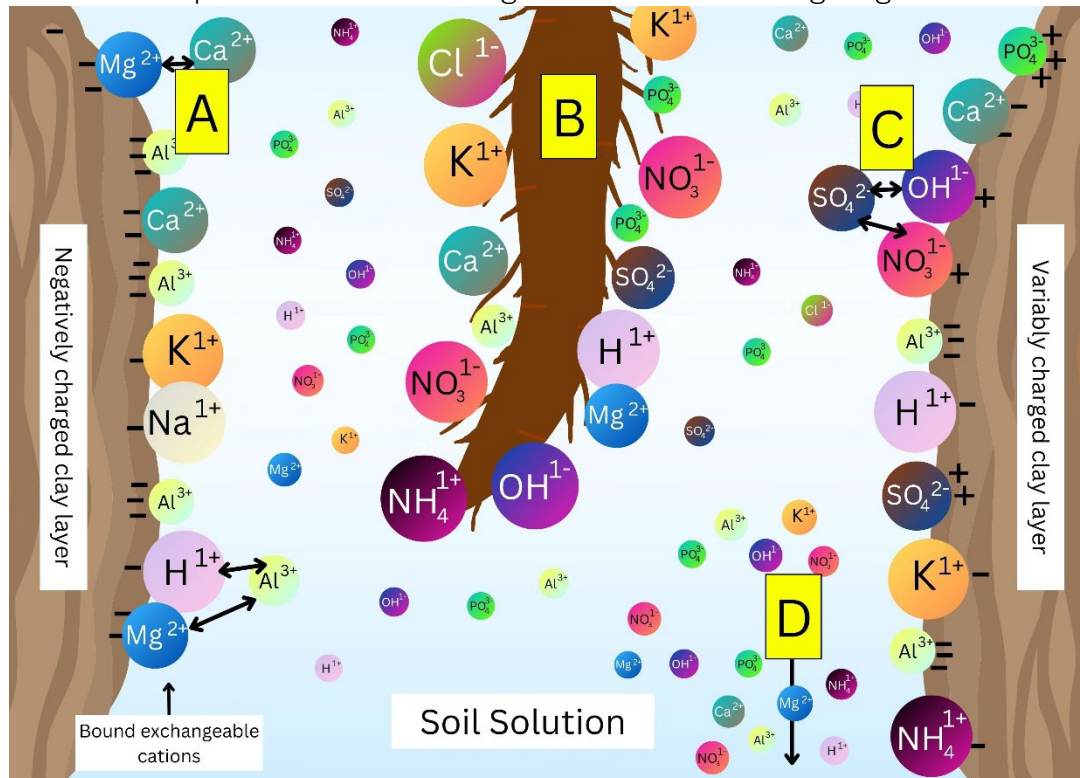
38. Explain how CEC is affected by:

a) Soil texture

b) Soil pH

c) Soil depth

39. Describe what processes are occurring at A-D in the following diagram



	Description
A.	
B.	
C.	
D.	

Practical activity –collecting soil samples for laboratory analysis

Content and procedure for obtaining measurements to supplement learning content for soil Cation Exchange Capacity (CEC), Soil Carbon, pH and nutrient status

Background: In commercial, sustainable agriculture, laboratory soil testing is used to make informed decisions for efficient and precision production.

Laboratory soil analysis measures a soil's chemical, physical and biological properties.

The reasons for soil sampling can be grouped into four categories:

- Predictive (e.g. identifying which nutrients are needed and how much?)
- Monitoring (e.g. have the soil nutrient concentrations changed over time?)
- Diagnostic (e.g. is a soil chemical property affecting crop or pasture growth?) and
- Compliance (e.g. does the soil meet required environmental standards?).

Benefits:

- Allows for evidence based, site specific nutrient management plans at a paddock level
- Allows for site specific and precise fertiliser application rates to be calculated for the best economic outcomes.
- Very useful in conjunction with using satellite imagery and Global positioning system (GPS) technologies to plan for varying rates of fertiliser applications or identifying plant health issues such as water deficiencies, and pest and disease burdens (precision agronomy)
- GPS uses satellites to match the position in a paddock with crop yields. By constantly monitoring yield (e.g. grain yield) during harvest, an accurate map is created showing areas with low and high yield. This allows for precise identification of locations for soil sampling to identify possible soil limitations and allow for planning for fertilisers or amendments into the future.

Disadvantages:

- Testing can be costly in the short term (basic test costs approximately \$100 and full diagnostic tests \$200+).
- Test results indicate the type and quantity of fertiliser or amendment to be used to treat the problem. But other factors must also be considered: soil type, soil pH, type and plant composition of the pasture/crop, previous fertiliser history and production goals.
- Results are representative and only as accurate as the sampling rigour.
- Lab error can distort sample results. However inaccurate test results are regularly due to sampling errors or varied sampling approaches.

Soil, water and plant diagnostic tests can be conducted by a range of private laboratories and agronomists through to government agencies. When selecting which organisation to

carry out testing research to see that they have [NATA accreditation](#) and offer the testing package you require.

Go to [Soil health tests and pricing](#) to see the range of NSW DPIRD test packages.

NSW DPIRD soil testing services conduct the following tests:

Test	Application
Soil pH	pH is a measure of acidity and alkalinity. pH affects nutrient uptake.
Electrical conductivity	Electrical conductivity is an indirect measure of salinity. Many plants are affected by high soil salinity.
Available phosphorous	This test is useful in assessing the need to fertilise crops and pasture with phosphorous
Phosphorous Buffering Index (PBI)	This test is a measure of the soil's ability to tie up phosphorous. It can assist in determining fertiliser requirements.
KCl 40 extractable sulfate, sulfur	Test used to determine sulfate availability in soils
Exchangeable cations and Cation Exchange Capacity (CEC)	The major exchangeable cations are calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na), and Aluminium (Al). CEC is a major factor affecting soil structure, nutrient availability, soil pH and the soil's response to fertiliser.
Organic carbon	Organic carbon is a measure of the organic matter level of a soil. This in turn is very important for soil structure and plant nutrient intake.
Chloride	Chloride is the most commonly occurring soluble anion in Australian soils. The importance of this anion in land-use assessment is due to its possible accumulation in soil profiles to levels that are detrimental to plant growth.
Total nitrogen	Total soil Nitrogen (N) provides an indication to the soil's long term nitrogen supplying capacity.
Boron, hot CaCl ₂ extractable	Test used to obtain an index of soil boron (B) status for plant growth
BTPA micronutrients (Fe, Mn, Zn, Cu)	Measures plant available forms of trace element Iron, Manganese, Zinc and Copper
Additional tests include	
Pesticide residues (Organochlorines, organophosphates, synthetic pyrethroids)	Useful if pesticide build-up is suspected, and for dip site remediation. Used by organic growers seeking certification
Total carbon	Carbon is the organic material in soil which improves moisture holding capacity, increases soil structural stability and protects soil from erosion. Carbonates are included in Total carbon. Carbon: Nitrogen ratio is used when

	making compost from organic material.
Full ICP scan (Al, Ca, B, Cr, Cu, Fe, K, Mg, Mn, Ni, Pb, Zn, As, Cd, P, Na, S, Co, Mo, V)	This test will assist in identifying any nutrient/metal deficiencies or toxicities in a soil or organic fertiliser. It is important to check for metals in organic fertilisers, particularly those sourced from human and animal waste.
Nutrient ICP scan (B, Ca, Cu, Fe, K, Mg, Mn, Na, P, S, Zn)	A nutrient scan will assist in solving nutrient deficiency or toxicity problems that you may have with your soil or organic fertiliser
Mineral nitrogen	Nitrogen requirements before sowing a crop

Watch DPIRD laboratory testing methodology at: [Soil, water and plant tissue testing- NSW DPI Wollongbar environmental Lab](#)



Accurate soil sampling procedure

The following gives an overview of a simplified procedure for soil sampling to take an accurate sample for laboratory testing. Accuracy and reliability of results is dependent on sampling procedure. For more information go to: [Fertcare soil sampling guide, Fertilizer Australia](#)

Areas to avoid:

- Areas which have recently been fertilised, limed or where lime has been dumped
- Burn patches
- Headlands (in cropping paddocks)
- Stock camps, fence lines and stock tracks
- Gates, troughs, dams and feed out areas
- Areas of poor growth or excessively good growth.

When to sample:

- Nutrient testing: At least 4 weeks before applying fertiliser (allow time to order fertiliser, book contractor, set up machinery etc).

- Where acidity, salinity (salt) or sodicity (structure) is the suspected problem, sample at least 3-4 months before planting to provide time for lime or gypsum to be applied and take effect.
- Avoid sampling during climatic extremes. Schedule sampling at the same time each year and to align with future fertiliser decisions.

Sample strategy:

There is a range of strategies that can be used when soil sampling a farm.

The most comprehensive and ideal sampling strategy is to sample every paddock or even sub-paddock areas, every year for an evidence-based approach to fertiliser decision making.

Other options include cycling around the farm over a 3-4 year period until the whole farm is completed, selecting 'typical or representative' paddocks, or bulking samples that have similar features (e.g. soil type, topography, drainage, fertiliser history, yield).

The strategy used depends on the reason for sampling and considers the cost of soil testing against the potential benefits, savings in fertiliser, and costs to implement other alternatives. Select a sampling pattern that provides a representative sample, is repeatable and efficient.

How many core samples?

- Topsoil sampling: minimum of 30-40 (19 mm diameter soil core) and 20-30 (25 mm diameter core sampler) surface samples per paddock.
- Subsoil sampling: the number of cores may be reduced as subsoils are less variable.

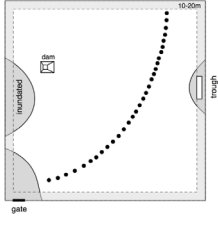
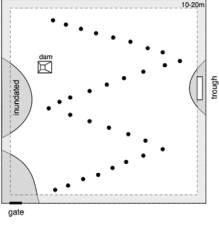
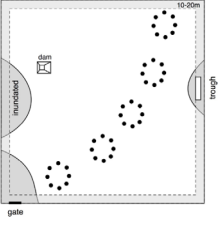
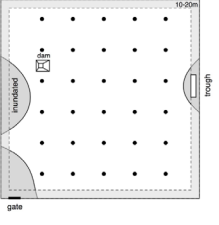
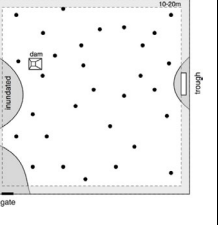
Watch: [Soil testing – how and why?](#)



Sampling pattern:

Dependant on the sampling strategy. For topsoil sampling individual paddocks patterns include:

Table 4 Different soil sampling patterns

Sampling pattern	Transect	Zigzag	Cluster	Uniform grid	Random
Image					
Repeatability for monitoring*	High	High	Medium	High	Low
Likelihood of representative sample	Low	High	Low	High	High
*Use of geo-coordinates and GPS map enables highest repeatability.					
Adapted from Fertcare soil sampling guide, Fertilizer Australia					

Aim: to obtain a representative topsoil sample (0-10 cm) for soil laboratory analysis in a single paddock

Materials:

- Soil dig stick (either 19 mm or 25 mm diameter corer; samples to 10 cm depth) (Dig stick could be substituted for a shovel/spade but results will be less accurate and will not reflect industry standard) or shovel
- Bucket for soil core samples
- GPS mapping technology e.g. smartphone with app 'My altitude' (free software which stores GPS co-ordinates and altitude data)
- Zip lock bag
- Access to a paddock for sampling (in schools could be a sports field if farm is unavailable)
- Refrigerator.

Method:

1. Select a paddock to sample.
2. Take bucket and dig stick or shovel.



3. Using zigzag or uniform grid sampling pattern move to a random location to be sampled (see areas to avoid above before choosing sample site). Use a set distance between sample sites e.g., 50 steps in zig-zag pattern.
4. Record you GPS co-ordinates and elevation using the My altitude app into the results table for each sampling location.
5. Do not 'scuff' the soil or remove any surface soil before core sampling. As little as 2mm of missing surface soil can have a significant impact on results. If lots of plant material is at the sample site, push plant leaves aside before sampling. Presence of some plant material in the sample is okay, as the lab will remove it.
6. Take dig stick, gently press and rotate it into the soil with foot so corer samples to depth of 10cm. If there is a rock, take a sample close by.
7. Empty soil core into clean bucket.
8. Repeat steps 3-7 for each sample. A minimum of 30 soil cores to be sampled/paddock.
9. Take bucket of soil cores and gently mix all core samples (breaking them up if necessary). Fill the Ziplock bag with the mixed soil sample.
10. Fill in sample submission forms recording all details required by the laboratory.
11. Store Ziplock bag in fridge* until sample is sent to the soil analysis lab. (*Nutrients mineralise as temperature increases, so heat affects soil nutrient analysis results).
12. Rinse soil dig stick and bucket with water to sanitise (do not use detergent).
13. Optional- if soil testing multiple paddocks. Repeat steps 1-12 for each paddock.

Accurate soil sampling



The three key areas of PLAN, SAMPLE AND DISPATCH must be done correctly to help achieve sound soil and plant nutrition recommendations. The practices identified below should be followed.



Figure 25 Source: [Fertilizer Australia, Fertcare soil sampling guide](#)

Results table:

Paddock name				Paddock use (e.g. grazing)	
Soil parent material (e.g. basalt, granite etc.)				Soil texture	
List the top 5 plant species					
Fertiliser history					
Sampling pattern		Zig zag or Uniform grid			
Sample number	Altitude (m)	Latitude e.g. 33.27S	Longitude e.g. 149.09E	Soil colour	Comments/observations
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					

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30					
<i>Add more rows as required</i>					

Practical Activity: Analysing soil laboratory analysis results

Background:

Interpretation of soil test reports requires knowledge of local climate, soil properties and paddock crop/pasture history and fertiliser history. Laboratory reports don't include any interpretation. Consult your local agronomist/horticulturalist advisor for in-depth interpretation.

Watch: NSW Agriculture, [Understand soils and interpreting soil tests – What do all the numbers mean?](#)



The following should be used as a basic guide when interpreting results:

Soil laboratory test- interpretation guide

pH (CaCl_2)

- pH less than 5 soil is at risk of soil acidity
- pH 5-7 ideal for most plants
- Aim for pH 5.5-7 in top 10cm soil

Organic Carbon (%C)

- Estimate of the total organic carbon in the soil
- % Organic matter = $\%C \times 2.2$ (if %C is measured using the Walkley Black method)
- Aim for approximately 2.5
- 5 soil organic carbon

Nitrate – plant available Nitrogen (N)

- Nitrate levels fluctuate
- Guide to interpreting total N (mineral N + mineralised N)
 - 0-100 kg N/ha too low
 - 100-200 kg N/ha marginal
 - 200-300 kg N/ha adequate
 - >300kg N/ha excellent

Available Sulfur (KCl 40 test) Guide to interpreting plant available sulfur as sulfate

- 0-5 mg/kg low
- 5-10 mg/kg medium
- >10 mg/kg high

Phosphorous

- Guide to interpreting phosphorous Colwell test
 - <20 mg/kg low
 - 20-35 mg/kg medium
 - >35 mg/kg high
- Guide for interpreting phosphorous Bray test
 - 15-20 mg/kg dryland pastures
 - 25-30 mg/kg irrigated and improved pastures
 - 30-50 mg/kg tree crops
 - >50 mg/kg vegetables

Cation Exchange Capacity (CEC)

- The higher the clay or organic matter content, the higher the CEC
- Guide for interpreting CEC
 - <6: very low
 - 6-12: low
 - 12-25: moderate
 - 25-40: high
 - >40: very high

Exchangeable Sodium Percentage (ESP)

- An ESP >6% soil will be dispersive and should give a response to addition of gypsum

Aluminium

- If Al% is >5% toxicity will start to affect plant growth in sensitive species. Apply lime to raise pH above 5 (the point where Al is no longer present as a cation)

Calcium: Magnesium (Ca: Mg)

- The ratio should be 2:1 Ca: Mg
- Higher levels of Ca are okay, but higher levels of Mg cause dispersive effect similar to Na.

Chloride and Electrical conductivity (EC)

- Measure salinity
- Risk of salinity if Cl (mg/kg) is >300; or EC_{se} (dS/m) >2

Activity:

- Analyse your soil laboratory test results and compare them to the interpretation guide content (above).
- Identify any soil chemical properties that are limiting production
- Make a list of possible fertilisers and amendments which could be added to treat the soil limitation/s. e.g. lime, gypsum, organic matter, super phosphate etc. (see [‘Soil and plant nutrients and fertilisers’](#) for assistance)

Soil and plant nutrients and fertilisers

Soil is a major source of nutrients needed by plants for growth. Plants adsorb nutrients dissolved in the soil solution.

Essential plant nutrients are defined as nutrients involved in plant metabolic functions. Plants cannot complete their life cycles without essential plant nutrients. There are seventeen essential plant nutrients to plant growth and metabolic function. Hydrogen, carbon and oxygen are readily available and not limiting.

Table 5 Essential plant nutrients and their average plant concentrations

Nutrient element	Average plant concentration	Classification
Hydrogen (H)	6%	Macronutrient
Oxygen (O)	45%	
Carbon (C)	45%	
Nitrogen (N)	1.5%	
Potassium (K)	1%	
Phosphorous (P)	0.2%	
Calcium (Ca)	0.5%	
Magnesium (Mg)	0.2%	
Sulfur (S)	0.1%	Micronutrient
Chloride (Cl)	100 ppm (0.01%)	
Iron (Fe)	100 ppm	
Boron (B)	20 ppm	
Manganese (Mn)	50 ppm	
Zinc (Zn)	20 ppm	
Copper (Cu)	6 ppm	
Molybdenum (Mo)	0.1 ppm	
Nickel (Ni)	0.1 ppm	

Adapted from: [J.L. Havlin 'Fertility', Encyclopedia of soils in the environment.](#)

The three main Macronutrients essential to plant function, growth and development are nitrogen (N), phosphorus (P) and potassium (K). Together they make up the trio known as N-P-K. Other important macro nutrients are calcium, magnesium and sulfur. Plants also need small quantities of iron, manganese, zinc, copper, boron and molybdenum, known as

trace elements, because only traces (small amounts) are needed by the plant. The role these nutrients play in plant growth is complex. The following provides a brief outline.

Major elements (macro-nutrients)

N

Nitrogen (N)

Nitrogen is a key element in plant growth. It is found in all plant cells, in plant proteins, hormones, and in chlorophyll. It is also important for stimulating microbial activity in soil.

Atmospheric nitrogen (N_2 gas) is a source of soil nitrogen. Some plants such as legumes fix atmospheric nitrogen in their roots. Commercial fertiliser factories use nitrogen from the air to make synthetic fertilisers ammonium sulfate ($(NH_4)_2SO_4$), ammonium nitrate (NH_4NO_3) and urea (CH_4N_2O). When applied to soil, nitrogen is converted to a mineral form, nitrate (NO_3), which plants can readily take up. (See [Nitrogen cycle](#) for more information).

Nitrate is easily leached down through the soil profile by heavy rain, resulting in [soil acidification](#). Nitrogen must be applied in precise amounts and more often, so that plants use all of it, or in organic form such as composted manure, so that leaching through the soil profile and eutrophication (run-off into waterways) is minimised/eliminated.

P

Phosphorus (P)

Phosphorus helps transfer energy from sunlight to plants, stimulates early root and plant growth, and accelerates plant maturity.

Very few Australian soils have enough phosphorus for sustained crop and pasture production. All manures contain phosphorus. Manure from grain-fed animals is a particularly rich source (poultry and pig manure).

Phosphorus is commonly supplied to crops and pastures by superphosphate ($Ca(H_2PO_4)_2$) made from rock sulfate and sulfuric acid.

K

Potassium (K)

Potassium increases vigour and disease resistance of plants, helps form and move starches, sugars and oils via the plant phloem, and can improve fruit quality.

Potassium is essential for flower and bud formation so is essential to maximising yield.

Potassium is low or deficient in many of the sandier Australian soils. Also, heavy potassium removal can occur in soils used for intensive grazing and intensive horticultural crops (such as bananas and custard apples).

Muriate of potash (KCl) and sulfate of potash (K_2SO_4) are the most common sources of potassium.

Ca Calcium (Ca)

Calcium is essential for root health, growth of new roots and root hairs, and the development of leaves. It is generally in short supply in acid soils. Lime (CaO), gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), dolomite ($\text{CaMg}(\text{CO}_3)_2$) and superphosphate ($\text{Ca}(\text{H}_2\text{PO}_4)_2$) (a mixture of calcium phosphate and calcium sulfate) all supply calcium. Lime is the cheapest and most suitable option for most broadacre systems. Dolomite is useful for magnesium and calcium deficiencies, but if used over a long period will unbalance the calcium/magnesium ratio. Superphosphate is useful where calcium and phosphorus are needed.

Calcium is important in providing stability to soils and has a flocculating effect.

Mg Magnesium (Mg)

Magnesium is a key component of chlorophyll, (the green pigment in plants), and is vital for photosynthesis (the conversion of the sun's energy to food for the plant- see [Carbon cycle](#)). Deficiencies occur mainly on sandy acid soils in high rainfall areas, especially if used for intensive horticulture or dairy production. Heavy applications of potassium in fertilisers can also produce magnesium deficiency, so banana growers need to monitor magnesium levels because bananas are big potassium users.

Magnesium deficiency can be overcome with dolomite ($\text{CaMg}(\text{CO}_3)_2$) (a mixed magnesium-calcium carbonate), magnesite (MgO) or epsom salts (MgSO_4).

S Sulfur (S)

Sulfur is a constituent of amino acids in plant proteins and is involved in photosynthesis in plants. It is responsible for many flavour and odour compounds in plants such as the aroma of onions and cabbage.

Sulfur deficiency is not a problem in soils high in organic matter, but it leaches easily. On the coast sea-spray is a major source of atmospheric sulfur. Superphosphate ($\text{Ca}(\text{H}_2\text{PO}_4)_2$), gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), elemental sulfur (S) and ammonium sulfate ($(\text{NH}_4)_2\text{SO}_4$) are the main fertiliser sources.

Trace elements (micro-nutrients)

Fe Iron (Fe)

Iron is a constituent of many compounds that regulate and promote plant growth and is important to photosynthesis.

Ferrous sulphate (FeSO_4) is a fertiliser source.

Mn Manganese (Mn)

Manganese helps with photosynthesis. It is freely available in Australian acid soils, often in toxic amounts in very acid soils, but can be deficient in sandy soils. Toxicity is remedied with lime (CaO). Manganese deficiencies are treated with Manganese sulfate (MnSO_4).

Cu Copper (Cu)

Copper is an essential constituent of enzymes in plants. Molybdenum deficiency in soils and plants, can cause copper deficiency in animals. Toxicity can be a problem for horticulturists who regularly use Bordeaux mixture or copper oxychloride sprays to control diseases in horticultural crops.

Zn Zinc (Zn)

Zinc helps in the production of a plant hormone responsible for stem elongation and leaf expansion.

Zinc deficiencies are treated with the addition of zinc sulfate (ZnSO_4) or crushed zinc minerals.

B Boron (B)

Boron helps with the formation of cell walls in rapidly growing tissue. Deficiency reduces the uptake of calcium and inhibits the plant's ability to use it. Boron is deficient in granite and sandstone derived soil (NSW Tablelands). Boron is easily leached from the soil. Deficiencies are easily treated with addition of borax ($\text{Na}_2[\text{B}_4\text{O}_5(\text{OH})_4] \cdot 8\text{H}_2\text{O}$).

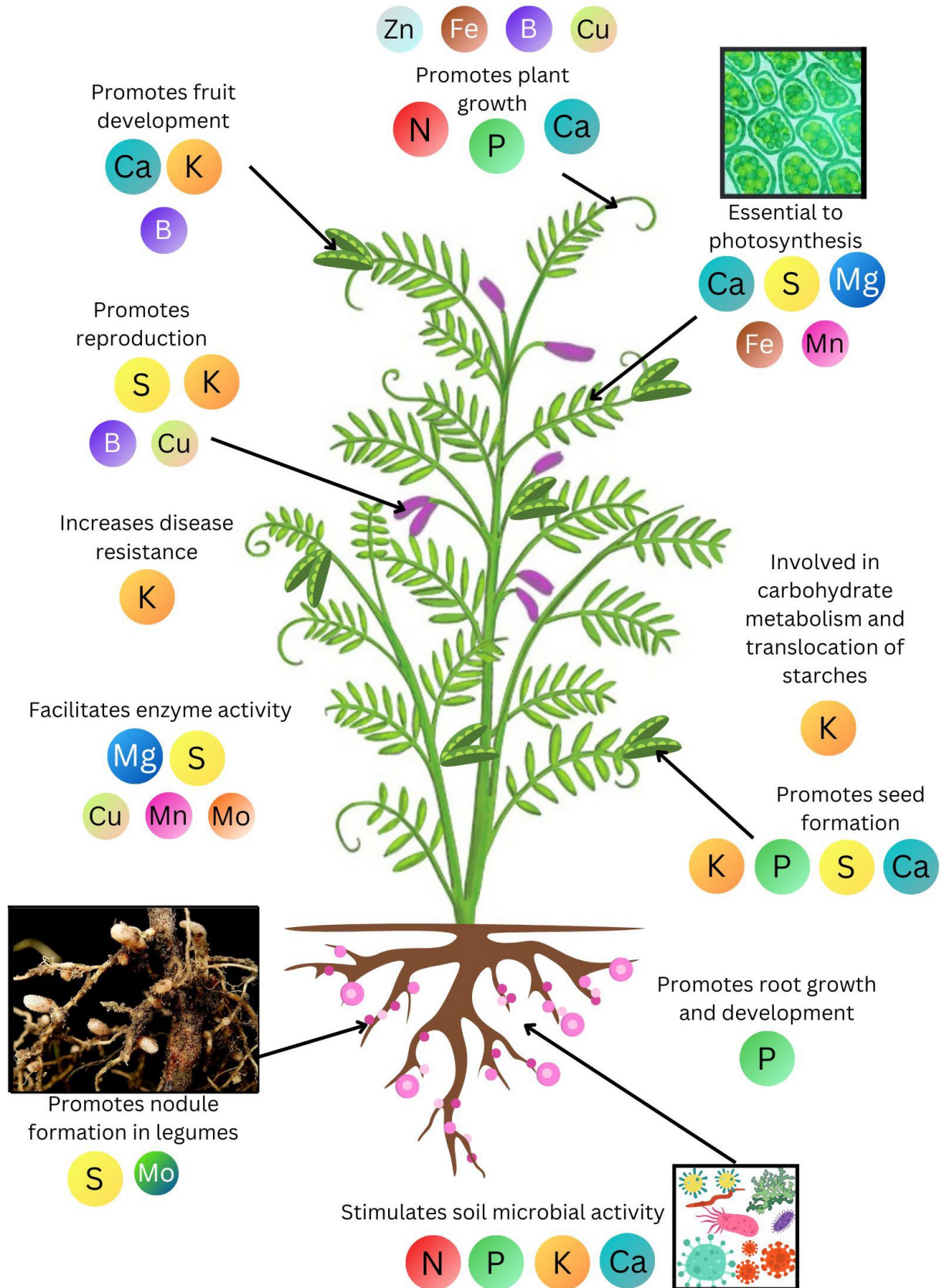
Mo Molybdenum (Mo)

Molybdenum is needed by Rhizobium bacteria to fix atmospheric nitrogen gas (N_2) and convert N to soluble (plant useable) ammonium and nitrate compounds in the soil, so is essential for legumes and nitrogen fixation. It is also essential in the formation of proteins from nitrate compounds. In legumes, a lack of molybdenum prevents proper nodulation. In non-legumes, symptoms can include scorching in leaves, yellow leaves or spotting and may be confused with a N deficiency.

Molybdenum is the least abundant of the trace elements in soils and very little is present in plant available (soluble) forms. Molybdenum deficiency is widespread in acid and sandy soils and is treated with applications of Mo + superphosphate, molybdenum trioxide (MoO_3) (applied during inoculation and lime pelleting of legume seed), or Ammonium molybdate ($(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$) (sprayed on young emerging plants).

See Figure 26 which summarises the essential macro and micro plant nutrients and how they are used by plants for function, growth and development.

Figure 26 Soil nutrients for plant function, growth and development



The law of the minimum

Plants need specific nutrients in different amounts. The law of the minimum states that the nutrient in scarcest supply is the first to restrict growth. A plant's growth is limited by the nutrient (or environmental requirement e.g., water, temperature, soil, light etc), in shortest supply. High yields are only possible if all macro and micronutrients are available in the required amounts. Liebig's Law of the minimum often uses a barrel metaphor. Read more at [The Law of the Minimum, Redmond Agriculture](https://www.redmondagriculture.com.au/the-law-of-the-minimum/).

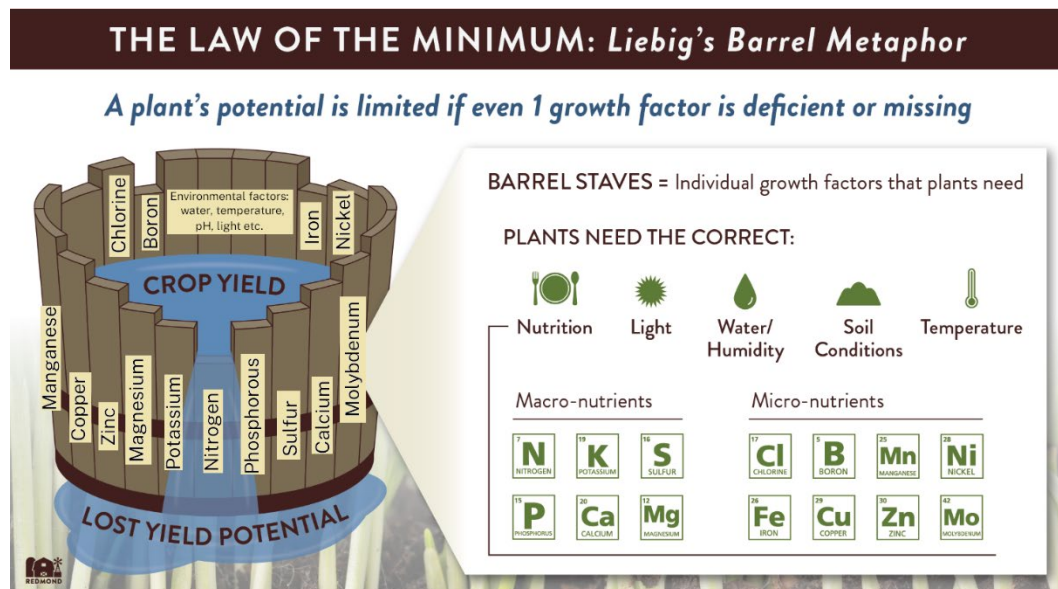


Figure 27 The Law of the minimum. Source: [Redmond Agriculture](https://www.redmondagriculture.com.au/the-law-of-the-minimum/)

Plant nutrient deficiencies and sufficiencies

The concentration and form of nutrients in the soil solution can cause plant nutrient toxicities or deficiencies and affects plant metabolic function, growth and development.

When plant nutrient concentrations are low enough to reduce plant growth, distinct deficiency symptoms appear (for example, poor root, leaf or stem growth, discolouration etc). Extreme deficiencies result in plant death. Visual symptoms may not appear when a nutrient is marginally deficient, but plant yield may still be reduced. A laboratory analysis of soil will accurately assess nutrient status of a soil and recommend a fertiliser to meet your needs.

For more information on Australian fertilisers, and plant nutrient requirements and deficiencies go to: [Incitec Pivot fertiliser](https://www.incitec.com.au/pivot-fertiliser), [Fact Sheets](#), [Reacquaint yourself with the basics](#).

Watch laboratory pH testing methodology to see how plants and soils are tested for nutrient status and deficiencies at: [Soil, water and plant tissue testing- NSW DPI Wollongbar environmental Lab](https://www.dpi.nsw.gov.au/soil-water-and-plant-tissue-testing)



Fertilisers- Organic and inorganic

Fertilisers may be broadly classified into one of two groups:

Organic fertilisers

These fertilisers include animal manures and animal or plant by-products. Animal manures contain small quantities of nitrogen, phosphorus and potassium, which vary with the kind of animal and its diet. Animal by-products include blood and bone, bone dust, etc. Animal by-products generally have a higher nitrogen content than animal manures.

Green manuring is the practice of growing a crop with the specific aim of returning it through tillage into the soil to increase soil organic matter, improve soil fertility and reduce weeds. Examples of green manure crops include sunflower, safflower, sorghum, millet or pulse crops which also have high levels of nitrogen.

Green manuring is an organic method of improving soil fertility and the levels of organic matter.

Some of the most widely used artificial or inorganic fertilisers include:

- Animal and plant manure: provide nitrogen, phosphorous, potassium and trace elements.
- Compost: made from decomposed plant and animal materials rich in nutrients such as nitrogen, phosphorous and potassium
- Fish emulsion: made from fish and fish waste (e.g. “Charlie carp”). High in Nitrogen.
- Bone meal: made from ground bones are high phosphorous and calcium.

Inorganic fertilisers (also called synthetic or artificial)

These fertilisers are derived from inorganic sources and require more processing in their manufacture. They can be manufactured with varying mineral contents. Some may provide mainly one element, these are called ‘straights’ or they may contain a range of elements, called compounds or mixtures. They may come in various forms such as a powder, granule, liquid or gas. Some of the most widely used artificial or inorganic fertilisers include:

- Superphosphate, Monoammonium phosphate (MAP), Diammonium Phosphate (DAP) are common phosphorus fertilisers.
- Sulfate of ammonia, anhydrous ammonia, ammonium nitrate and urea. These provide nitrogen.
- Potassium chloride (Muriate of Potash) and Potassium sulfate. These provide potassium.

All fertiliser packaging (whether it is organic or inorganic) must display the percentage of the three major nutrients they contain i.e. nitrogen, phosphorus and potassium (NPK). For example, a fertiliser labelled 10:10:6 contains 10% nitrogen, 10% phosphorus and 6%

potassium. Most fertiliser packages contain a complete list of all the nutrients in that fertiliser.

Both organic and inorganic fertilisers are used to provide nutrients to plants, but they differ in their nutrient content and environmental impacts. Each have advantages and disadvantages. Organic fertilisers are often slower acting but can improve soil health and fertility over time, while inorganic fertilisers are more quickly available to plants but when not used correctly can contribute to soil acidity and other environmental issues if used in excess.

Fertilisers and the environment

There is much adverse publicity and media coverage regarding agriculture's role in polluting the environment, which paints industry in a poor and inaccurate light.

It is important to be aware of the effects of fertilisers and to use them carefully, but it is also important to realise that agricultural fertilisers are not a main source of environmental pollution. If fertilisers are applied correctly, so that plants use all the nutrients and none are leached, there is little opportunity for pollution or soil degradation. Reducing fertiliser inputs often leads to reduced plant growth which can aggravate problems such as soil erosion.

The following describes types of fertiliser-induced environmental pollution due to incorrect application.

Groundwater pollution - Nitrate leaching through the soil can be a serious human health hazard and contributes to soil acidification. Nitrates can be leached into groundwater and the watertable because of high applications of nitrogen fertilisers.

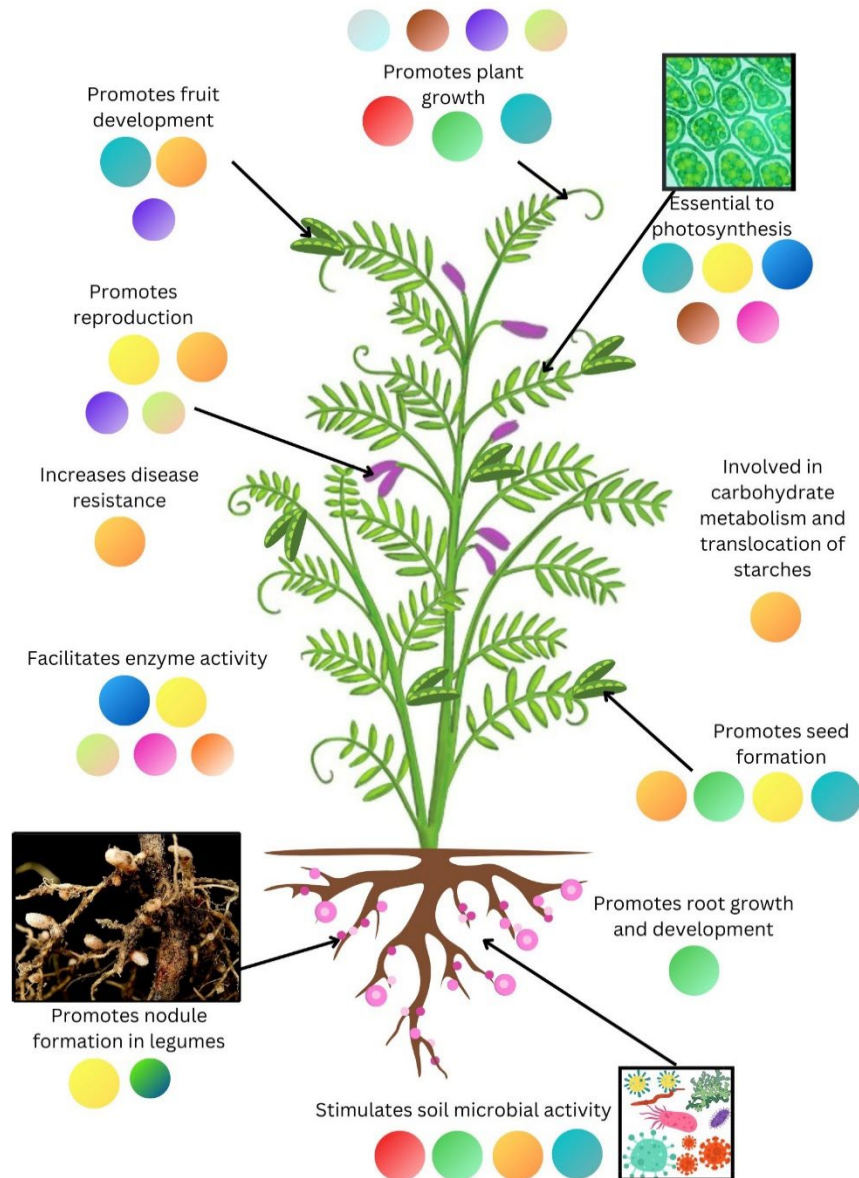
Eutrophication – is the enrichment of water by nutrients. The extra nutrients cause algal blooms (particularly in stagnant water). For example, phosphorous promotes Blue-green algae which is poisonous to animals and humans. Nutrients reach waterways in run-off and in effluent drainage, if not managed correctly.

Soil acidity- There are three major acidifying processes in agricultural systems:

- addition of nitrogen to the soil by fertiliser or fixation of atmospheric nitrogen, followed by loss of nitrate from the soil due to leaching or run-off
- production of organic acids from decomposing organic matter
- removal of alkaline products such as hay from the soil.

Heavy metal contamination - Cadmium is present in tiny amounts (less than 0.5 mg/L) in the soil, and in larger amounts in rock phosphate. The accumulation of cadmium in soils results from superphosphate application. The cadmium can accumulate in animal products and create a health risk to humans.

40. Complete the diagram by labelling the nutrients using their symbols (match the colours). Complete the key to identify each nutrient.



Key

Major elements (macro nutrients)		Trace elements (micro nutrients)	
N		Zn	
P		B	
K		Mo	
Ca		Fe	
Mg		Mn	
S		Cu	

41. Complete the table to name the following common fertilisers, identify the nutrient deficiency and identify if that nutrient is a major element or trace element for plant growth. The first has been given for you.

Common agricultural and horticultural fertilisers			
Formula	Common name	List the nutrient/s deficiency treated	Major or trace nutrient deficiency
$(\text{NH}_4)_2\text{SO}_4$	<i>Ammonium sulfate</i>	<i>Nitrogen (N)</i>	<i>Major</i>
$(\text{NH}_4)_2\text{SO}_4$			
$\text{CH}_4\text{N}_2\text{O}$			
$\text{Ca}(\text{H}_2\text{PO}_4)_2$			
KCl			
K_2SO_4			
CaO			
$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$			
$\text{CaMg}(\text{CO}_3)_2$			
MgO			
MgSO_4			
S			
MnSO_4			
CuSO_4			
ZnSO_4			
$\text{Na}_2[\text{B}_4\text{O}_5(\text{OH})_4] \cdot 8\text{H}_2\text{O}$			
MoO_3			
$(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$			

[illegible]

Technology activity- Calculating P with the MLA Soil phosphorous tool.

This activity is adapted from: [MLA soil phosphorous tool](#)

Background:

To undertake this activity, you will need Soil laboratory test results including Colwell P (mg P/kg); Phosphorous Buffer Index (PBI) and fertiliser labels. See materials list and read [‘Five easy steps technical booklet’](#) before carrying out this class activity.

Phosphorus (P) is applied to Australian pastures because most soils have low P availability for plant growth, and this limits pasture growth. For legume-based pastures, improving P availability boosts the legume content of the pasture and increases the amount of biological nitrogen fixation. Nitrogen is often the most limiting soil nutrient. Thus, using P fertiliser can increase overall pasture productivity.

The reason for applying P is to lift or maintain stocking rate and consequently to improve profit per hectare.

This tool is intended to assist P fertiliser decisions for temperate, legume-based pastures grazed by sheep and beef cattle on acid soils in southern Australia.

Before using the P tool teachers should read [‘Five easy steps technical booklet’](#) and explore the [MLA Soil Phosphorous tool](#)

Materials:

- Computer with internet
- [MLA Soil Phosphorus tool](#)
- Range of P fertiliser labels e.g. Superphosphate, Diammonium phosphate (DAP), Mono-Ammonium Phosphate (MAP) etc. (Hint: Look up [Incitec Pivot Fertilisers, Product Range](#) if you do not have access to fertiliser labels)

To use the tool, you will need to compile the following production data:

- Soil laboratory results for P fertility status
 - Colwell P (mg P/kg) test results and
 - Phosphorous Buffer Index (PBI) results
- Soil texture
- Average rainfall (mm)
- Production details:
 - Average growing season length
 - Livestock carrying capacity (DSE/Ha)
 - Actual stocking rate (DSE/Ha)
 - Pasture details (improved or native)
- Fertiliser P concentration % by weight (details found on fertiliser label)
- Planned increase in soil P test (mg P/kg per year)

Method:

1. Compile production data for a chosen farm into the results table
2. Access the [MLA Soil Phosphorous tool](#)

Enter your enterprise and production data into the Soil Phosphorous tool using the instructions in the five steps

3. Save your data.
4. Run analysis using different P fertilisers
5. Download reports
6. Make long term Phosphorous application plans and budgets for your enterprise

Optional activity: prepare a Gross margin and Cash flow budget using Step 5.

Results table:

Compile the following information before using the calculator

Production data and soil test results	
Soil laboratory results for P:	
Colwell P (mg P/ kg)	
Phosphorous Buffer Index (PBI)	
Soil texture (e.g. clay, loam)	
Average rainfall (mm)	
Production details:	
Average growing season length	
Livestock carrying capacity (DSE/Ha)	
Actual stocking rate (DSE/Ha)	
Pasture details (improved or native)	
Fertiliser 1- P concentration % by weight (details found on fertiliser label)	
Fertiliser 2- P concentration % by weight (details found on fertiliser label)	
Fertiliser 3- P concentration % by weight (details found on fertiliser label)	
Add more rows as required	
Planned increase in soil P test (mg P/ kg per year)	

Soil biological properties

Soil Organic Matter and soil carbon

Soil Organic Matter (SOM) is the term used for all living, or once-living, materials within, or added to, the soil. All organic matter contains carbon (C), but it also contains nitrogen (N), phosphorus (P), sulfur (S), potassium (K), magnesium (Mg), calcium (Ca) and a whole range of micronutrients (trace elements) e.g. copper, (Cu) and zinc (Zn). Soil organic carbon (SOC) refers only to the carbon component of soil organic matter.

There are many important and beneficial roles that organic matter plays in soil:

- Provides nutrients (food) and energy for soil microbes
- Provides nutrients to plants (particularly nitrogen, phosphorus and sulfur)
- Stabilises soil structure and increases water holding capacity
- Acts as 'glue' holding soil particles and aggregates together due to its negative surface charge (very high [CEC](#))
- Makes it easier for water to enter the soil
- Reduces run-off and erosion
- Improves the soil's ability to hold nutrients, reducing nutrient leaching
- Helps buffer the soil against changes in pH

Many factors affect soil organic matter levels:

- Soil depth – the organic matter content generally decreases deeper through a soil profile. Organic matter levels will be highest in the upper horizon (topsoil)
- Soil type – sandy soils generally have lower soil organic matter than heavier soils such as loams
- Management practices – excessive cultivation reduces organic matter levels
- Temperature – organic matter breaks down quicker in hot climates compared with cool climates
- Soil water content – organic matter breaks down quicker in moist soil (though not permanently saturated) compared with dry soil

Organic matter can be split into separate types or 'fractions'. Each fraction has a different function in the soil. The main fractions are outlined in Table 6.

Table 6 Different types of Soil organic matter

Organic matter fractions	What is it?	What does it do?
Microbial biomass	Bacteria, fungi, protozoans (the living part) and soil fauna	Decomposes organic matter
Fresh plant and animal residues	Organic matter that has recently been incorporated e.g. animal manure, green manure, crop residues	Food for microbes, releases soil nutrients
Active (decomposing) organic matter	Root exudates (composed of simple carbohydrates (sugars) and amino acid compounds) and actively decomposing organic matter	Moves through the soil profile. Binds soil particles, available plant uptake
Inert organic matter	e.g. charcoal, biochar and coal fragments	Does not breakdown but improves soil structure
Stable organic matter - Humus	Completely decomposed organic matter	Supplies nutrients and improves soil structure

Soil Organic Matter (SOM) represents organic material both living and in various stages of decay. The most important fraction of organic matter to soil fertility is humus. Humus is dark brown/black, organic material that is fully decomposed. Humus rich soil is very dark, almost black colour, has a spongy texture, and earthy smell.

Humus is highly resistant to microbial degradation and is essential for maintaining optimum soil physical conditions important for plant growth. Fresh crop residues undergo rapid microbial decomposition.



Figure 28 Soil with high organic matter content has a characteristic dark black/brown colour

The Microbial biomass include the soil microorganisms and fauna and influence availability of N, P, S, and other nutrients.

Decomposition and humus formation depend on climate, soil type, and soil and crop management. SOM can greatly influence nutrient availability and soil properties. For example, increasing SOM increases soil aggregation and decreases bulk density, which improves water infiltration, air exchange, root growth, and crop productivity. SOM levels depend on soil and crop management. If management is changed, a new organic matter level is set that may be lower or higher than the previous level. Management systems should

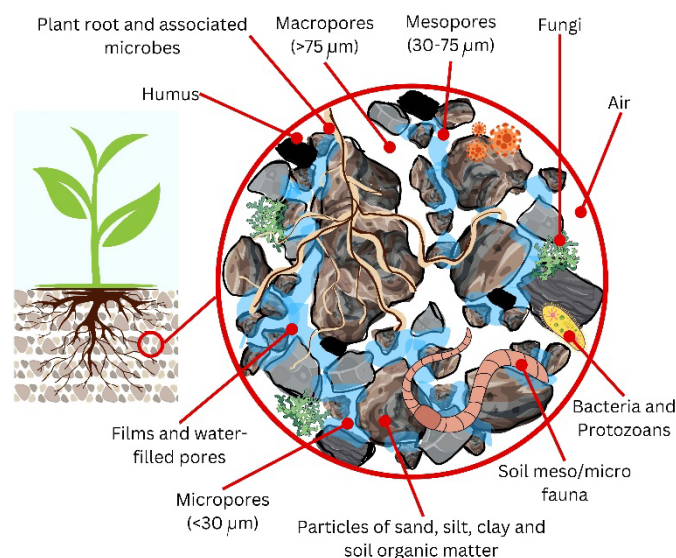


Figure 29 Soil components humus and microbial biomass (bacteria, protozoans, fungi and fauna)

aim to increase SOM and productivity. Proper nutrient management will produce high yields, which will increase the quantity of residues and SOM.

Increasing SOM levels

Grow perennial pasture - A period under perennial, grass-dominant pasture will increase organic matter levels in farm soils. Short-lived annual grasses are a source of dead roots; perennial grasses are a source of leaf matter. Even short periods (1–2 years) under pasture can improve soil structure, even though the actual increase in organic matter may be small.

Grow cereal crops - Cereal crops leave significant amounts of organic matter in their dead roots and stubble after harvest which, when incorporated into soil, increases the organic matter content.

Grow green manure crops - Green manure crops provide protective cover until they are ploughed into the soil. Initially they provide a large increase in organic matter levels, but they break down rapidly to give only a small increase in long-term organic matter levels. Also, ploughing causes organic matter to rapidly break down and disrupts soil structure.

Spread manure - Bulky organic manures will increase organic matter, but frequent and heavy applications are needed to produce significant long-term changes.

Organic fertilisers - Organic fertilisers applied in large amounts can boost organic matter levels but are generally less cost-effective at supplying nutrients compared to inorganic (synthetic) fertilisers. Applied in small quantities, they are unlikely to have much effect on organic matter levels.

Keep cultivation to a minimum - Cultivation breaks down the stable soil aggregates, exposing humus in the aggregates to air and faster decomposition. Direct drill techniques allow you to sow seed while leaving stubble residues on top of the soil and leaving aggregates intact.

Concentrate organic matter - An alternative to increasing inputs is to make more effective use of what is already there. Retain all organic additions, whether roots, stubble or manure, close to the surface to protect the soil from erosion. The stability of soil structure is related to the amount of organic matter at the surface, not the total quantity in the soil.

43. Contrast SOM and SOC

44. List five advantages of organic matter in soils

45. Outline five factors which affect the level of organic matter in soils.

46. Complete the table by identifying the organic matter fraction and describing what each does.

Organic matter fractions	What is it?	What does it do?
	e.g. charcoal, biochar and coal fragments	
	Organic matter that has recently been incorporated e.g. manure, crop residues, stubble	
	Week decomposed organic matter	
	Root exudates (composed of simple carbohydrates (sugars) and amino acid compounds) and actively decomposing OM	
	Protected chemically or physically	
	Bacteria, fungi, protozoans (the living part) and soil fauna	

Practical activity- Estimate Soil Organic Matter (SOM) content by Loss of Ignition (LOI)

Background: Loss on Ignition (LOI) analysis is used to determine the organic matter content (SOM%) of a soil sample. It is a relatively simple procedure used to determine SOM%. It does not involve the use of any chemicals, only the use of a muffle furnace which will heat the soil samples greater than 550°C. As few schools will have access to a muffle furnace a Bunsen burner can be substituted.

The following procedure gives an indication of the LOI procedure but will not give accurate results for SOM%. To get an accurate SOM% result it is recommended to obtain

a laboratory analysis. See [Practical activity – Collecting soil samples for laboratory analysis](#).

Aim: to determine the indicative organic matter % content of a soil sample

Materials:

- Dry soil samples
- Oven (set to 105°C)
- Porcelain crucible
- Bunsen burner
- Tripod
- Desiccator tongs
- Heat proof mat
- Clay-pipe triangle
- Copper wire
- Digital scales
- Mortar and pestle
- Heat proof gloves
- Safety glasses

Method:

1. Weigh the crucible and record the mass in the results table
2. Take a tablespoon sized sample of soil in mortar and pestle and grind it for 2 minutes until it is a very fine powder.
3. Weigh 5 grams of the ground up soil sample on digital scales and place it in the crucible.
4. Place crucible in oven set to 105°C and leave for 24 hours.
5. Weigh the soil and crucible when cool enough to touch (it is important that you do not wait too long as the soil will absorb moisture from the air as it cools). Record the soil mass in the results table. This is the Soil pre-ignition weight. (Weight – crucible weight.)
6. Set up Bunsen burner, heat proof mat, tripod and clay-pipe triangle and crucible as seen in Figure 30.
7. Time and heat the crucible with a strong Bunsen burner flame continuously for 30 minutes.
8. Weigh the soil and crucible on the digital scales. Use tongs to transfer the crucible - be careful not to burn yourself. Weigh the sample quickly as the sample will absorb moisture from the atmosphere as it cools. This is the soil's post-ignition weight (weight- crucible weight).
9. Calculate the % organic matter in the results table. Use the formula:

$$\text{SOM}\% = \frac{\text{pre-ignition weight (g)} - \text{post ignition weight (g)}}{\text{pre-ignition weight (g)}} \times 100\%$$
10. Repeat steps 1-9 for each soil sample.

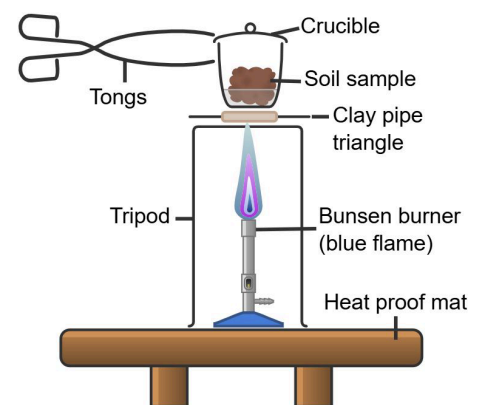


Figure 30 OM% LOI apparatus

Results table:

Soil sample	Crucible weight (g)	Soil pre ignition weight (g)	Soil post-ignition weight (g)	SOM% = $\frac{\text{pre-ignition weight (g)} - \text{post ignition weight (g)}}{\text{pre-ignition weight (g)}} \times 100\%$
Add extra rows as required				

Loss on Ignition (LOI) calculates SOM% by comparing the weight of a sample before and after the soil has been ignited. Before ignition the sample contains organic matter, but after ignition all that remains is the mineral portion of the soil. The difference in weight before and after ignition represents the amount of organic matter in the sample.

Soil microbes, invertebrates and nutrient cycling

Microbes and invertebrates are essential for decomposing organic matter and nutrient cycling, processes that are essential for ecosystem health, agricultural productivity and sustainability.

Soil microorganisms are broadly defined as a group of microscopic life forms that include bacteria, archaea, viruses, algae and eukaryotic fungi. Soil animals (invertebrates) include:

- Microscopic protozoa and nematodes (Microfauna, μm)
- Mesoscopic springtails, mites and other microarthropods (mesofauna, mm), and
- Earthworms, termites, ants, beetles, and millipedes, among others (macrofauna, cm)

Microbes in decomposition

Micro-organisms (bacteria, fungi, and protozoa) are the primary agents in the initial stages of decomposition. Collectively they:

- Break down organic matter and biomass, such as dead plant and animal material, into simpler compounds
- Carry out plant symbiotic relationships (e.g. *Rhizobium* bacteria and *Mycorrhizae* fungi)
- Control pathogens and parasites
- Store carbon (combined biomass of soil micro-organisms exceeds that of all animals on earth)

Here's how they contribute:

- **Bacteria:** These microorganisms are often the first to colonise dead organic matter. They use enzymes to break down complex molecules like proteins, lipids, and carbohydrates into simpler compounds, such as amino acids and sugars. Some bacteria are specialised to breakdown specific types of organic material, such as cellulose in plant matter e.g. cellulolytic bacteria species: *Bacillus*, *Pseudomonas*, *Streptomyces*, and *Clostridium*. *Rhizobium* bacteria are essential for nitrogen cycling forming a *mutualistic symbiotic relationship* with legume plants. They are found in root nodules and supply the plant with Nitrogen in exchange for a habitat and energy.
- **Fungi:** Fungi, particularly *saprophytic* fungi, play a key role in breaking down tough organic compounds like lignin and cellulose in plant cell walls. These fungi decompose organic matter more slowly but are critical for the breakdown of wood and other plant material that bacteria alone cannot process effectively.

- **Other microbes:** microscopic animals, protozoa and nematodes also aid decomposition by feeding on bacteria, fungi, and organic molecules (e.g. root exudates), which helps release nutrients that can be used by plants and other organisms in the soil ecosystem.

Key Functions:

- **Nutrient release:** Microbial decomposition is essential for nutrient cycles of nitrogen (N), phosphorus (P), and potassium (K) and the cycling of these essential nutrients into plant available forms in the soil which can then be cycled through food webs.
- **Organic Matter breakdown:** Without microbes, organic material would accumulate in the environment, immobilising (locking up) the cycling of carbon and other elements.

Watch: [How microbes are the answer to healthy soil](#)



Root exudates and micro-organisms

Plant roots influence the physical, chemical, and biological conditions of the soil in the soil-root region (rhizosphere) through the release of exudates. Exudates are organic substances containing sugars, amino acids, organic acids and enzymes secreted by living plant roots. They can have many functions including:

- Providing an energy source in a symbiotic relationship which attracts thousands of different species of beneficial micro-organisms that in return supply the plant with plant available nutrients (e.g., *Mycorrhizal* fungi)
- They may also have a toxic effect on root pathogens or pests and
- Allelopathic effects on neighbouring weeds/plants.

The microbial populations are an essential part of the rhizosphere and affect the soil rhizosphere by their various activities such as water and nutrient uptake.

Find out more at: [What are root exudates?, Agriculture explained.](#)



Invertebrates in decomposition

Invertebrates, such as earthworms, nematodes, beetles, ants, and other arthropods, play complementary roles in decomposition, mainly by physically breaking down larger organic material and supporting microbial activity. They help process plant and animal remains and aid nutrient cycling as follows:

- **Detritivores** (e.g., earthworms, dung beetles, millipedes, isopods): These organisms feed directly on dead plant material, dead animals, and decaying organic matter.

By digesting this material, they break it down into smaller particles, increasing the surface area for microbes to act upon. Earthworms and potworms for example, consume soil and organic matter, creating nutrient-rich casts that enhance soil fertility.

- **Carnivorous invertebrates:** Many invertebrate carnivores, such as carrion beetles, ants, nematodes feed on decomposing animal carcasses and waste. By breaking down animal remains, they help release nutrients into the soil.
- **Saprophytic (decomposers), predaceous and parasitic macro-organisms (e.g. nematodes)** Nematodes feed on beneficial and harmful bacteria, fungi, and other microscopic soil organisms. In some cases, pest nematode species feed on plant roots. Thousands of nematode species live in soils. They are essential to healthy soils, decomposition and nutrient cycling.
- **Mechanical Breakdown:** Invertebrates also perform mechanical breakdown by chewing, burrowing, and shredding plant material, which increases the surface area and accelerates decomposition by exposing organic matter to microbial decomposition.

Key Functions:

- **Soil aeration:** Invertebrates like earthworms, mites, millipedes and ants create channels in the soil as they burrow, which helps aerate the soil and improves its structure and porosity. This enhances microbial activity, which is critical for decomposition and nutrient cycling.
- **Nutrient recycling:** The excrement of invertebrates often contains nutrients that have been partially digested, which can be easily used by plants and other organisms. For example, earthworm casts are rich in nitrogen, phosphorus, and other nutrients.

Nutrient cycling and soil health

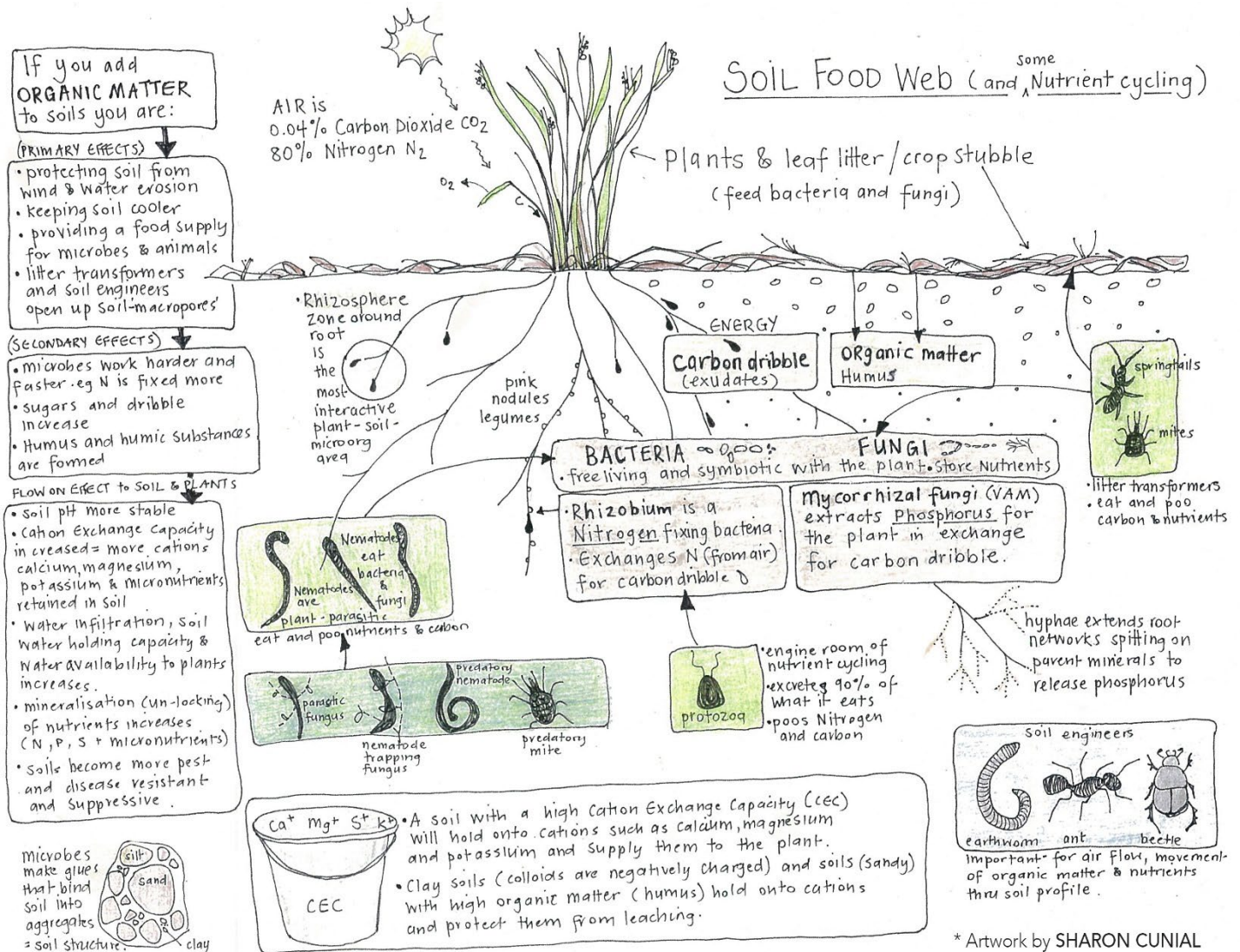
The work of microbes and invertebrates in decomposition and nutrient cycling ensures that essential nutrients are recycled and made available to plants, which are the foundation of most food chains. Without these processes:

- **Nutrient imbalances:** Nutrients would remain immobilised in dead organic matter, preventing their recycling into the soil and reducing their availability for plants.
- **Soil fertility decline:** Soil health would decline over time without the constant replenishment of nutrients through decomposition, impacting agricultural productivity and natural ecosystems.
- **Carbon sequestration:** Decomposition and nutrient cycling also play a critical role in the global carbon cycle. Carbon is released from decaying organic material in

the form of carbon dioxide, which is then reabsorbed by plants and used in photosynthesis.

The Soil Food web and some nutrient cycling

The following image summarises the role of soil invertebrates and microorganism's interactions in nutrient cycling. Refer to it as you carry out the following activities 'A day in the life of soils' and '[Common soil fauna identification](#)'.



47. Use research to outline the role of microorganisms and invertebrates in decomposition and nutrient cycling.

Some helpful sites include:

- [Decomposition and Nutrient cycling, Ozsoils, UNE Soil science](#)
- [Life in the soil, CSIRO](#)
- [Organic matter decomposition and the soil food web, FAO](#)
- [Soil Organisms and litter decomposition](#)
- [The soil biota](#)

Playing the Game

Full instructions for the 'basic' game are over the page.

Game extensions (optional)

Building on the basic model, this role play can be extended in the following three topic areas:

1. **Nutrients:** forms, cycles and pools: parent materials, primary and secondary minerals, storage, fixation, loss, turnover, solubilisation, mobilisation, mineralisation, assimilation, translocation. Available, exchangeable and total soil nutrient pools. 2 types of nutrients - Inorganic and organic forms. 4 pathways of cycling, 2 ways of uptake. Use the N and P cycles to illustrate these processes.
2. **Carbon and organic matter:** photosynthesis, living biomass, root exudation, organic matter (categories), organic biochemicals, active and stable carbon, oxidation and respiration, the rhizosphere, the O and A horizons, humus categories, humification.
3. **Soil emergent properties:** Humus and humus forms, soil structure, aeration and water holding capacity, Clay-Humus exchange complex, CEC. Balanced nutrient cycling to plants, production of growth co-factors, Plant disease resistance via optimal nutrition, soil disease suppression through functional diversity and biological fertility.

Begin by looking at an undisturbed ecosystem and how the above processes occur in a natural ecosystem. After looking at how 'natural soil' functions, introduce various farming practices and show how disturbance influences the different processes. Grazing, tillage and equipment, fertilisers (slow and soluble forms) and agricultural chemicals can all alter the system.

A Day in the Life of Soil role play is licensed under the Creative Commons Attribution-ShareAlike 3.0 Unported License. To view a copy of this license, visit <http://creativecommons.org/licenses/by-sa/3.0/>.



What is in the kit

- 18 role play cards
- These instructions

What you will need to provide

- Printout of these instructions - double sided; fold as directed
- 15 Black Unifix blocks ('Carbon')
- 15 Blue Unifix blocks ('Phosphorus')
- 15 Green Unifix blocks ('Nitrogen')

If you do not have Unifix blocks, you may substitute three different sorts of wrapped sweets (or three different kinds of anything).



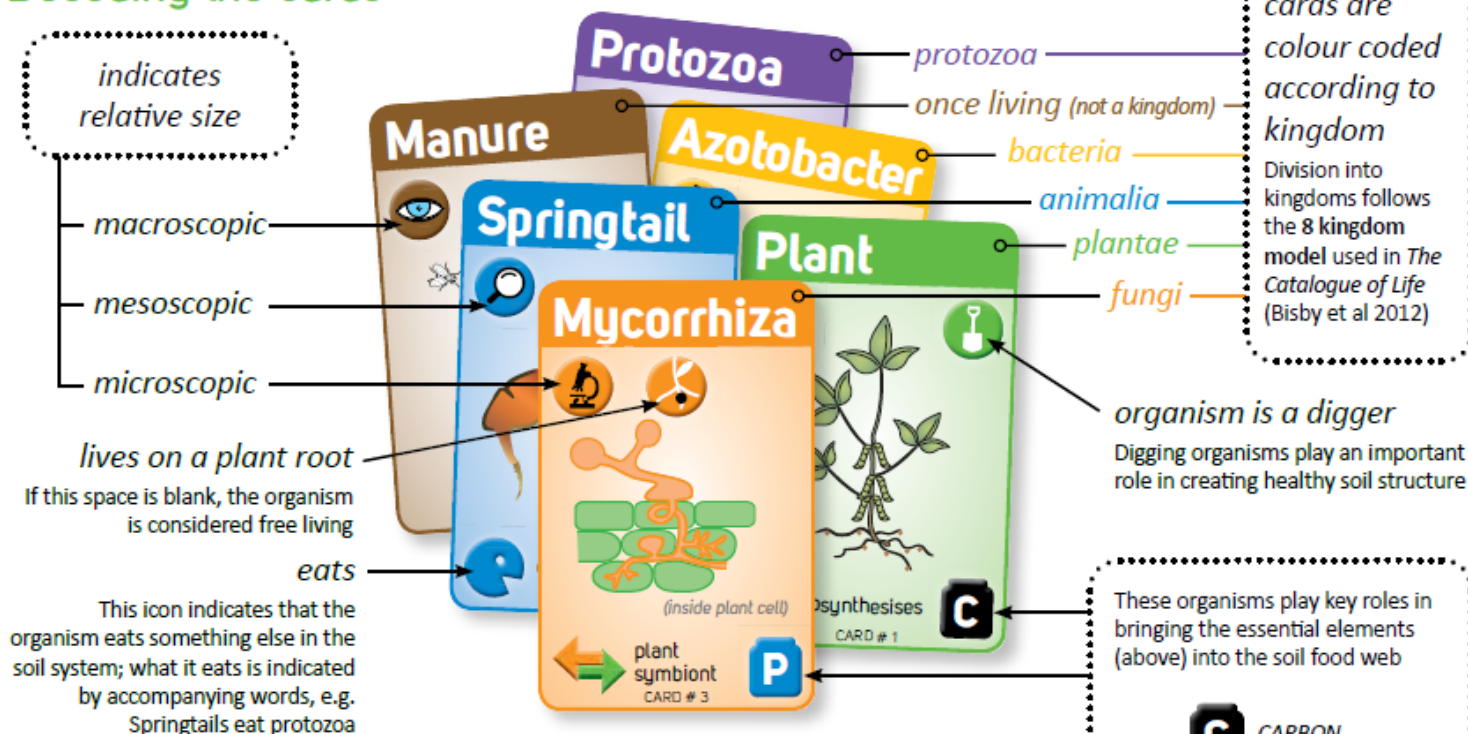
Queensland Government



Soil Land Food

Soil & Farm Fertility Services * Agriculture & Food Systems Consultancy

Decoding the cards



References

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- Nardi, J. B. (2007) Life in the soil: a guide for naturalists and gardeners. University of Chicago Press.

Some of the organism illustrations on cards were obtained from the IAN Library, courtesy of the Integration and Application Network (ian.umces.edu/symbols/)

A Day in the Life of Soil was first developed by David Hardwick, a consultant with Soil Land Food. It was released under a Creative Commons 3.0 licence in 2012. This version has seen some modification by Simon Hamlet (Department of Agriculture, Fisheries and Forestry Queensland).

David's iteration of the game has two phases, only one of which is described in these instructions. The potential and scope for Phase 2 is described overleaf. In the hands of a skilled facilitator, this role play is a very powerful tool. These instructions will help you to facilitate Phase 1.

Full instructions for the 'basic' role play.

1. Hand out the eighteen cards to participants. Not all the cards are needed for the exercise; the essential group is cards 1-8.
2. Have participants examine their cards and ask them to stand in groups according to their organism's characteristics, grouping one feature at a time; eg. kingdom, size, diggers, etc. Facilitate a conversation about diversity in the soil system, and the way in which many of the important components in the soil are not visible to the naked eye.
 - a. Point out that only 18 cards are represented in the role play. Can participants think of other organisms which could be on cards? James Nardi's book *Life in the Soil* is an excellent resource to help with this.
 - a. Inform participants that at the end of the role play they will be using the cards to construct a soil food web.

BUILDING THE SOIL

3. Call out Card 1, 'the plant'. The plant is the key focus for the agricultural soil system; this is the crop. It is also the only primary source of carbon (C). Plants bring C into the soil via photosynthesis; water plus carbon dioxide in the presence of light (and chlorophyll) produces oxygen plus carbohydrates (which contain C). C is represented by black Unifix blocks. Give a handful of these blocks to the 'plant'. Stress that this C comes from the air. The vast majority of plant biomass is derived from air.
4. There are two symbiont cards in the deck: rhizobia (bacteria) and mycorrhiza (fungi). A symbiont is a member of a symbiotic relationship, in this case with a plant. Symbiosis is the process by which organisms live together for mutual benefit, in this case the mycorrhiza invades the plant cell and the rhizobia live in nodules specially produced by the plant for them to live in.
 - a. **Rhizobia.** Nitrogen (N) is an essential and common element. Every amino acid contains some N, and 78% of the earth's atmosphere is N. However atmospheric N is in a form called dinitrogen (N_2) which is not accessible to plants. Rhizobia contain enzymes which convert this N_2 into plant usable forms of N. N is represented by green Unifix blocks. Give a handful of these to the 'rhizobia'. Like the C captured by photosynthesis the N in plants also comes from the air.
 - b. **Mycorrhiza.** Phosphorus (P) is also an essential element. Most of the cellular processes in all living things are powered by an enzyme called adenosine tri-phosphate, which as its name implies contains P. The P in rocks is not in a form usable by plants, so plants require the services of other organisms to solubilise the P in the environment. Mycorrhiza do this by excreting acid. 80-90% of plant species have some form of mycorrhizal relationship that assists the plant in many ways, but for the purposes of the role play we are focusing on their ability to solubilise P. P is represented by blue Unifix blocks. Give a handful of these to the 'mycorrhiza'. You may like to store the blue Unifix blocks in a container with some rocks to show that the P comes from rocks rather than from the air.
 - c. Both rhizobia and mycorrhiza live inside the plant roots. The plant exchanges C captured via photosynthesis for the N and the P converted by the symbionts. Encourage the plants and the symbionts to negotiate the value of the N and the P and engage in an exchange. Show that the symbiont makes a direct exchange with the plant ie. injecting into the plant root, not into the soil.

5. In this game the uptake of N is via rhizobia in a symbiotic relationship with the plant, ie. the plant is a legume. What if the plant was not a legume? How would the plant get its N? It would be reliant on organic matter in the soil, or free-living nitrogen-fixing organisms, eg. Card 15, azotobacter. The plant 'leaks' C into the soil to attract organisms which may benefit the plant, a process called exudation. Up to 20% of the carbohydrates produced via photosynthesis are released into the soil as exudates. David Hardwick likens this to the discarded by-catch from a fishing trawler that attracts many creatures from the ocean; likewise many creatures are attracted to plant exudates. This process is less efficient than a direct exchange between symbionts, as losses can occur due to other processes in the soil.
6. The next two cards both solubilise phosphorus: the fungi (pencilium, card 4) and the bacteria (azotobacter, card 5). Note that the soil system has multiple pathways to perform the one function that is the solubilising of phosphorus.
7. Progressively call up other organisms that eat the organisms already called up. Eg. Ask "who eats plants?" and 'Root-feeding Nematode' should come forward. Ask "who eats root-feeding nematodes?" and 'Carnivorous Fungi' should come forward. Be aware that some organisms are consumed by multiple organisms, eg. protozoa are eaten by predatory nematodes, mites and springtails.
8. Participants enact 'eating' by taking Unifix blocks from other organisms. After eating, participants should 'excrete', by dropping some blocks on the floor. This process is called mineralization. The blocks that fall on the floor are elements in a form that other organisms, including plants, can uptake; this cycles the N and the P in the top soil. The Unifix blocks on the floor represent organic matter, so organisms who eat organic matter can come and 'eat' this material on the floor.
9. Some organisms have a digger icon on their card and should be encouraged to 'excrete' on a different part of the floor to the one they were standing on when they 'ate'. This will demonstrate that digger organisms have an important role in moving essential elements within the soil profile, both vertically and horizontally.

10. Play until only the 'farmer' card remains unplayed. Note that this is a model of soil in its natural state and a good opportunity to stop and record the soil food web.

THE FARMER (CARD 9)

11. The farmer has no role indicators at the bottom of the card. This is because the role he or she plays in the system is very much determined by the management practices they choose to use. For example, if a plant is given an application of soluble fertiliser, what impact will this have on the system?
 - a. **Start at the plant.** The plant no longer needs the symbiotic relationships to provide P and N, so it will reduce the amount of C it exchanges with them, instead applying it to vegetative growth. It will reduce its root-based search for nutrients. It will reduce its root exudation rate, as the services of some of the other organisms are no longer needed.
 - b. **What impact does this have on the system?** Role play the reduced contribution of carbon by the plant into the system.

This is just one scenario. Other scenarios are in the stage 2 list (overleaf). The modelling of other scenarios would be a valuable extension activity.

In the spirit of a Creative Commons Licence these instructions are a work in progress. The opportunity is present for farmers, scientists and participants to engage in an ongoing collaboration to refine this tool for a number of uses. If you find a way to improve this document, or you develop new cards we would appreciate hearing from you. Please contribute your instructions and observations to simon.hamlet@daff.qld.gov.au. Your contribution will be acknowledged. You can download additional copies of the cards on printable sheets at https://www.daff.qld.gov.au/__data/assets/pdf_file/0009/75933/DILOS-card-set-for-printing.pdf

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Plant



photosynthesises



CARD #1

Rhizobia



plant
symbiont



CARD #2

Mycorrhiza



(inside plant cell)



plant
symbiont



CARD #3

Penicillium



eats organic
matter



CARD #4

Pseudomonas



eats organic
matter



CARD #5

Protozoa



eats bacteria

CARD #6

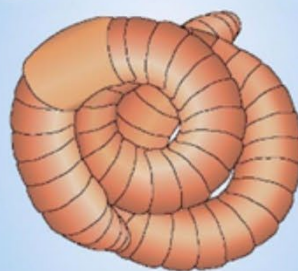
Springtail



eats protozoa

CARD #7

Earthworm



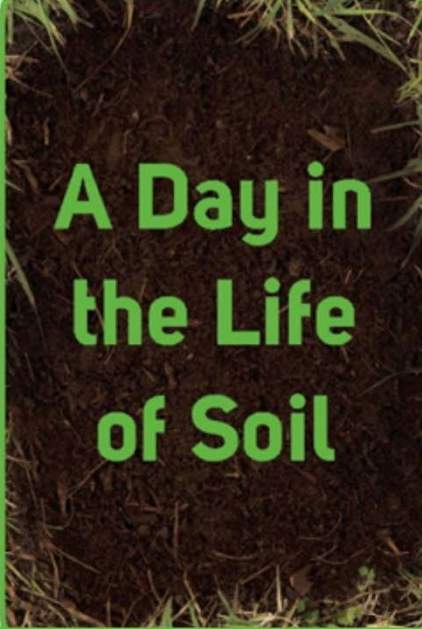
eats organic
matter

CARD #8

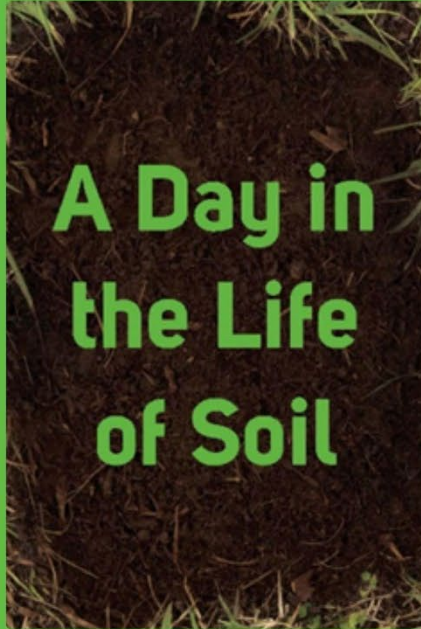
Farmer



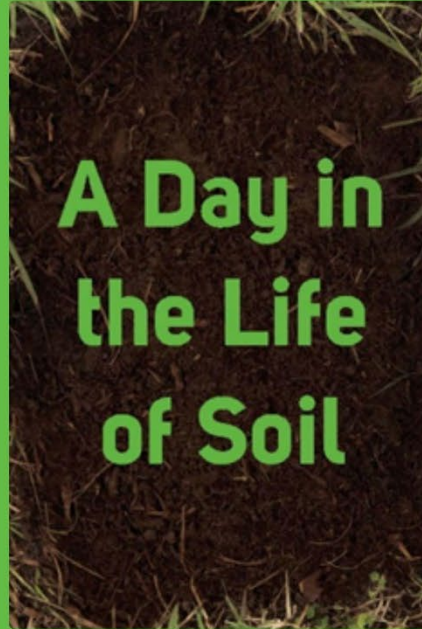
CARD #9



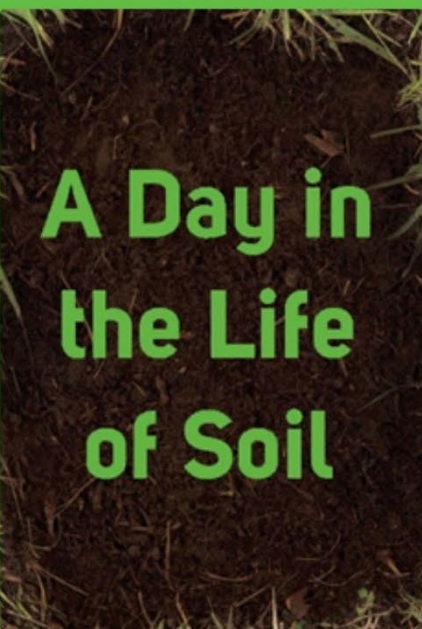
**A Day in
the Life
of Soil**



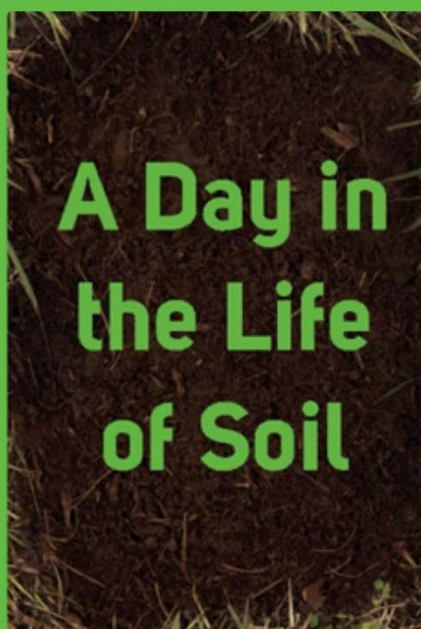
**A Day in
the Life
of Soil**



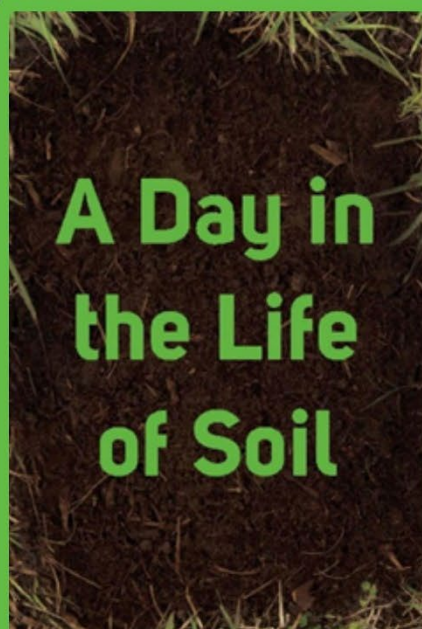
**A Day in
the Life
of Soil**



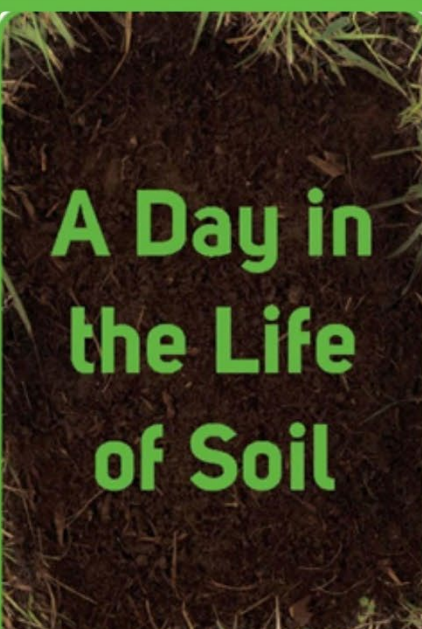
**A Day in
the Life
of Soil**



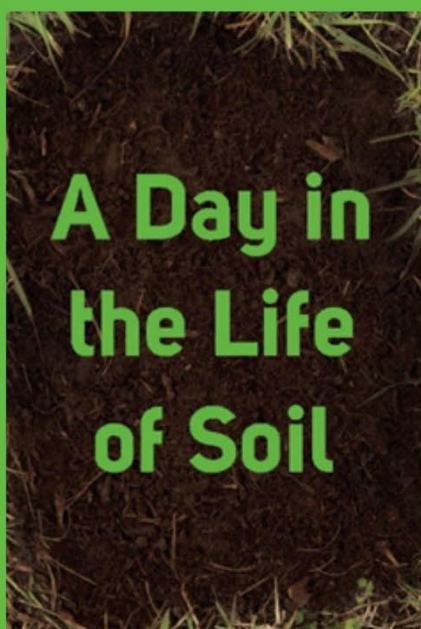
**A Day in
the Life
of Soil**



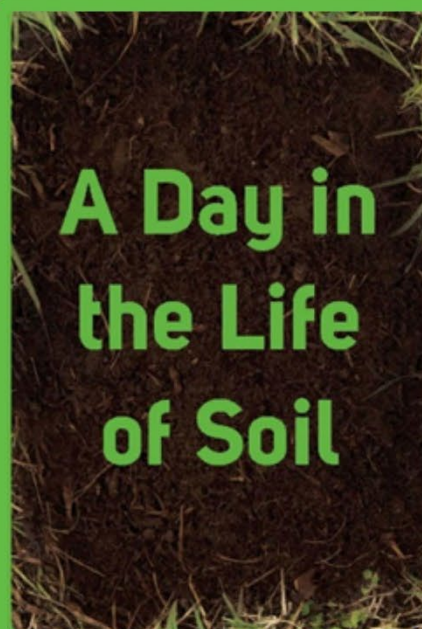
**A Day in
the Life
of Soil**



**A Day in
the Life
of Soil**

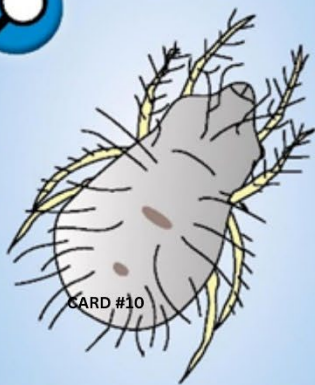


**A Day in
the Life
of Soil**



**A Day in
the Life
of Soil**

Mite



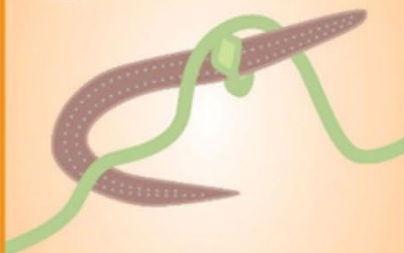
CARD #10



eats protozoa
and fungi

CARD #10

Carnivorous Fungi



eats root-feeding
nematodes

CARD #11

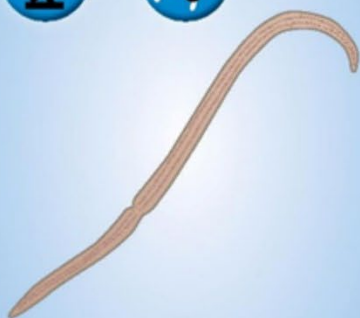
Predatory Nematode



eats protozoa

CARD #12

Root-feeding Nematode



eats plant roots

CARD #13

Pathogenic Fungi



eats plant tissue

CARD #14

Azotobacter



eats organic
matter



CARD #15

Manure



adds organic
matter to soil



CARD #16

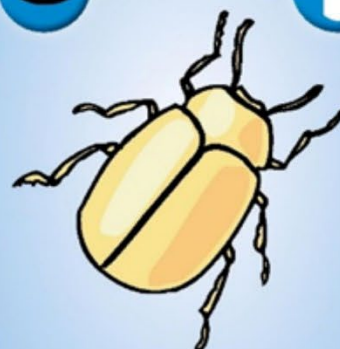
Ant



eats plants, fungi
and other animals

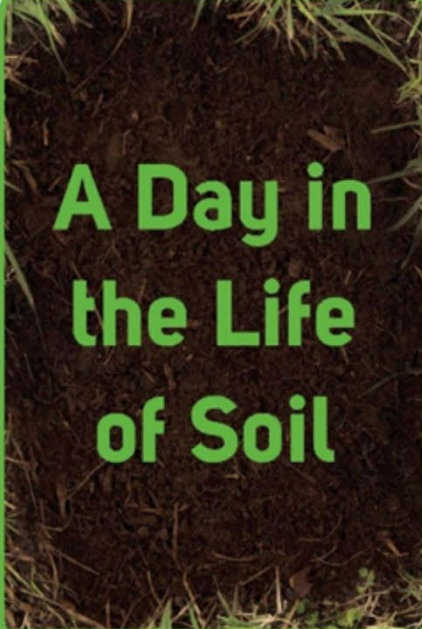
CARD #17

Beetle

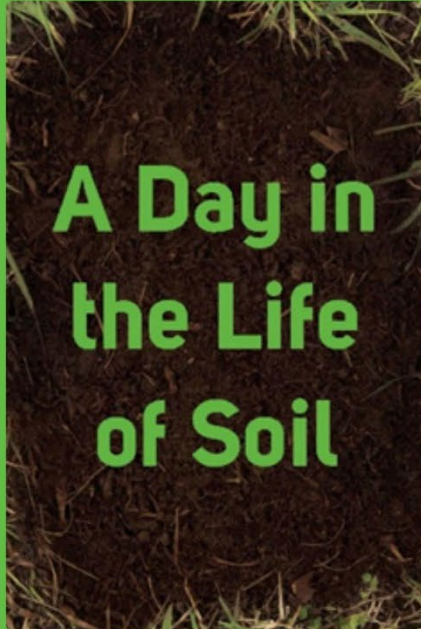


eats plants, fungi
and smaller animals

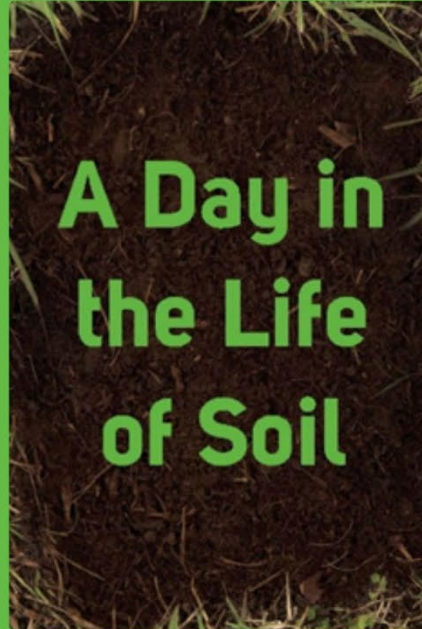
CARD #18



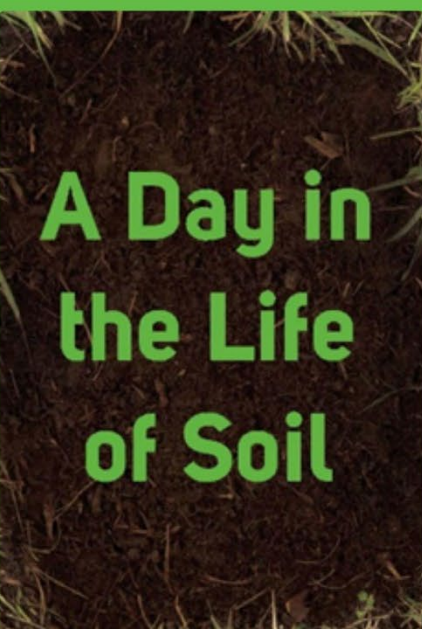
**A Day in
the Life
of Soil**



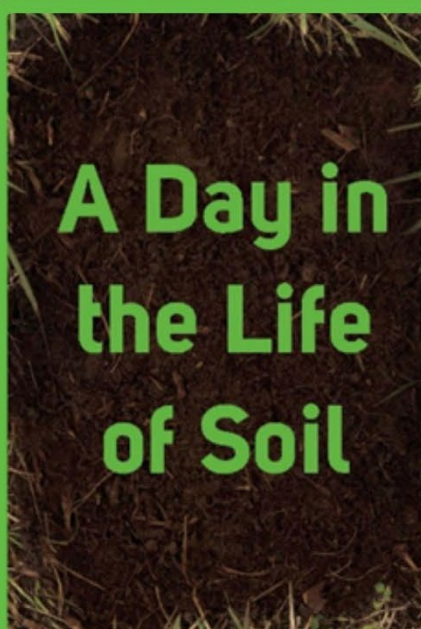
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the Life
of Soil**



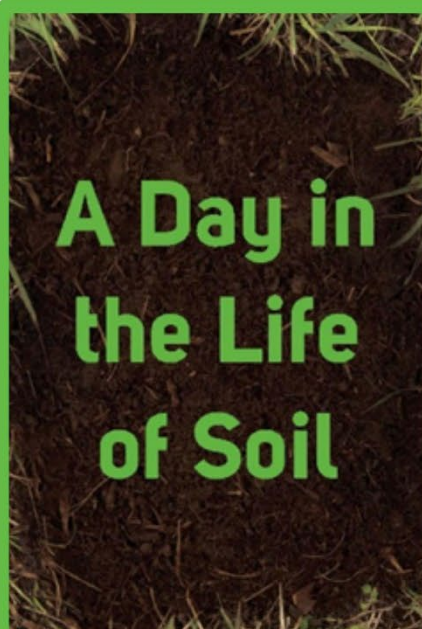
**A Day in
the Life
of Soil**



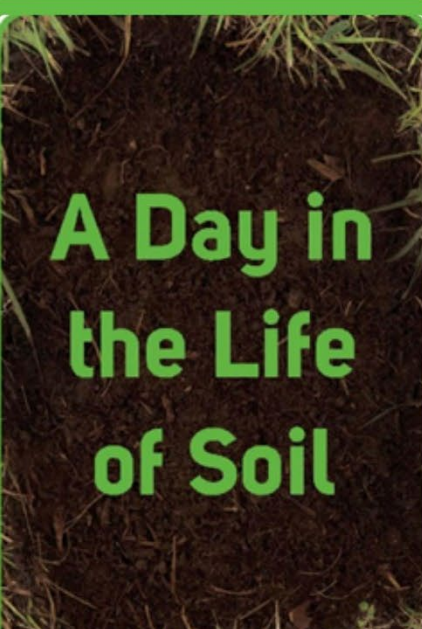
**A Day in
the Life
of Soil**



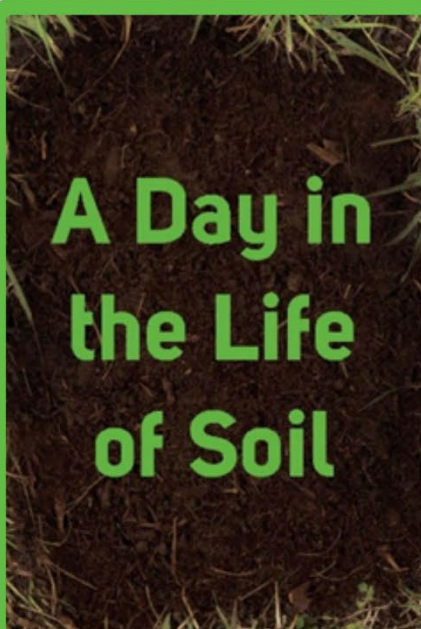
**A Day in
the Life
of Soil**



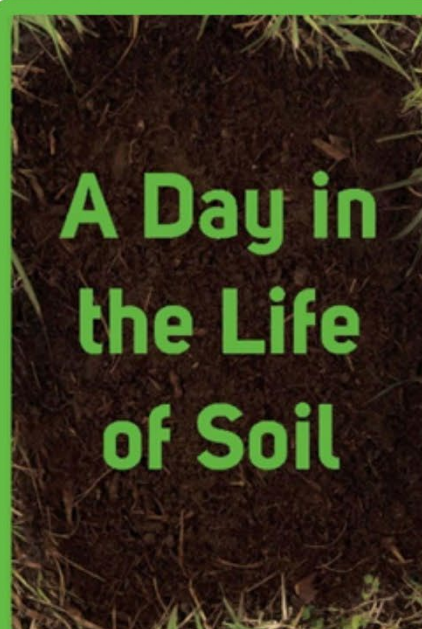
**A Day in
the Life
of Soil**



**A Day in
the Life
of Soil**



**A Day in
the Life
of Soil**



**A Day in
the Life
of Soil**

Soil food web and nutrient cycling

List all soil biota, what they consume and cycle, from 'A day in the life of soils' card game

Plant residues and exudates

Microflora (µm)

Bacteria and fungi have diverse metabolic capabilities and are the principle agents for the cycling of nutrients e.g. nitrogen, phosphorus and sulphur. They may be free living or symbiotic and active in the decomposition or build-up of organic matter. They also help in the formation of stable soil aggregates.

Microfauna (µm)

Protozoa and nematodes are a crucial link between microflora and larger fauna. They regulate the populations of bacteria and fungi and play a major role in the mineralisation of nutrients

Mesofauna (mm)

Mites and springtails (colembola) feed on litter and help fragment organic residues. They are predators of fungi and microfauna, playing an important role in regulating microbial populations and nutrient turnover.

Macrofauna (cm)

Earthworms, termites and dungbeetles, etc are important biological agents fragmenting organic residues and causing a large surface area to be exposed. They also help the formation of soil aggregates and soil pores.

Soil

functions

- Organic Matter decomposition
- Nutrient cycling
- Soil structure improvement
- Disease transmission and prevention
- Pollutant decomposition
- Soil engineering

Soil biota consists of **micro-organisms** (bacteria, fungi, archaea and algae), **soil animals** (protozoa, nematodes, mites, springtails, spiders, insects, insects, termites, potworms, earthworms) and **plants**

Practical activity- Common soil fauna identification

Suggestion- carryout practical in Spring, Autumn or Summer. In winter the low soil temperatures (<10°C), macro-organisms will not be easily observed as they become dormant or die

Background:

A healthy topsoil should contain a diverse range of macro-organisms and insects along with micro-organisms, fungi, bacteria and protozoa. These include earthworms, dung beetles, springtails, ants, nematodes, mites, potworms, millipedes and a range of other insects. Many of these are visible to the naked eye. These larger organisms are called soil invertebrates or soil organisms.

Generally, the more diversity of soil organisms, the more effective nutrient cycling and better the soil structure and disease suppression will be (some soil invertebrates feed on pathogenic bacteria and fungi).

Soil organism diversity can be assessed by counting the number of different types of organisms seen in a soil sample in a set period. Taking a sample of topsoil from an intact soil cube, the soil organisms can be observed with the naked eye or with the aid of a hand lens, or magnifying glass.

A simple way to identify an organism in the soil involves observing two characteristics – its size (less than 1mm, 1mm-5mm and bigger than 5mm) and the number of legs (none, six, eight or many) See Figure 31.

Aim: to identify and count soil invertebrates present in a soil (as an indicator of soil microbial activity and health).

Materials:

- Spade
- Tray or board
- Magnifying glass or hand lens
- Common soil organism chart (Figure 31)
- Time keeping equipment

Method:

1. Use a spade to dig a cube 20 cm x 20 cm of topsoil
2. Carefully remove the surface plant material of the sample with a spade
3. Gently spread/crumble the sample out thinly onto a tray /board
4. Allow your eyes to adjust to the soil scale and do not move the soil around for 1 minute
5. Spend at least 5 minutes observing the different types of organism's present (Use a hand lens or magnification tool if required). Occasionally gently shift and spread the sample to disturb the organisms present.
6. Count and identify the organisms present. Use the Figure 31 for assistance.

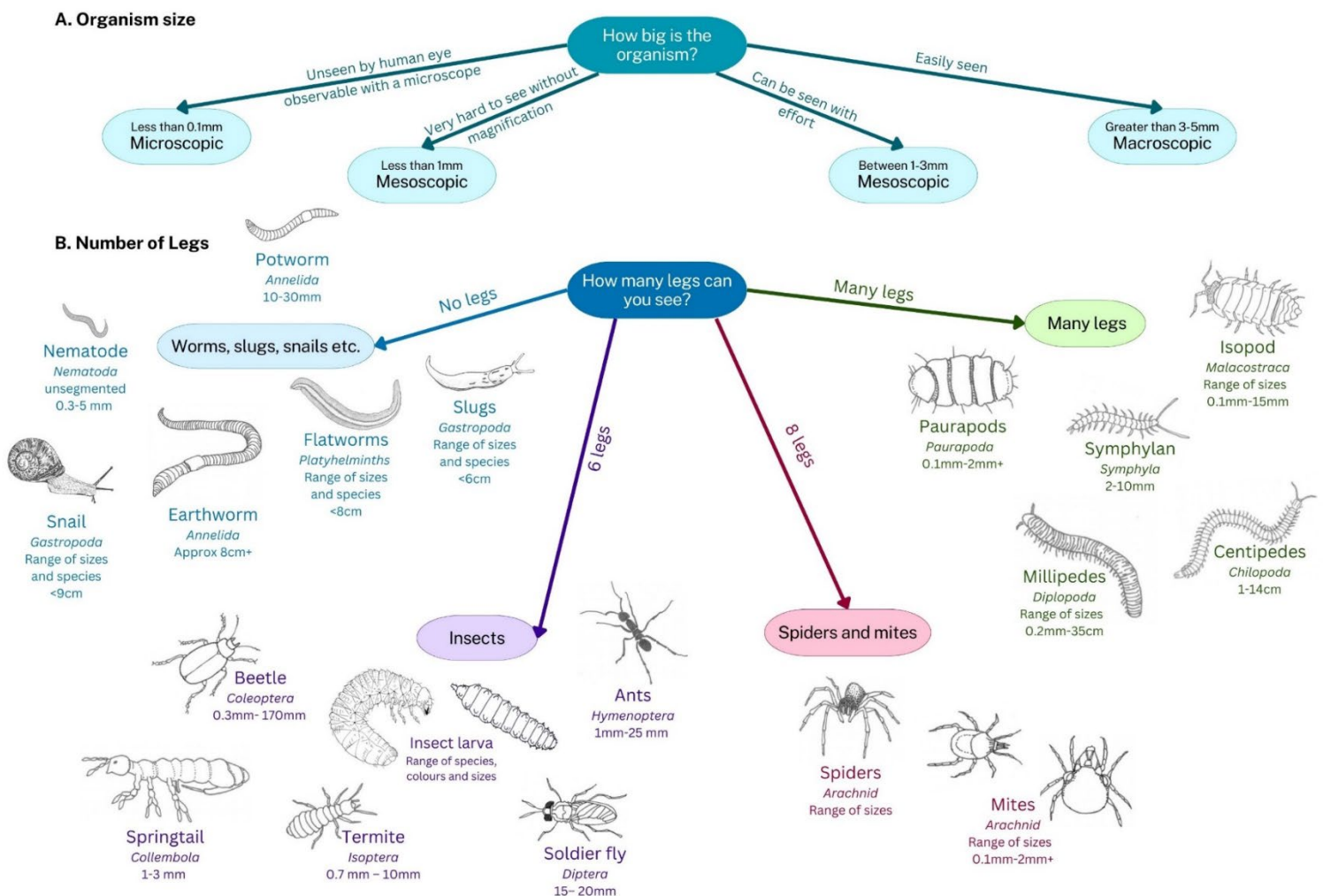
7. Score the soil's organism diversity as poor, moderate, good or very good refer to Table 7.
8. Record results into results table.
9. Complete steps 1-8 for multiple soil samples at different locations.

Table 7 Scoring soil organism diversity

Scoring soil organism diversity				
Total organism types seen	Nil seen	1-2 types	3-5 types	More than 5 types
Soil health indication	Poor	Moderate	Good	Very good

Figure 31 Common soil macro organisms

Common soil macro-organism identification guide



Results table:

Give a ✓ for each individual insect observed

Soil sample/ location:					
Worms, slugs, snails	Nematode				
	Potworm				
	Flatworm				
	Slug				
	Snail				
	Earthworm				
Insects	Termite				
	Ant				
	Springtail				
	Soldier fly				
	Beetle				
	Insect larvae				
Spiders and mites	Mite				
	Spider				
Many legs	Paurapod				
	Isopod				
	Symphylan				
	Millipede				
	Centipede				
Other organisms					
Total number of soil organisms					
Number of different <i>TYPES</i> of organisms					
Soil organism diversity (poor, moderate, good, very good)					

Add more columns as required

Nutrient cycles

Decomposers (bacteria, fungi, protozoan) and fauna are essential to all nutrient cycles on earth. The Nitrogen and Carbon cycles will be explored in the following.

Nitrogen cycle

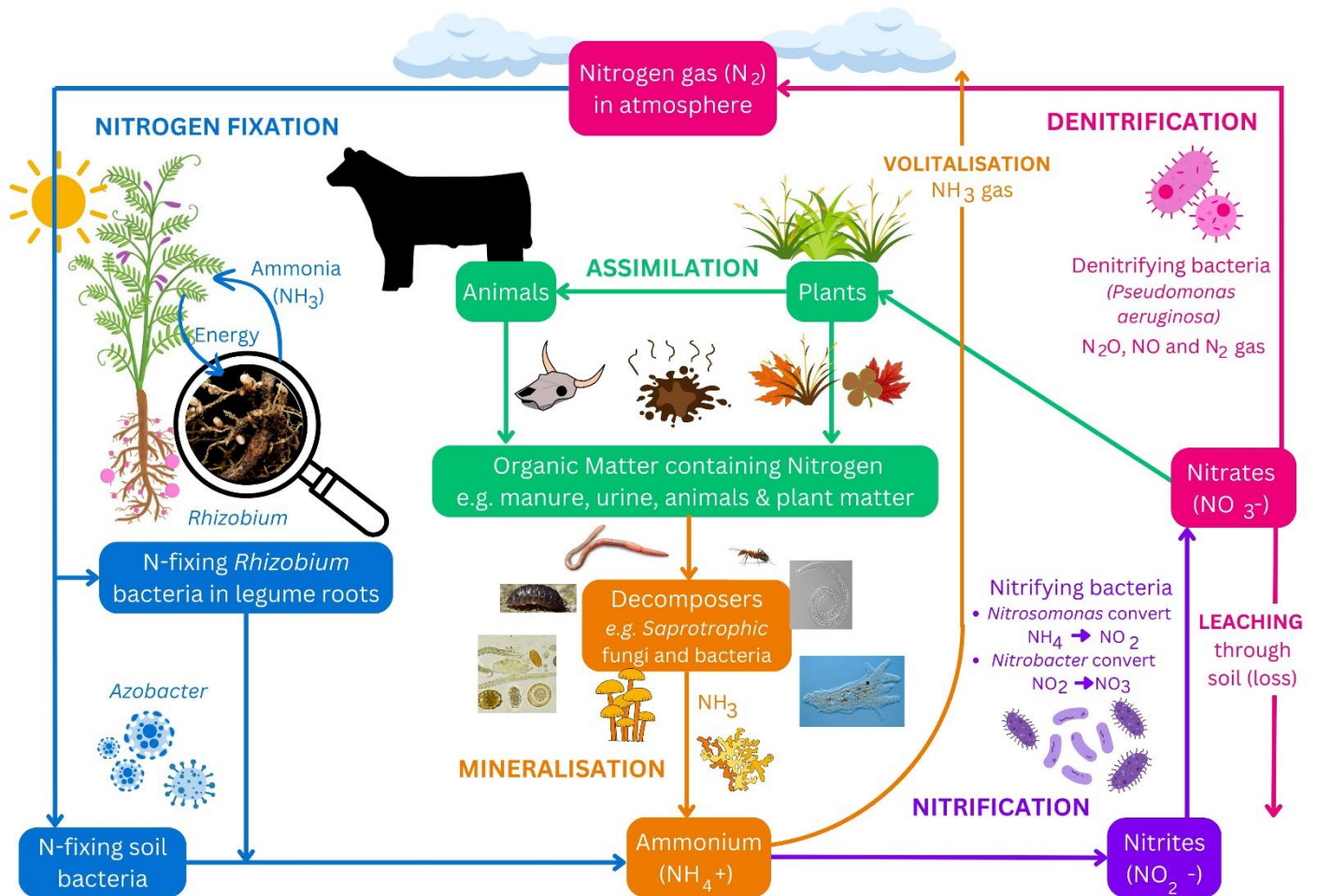


Figure 32 The Nitrogen cycle

The seven key stages of the nitrogen cycle:

- Nitrogen fixation
- Mineralisation (ammonification)
- Volatilisation
- Nitrification
- Assimilation
- Immobilisation
- Leaching
- Denitrification

Nitrogen fixation: Plants cannot use atmospheric nitrogen (N_2) until it has been fixed and converted to a plant available form. The majority of nitrogen fixation is performed by bacteria, either free-living (e.g. *Azotobacter*) or symbiotic (e.g. *Rhizobium*). *Rhizobium* bacteria infect and live in the root nodules of legume plants (e.g. lucerne, clover, peas etc). They produce a nitrogenase enzyme that combines the gaseous, atmospheric N_2 with hydrogen (H_2 gas) to produce ammonia (NH_3). Ammonia (NH_3) becomes ammonium (NH_4) when mixed with water in soil solution, and this can be used by plants and stored in the soil.

Rhizobium bacteria receive carbohydrates from the legumes (from photosynthesis) which they use as an energy source. In return the bacteria produce and supply ammonia which plants use as an energy source. This is a *mutualistic symbiotic relationship*.



Figure 33 Pink *Rhizobium* nodules in legume roots

Nitrogen can also be fixed artificially using the Haber- Bosch process to make nitrogenous fertiliser. A small amount of nitrogen can also be fixed when lightning provides the energy needed for N_2 to react with oxygen, producing nitrogen oxide (NO), and nitrogen dioxide (NO_2). These forms of nitrogen enter the soil through rain or snow.

Mineralisation (ammonification): This stage takes place in the soil. It involves the breakdown of nitrogen in organic matter (plant matter, manure and dead organisms- plants, animals, microbes etc). Mineralisation occurs when microbes (*saprotrophic* bacteria and fungi) break down and decompose organic matter and convert the locked-up nitrogen into a plant available form of nitrogen (NH_3).

Mineralisation rates (microbial activity) are controlled by temperature, moisture and soil oxygen (bulk density and porosity).

The first form of nitrogen produced by the process of mineralisation is ammonia (NH_3). The NH_3 in the soil then reacts with soil water to form ammonium (NH_4). This ammonium is held in the soil and is available to plants (non-legumes) that do not get nitrogen through the symbiotic nitrogen fixing relationship described above.

Volatilisation:

Volatilisation is the loss of N through the conversion of ammonium (NH_4) to ammonia gas (NH_3), which is released to the atmosphere. Volatilisation losses increase at higher soil pH and conditions that favour evaporation (e.g. hot and windy).

Volatilisation losses are higher for manures and urea fertilisers that are surface-applied and not incorporated (by tillage or by rain) into the soil. Manure contains N in two main forms: ammonium and organic N. If manure is incorporated within one day, 65% of the ammonium N is retained; when incorporated after 5 days the ammonium N will have been

lost through volatilisation. Organic N in manure is not lost through volatilisation, but it takes time to mineralise and become available to plants.

Nitrification: The ammonium (NH_4) produced from nitrogen fixation process, is further broken down by bacteria into nitrites and nitrates, which are easier for plants to use for growth (and hence the dominant nitrogen sources for plants). Soil micro-organisms also use nitrates.

- **Step 1** - Ammonium ions (NH_4^+) are converted to nitrites (NO_2^-) by *Nitrosomonas* bacteria
- **Step 2** - Nitrite ions (NO_2^-) are converted to Nitrates (NO_3^-) by *Nitrobacter* bacteria

These reactions require oxygen and hence soil must be well aerated to ensure a rich supply of nitrites and nitrates

Nitrate is the most plant available form of N but is also highly susceptible to leaching.

Nitrification is most rapid when soil is warm (19- 30°C), moist and well-aerated, but is virtually halted below 5°C and above 50°C.

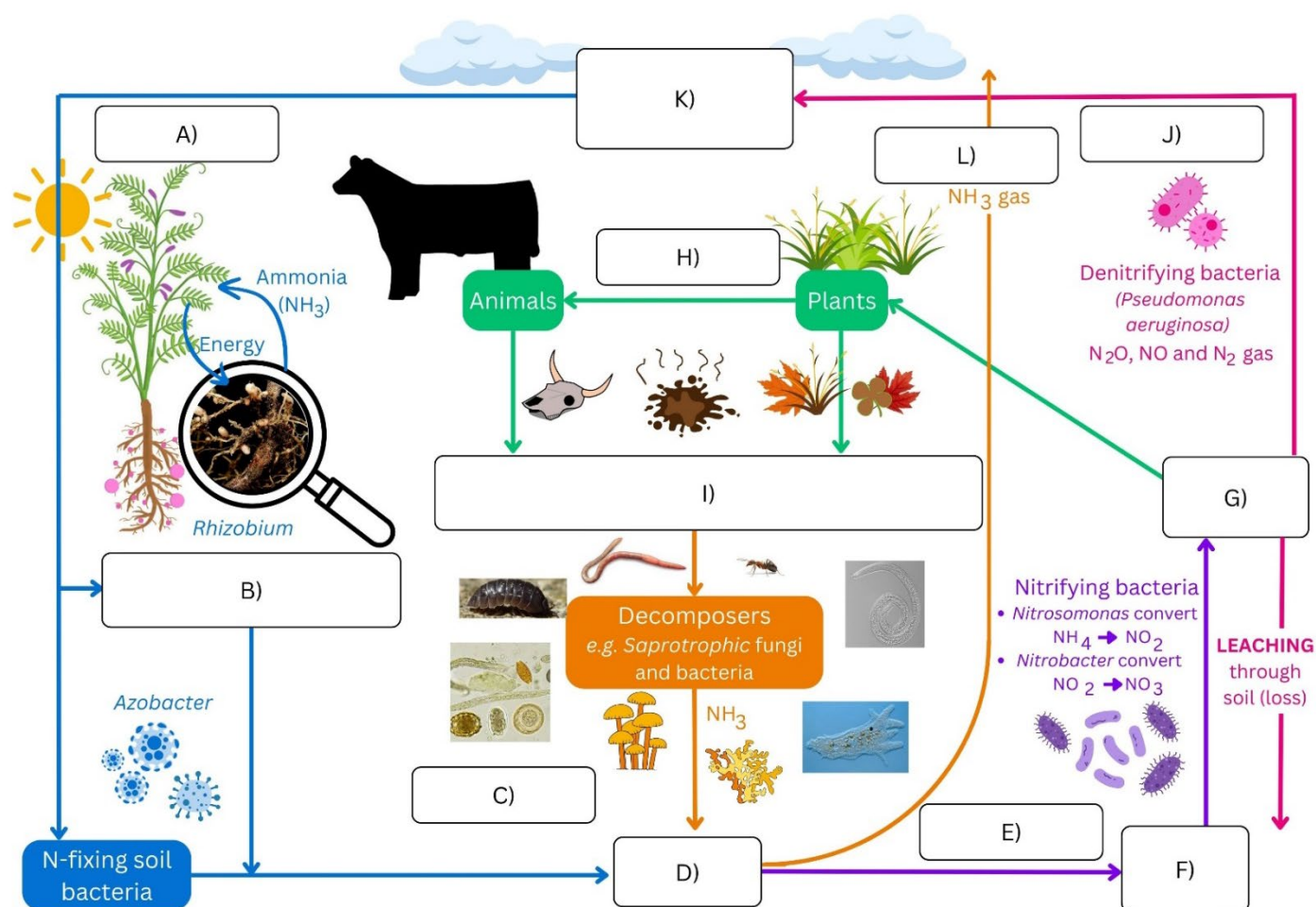
Assimilation: Is the process by which nitrate (NO_3^-) and ammonia (NH_4^+) form organic tissue compounds e.g. DNA, chloroplasts, amino acids etc. Nitrogen is then passed on throughout food chains.

Immobilisation: The reverse of mineralisation. Mineralisation and immobilisation together control the amount of nitrogen available to plants. All living things require N, so microorganisms in the soil compete with plants for N. When microorganisms consume ammonium (NH_4) and nitrate (NO_3), these forms of nitrogen are no longer available to the plants and may cause nitrogen deficiency. Immobilisation is important because it helps control and balance the amount of nitrogen in the soils by tying it up, or immobilising the nitrogen, in microorganisms. Immobilisation only locks up N temporarily. When the microorganisms die, the organic N contained in their cells is converted by mineralisation and nitrification to plant available nitrate.

Leaching: is the loss of N that is a threat to water quality (eutrophication). Soil particles do not retain nitrate (NO_3^-) very well because both are negatively charged. As a result, nitrate easily moves with water in the soil. The rate of leaching depends on soil drainage, rainfall, amount of nitrate present in the soil, and crop uptake. Well-drained soils, unexpected low crop yield, high N inputs (especially outside of the growing season) and high rainfall are all conditions that increase the potential for nitrate leaching.

Denitrification: Denitrification completes the nitrogen cycle. Here, nitrate (NO_3) is converted back into nitrogen gas (N_2) as well as nitrous oxide (N_2O) and nitric oxide (NO) gases. This stage of the nitrogen cycle is anaerobic and performed by denitrifying bacteria e.g. *Pseudomonas aeruginosa* and *Thiobacillus*. Denitrification occurs in waterlogged soils. Denitrification reduces the amount of nitrogen available to the plants.

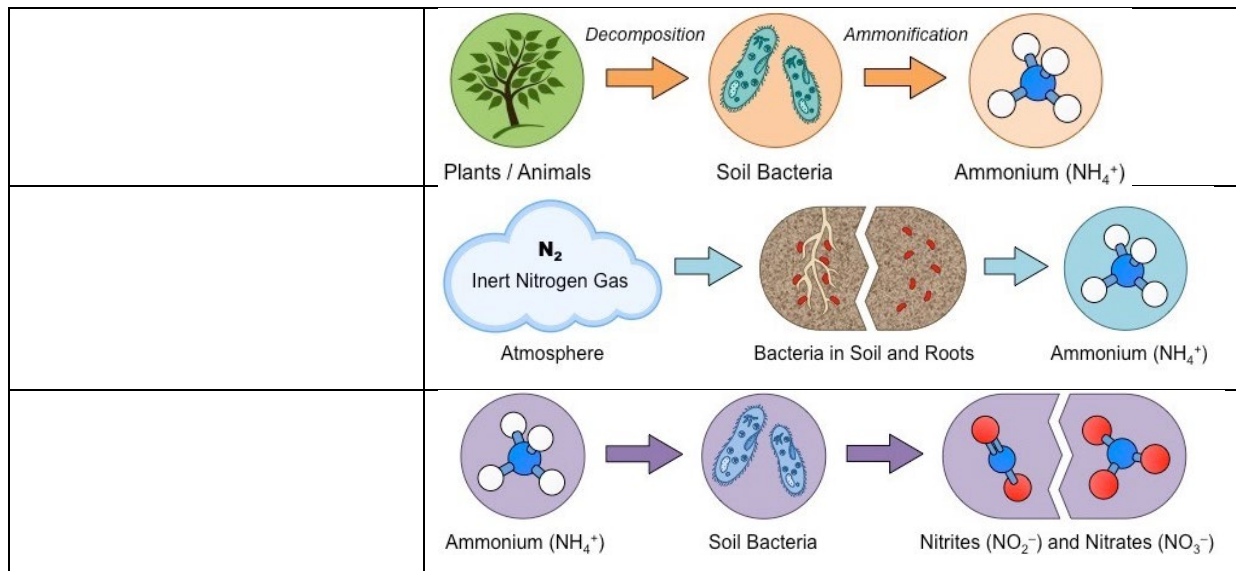
48. Complete the table to label the processes in the Nitrogen cycle



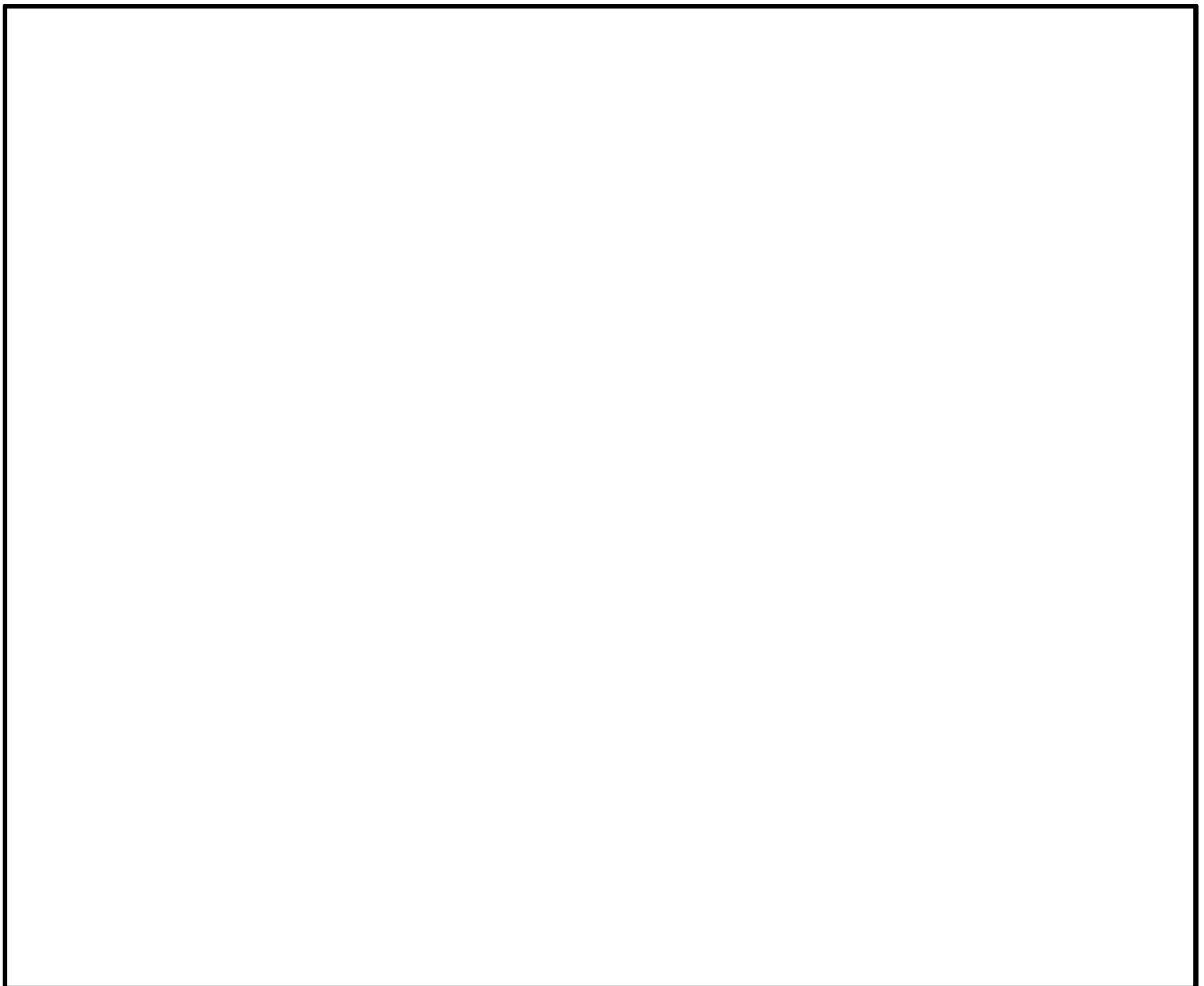
Nitrogen cycle processes			
A		G	
B		H	
C		I	
D		J	
E		K	
F		L	

49. Identify the name of the following processes illustrated from the Nitrogen cycle.
For each process list micro-organisms involved.

Nitrogen cycle process	Image
	Nitrites (NO_2^-) and Nitrates (NO_3^-) → Soil Bacteria → Inert Nitrogen Gas (N_2) Atmosphere



50. Construct and label a simplified diagram of the nitrogen cycle.



Carbon cycle

Carbon is an essential chemical element and component to all life on earth. It helps to regulate the Earth's temperature, makes all life possible; is a key ingredient in food, and is a major source of fossil fuel energy supplies.

Most of earth's carbon is stored in rocks and sediments (geosphere), the rest is found in the oceans (hydrosphere), soils (pedosphere), living things (biosphere) and the atmosphere. The term "carbon sinks" is used to refer to places where carbon is stored away from the atmosphere e.g. ocean, soils and rock.

The amount of carbon on Earth stays the same and is continuously cycled. The carbon cycle shows how carbon moves and is exchanged between the different spheres of the Earth. The four spheres are the atmosphere (air), lithosphere (earth's crust), hydrosphere (water / oceans) and biosphere (living things). Carbon is exchanged between a variety of forms, including:

- Atmospheric gases – mainly carbon dioxide (CO₂), but also methane (CH₄)
- Oceanic carbonates – including bicarbonates dissolved in the water and calcium carbonate in corals and shells
- Organic materials – including the carbohydrates, lipids, DNA and proteins found in all living things
- Non-living materials – such as fossil fuels (coal, crude oil, natural gas) and carbon rich peat soils, limestone etc.

Carbon flows between each form in the carbon cycle, which has Slow and Fast components. Any change in the cycle that shifts carbon out of one form puts more carbon in the other forms. Changes that put carbon gases into the atmosphere result in warmer temperatures on Earth.

Over the long term, the carbon cycle naturally maintains a balance that prevents all of Earth's carbon from entering the atmosphere or from being stored entirely in rocks. This balance helps keep Earth's temperature relatively stable, like a thermostat.

Humans have a huge effect on the carbon cycle when we burn wood, fossil fuels (such as oil, coal, and natural gas), and other forms of carbon. This action releases the stored carbon into the atmosphere, where it becomes a greenhouse gas. Greenhouse gases in the atmosphere absorb and release heat.

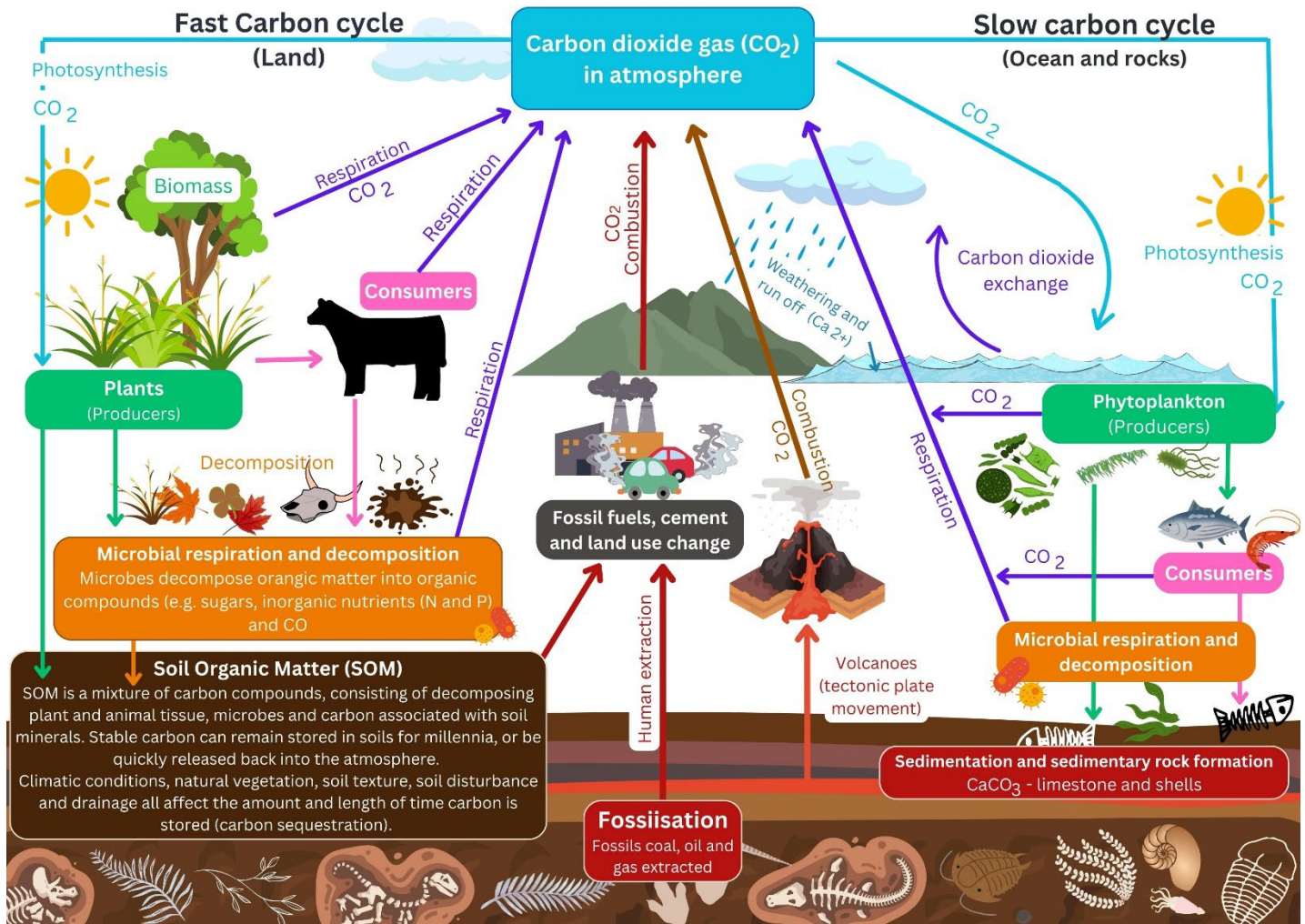


Figure 34 The Carbon cycle

Slow Carbon Cycle (oceans, rocks and weathering)

Through a series of chemical reactions and tectonic activity, carbon takes between 100-200 million years to move between rocks, soil, ocean, and atmosphere in the slow carbon cycle.

The movement of carbon from the atmosphere to the lithosphere (rocks) begins with rain. Atmospheric carbon combines with water to form a weak acid (carbonic acid), that falls to the surface in rain. The acid dissolves rocks, a process called chemical weathering — and releases calcium, magnesium, potassium, or sodium ions. Rivers carry the ions to the ocean.

In the ocean, the calcium ions combine with bicarbonate ions to form calcium carbonate. In the modern ocean, most of the calcium carbonate is made by shell-building (calcifying) organisms (such as corals) and plankton. After the organisms die, they sink to the seafloor. Over time, layers of shells and sediment are cemented together and turn to rock, storing the carbon in stone, limestone and its derivatives.

Only 80 percent of carbon-containing rock is made this way. The remaining 20 percent contain carbon from living things (organic carbon) that have been embedded in layers of mud (sediment). Heat and pressure compress the sediment and carbon over millions of years, forming sedimentary rock such as shale. In special cases, when dead plant matter builds up faster than it can decay, layers of organic carbon become oil, coal, or natural gas instead of sedimentary rock like shale.

The slow cycle returns carbon to the atmosphere through volcanoes, (caused by tectonic plate movement). When volcanoes erupt, they vent the carbon dioxide (CO₂) gas to the atmosphere and cover the land with fresh silicate rock to begin the cycle again. At present, volcanoes emit between 130 and 380 million metric tons of carbon dioxide per year. For comparison, humans emit about 30 billion tons of carbon dioxide per year by burning fossil fuels; 100–300 times more than volcanoes.

The slow carbon cycle also includes a faster component the ocean. At the surface, where air meets water, carbon dioxide gas dissolves in and out of the ocean in a steady exchange with the atmosphere. Once in the ocean, carbon dioxide gas reacts with water molecules to release hydrogen, making the ocean more acidic. The hydrogen reacts with carbonate from rock weathering to produce bicarbonate ions.

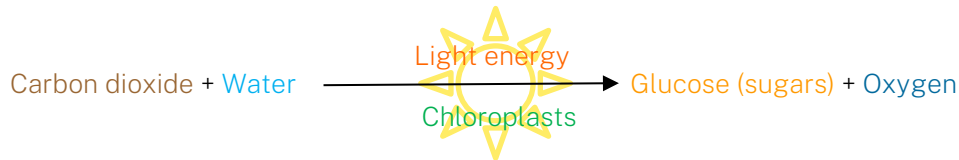
Before the industrial age, the ocean vented carbon dioxide to the atmosphere in balance with the carbon the ocean received during rock weathering. However, since carbon concentrations in the atmosphere have increased, the ocean now takes more carbon from the atmosphere than it releases. It will take millions of years for the cycle to find equilibrium. (Find out more at [The Oceans Carbon Balance, NASA Earth Observatory](#)).

Fast Carbon Cycle (land and agriculture)

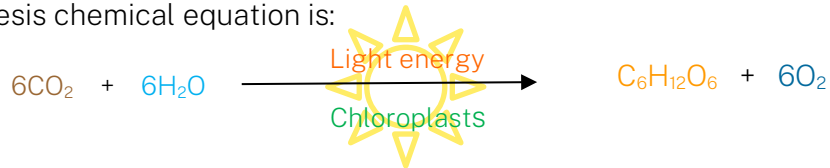
The Fast carbon cycle is essential to agricultural production. The largest source of carbon on land is found in the soil and includes both organic and inorganic forms. Exports of carbon from the C cycle on land have greatly increased by human activities. Mining and use of fossil fuels, clearing of vegetation and soil disturbance have added CO₂ to the atmosphere at rates far higher than it can be naturally cycled through both land and ocean Carbon cycles.

The time it takes carbon to move through the fast carbon cycle is measurable in decades. The fast carbon cycle involves the movement of carbon through life forms on land.

Plants and phytoplankton (producers) are the main components of the fast carbon cycle. Phytoplankton (algae and photosynthetic microorganisms in water) and plants take carbon dioxide from the atmosphere by absorbing it into their cells. Using energy from the Sun, both plants and plankton combine carbon dioxide (CO₂) and water to form sugar and oxygen. The photosynthesis word equation is:



The photosynthesis chemical equation is:



CO_2 is converted to energy rich organic molecules (sugars/ carbohydrates) which are either stored in all cells e.g. in plant stems, leaves and roots or respired releasing CO_2 . Consumers cannot synthesise their own organic carbon energy and instead gain carbon compounds by feeding on plant material. This results in the movement of carbon through food chains.

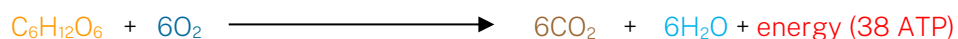
Four things can happen to cycle carbon from a plant and return it to the atmosphere, but all involve the same chemical reaction, respiration.

- Plants break down the sugar from photosynthesis to obtain energy for growth (respiration).
- Animals (consumers) eat the plants or phytoplankton and break down the plant sugar to obtain energy (respiration). Consumers can only obtain energy from feeding. Most of the carbon digested by animals is respired back into the atmosphere as CO_2 , however a small amount of the carbon that the animal consumes is turned into methane (CH_4) and belched out as a gas into the atmosphere.
- Plants and plankton die and decay and are decomposed and consumed by microorganisms and invertebrates which also die and decay, cycling the carbon (respiration).
- Fire consumes plants, and the combustion reaction is also respiration.

The respiration word equation is:



The respiration chemical equation is:



Respiration is the reverse of photosynthesis without the energy release.

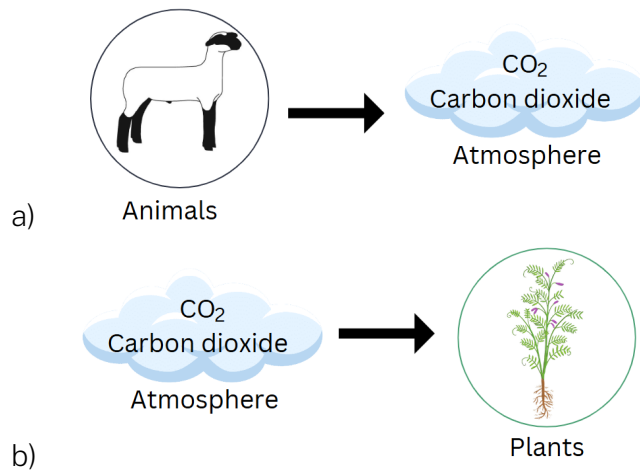
In all four processes, the carbon dioxide released in the reaction usually ends up in the atmosphere.

Carbon that the plant doesn't need for growth is released as exudates through the roots to feed soil organisms. Through this process, carbon dioxide is transformed into stable carbon-containing molecules that are stored in the soil instead of the atmosphere. This is Soil organic matter (SOM). Some of the carbon is stored as organic matter in the topsoil,

where it is considered active carbon. Perennial plant species store (sequester) more carbon for longer periods of time compared to short-lived annual plants.

Carbon-based organic matter helps give soil its structure, its ability to retain water, and its fertility, and soil can hold huge amounts of it. Agriculture holds a huge place in reducing carbon dioxide levels in the atmosphere by sequestering it into the soil by sustainable management practices, such as cover cropping, green manuring, reduced tillage, maximising ground cover, growing perennial species and minimising stubble burning.

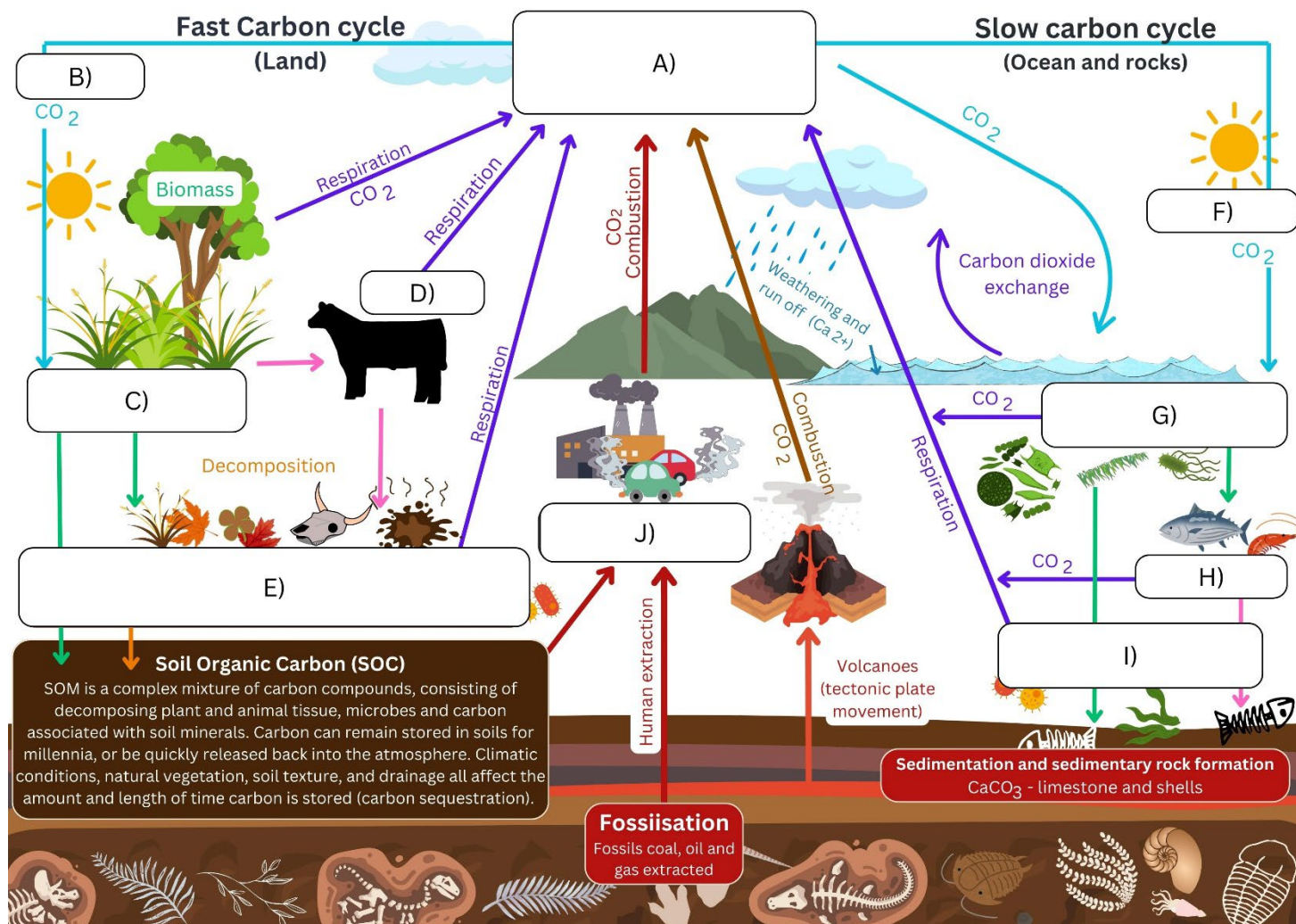
51. Identify the name of the process being represent in the following diagrams.



52. Complete the table to write the word and chemical equations for photosynthesis and respiration.

Process	Photosynthesis	Respiration
Word equation		
Chemical equation		

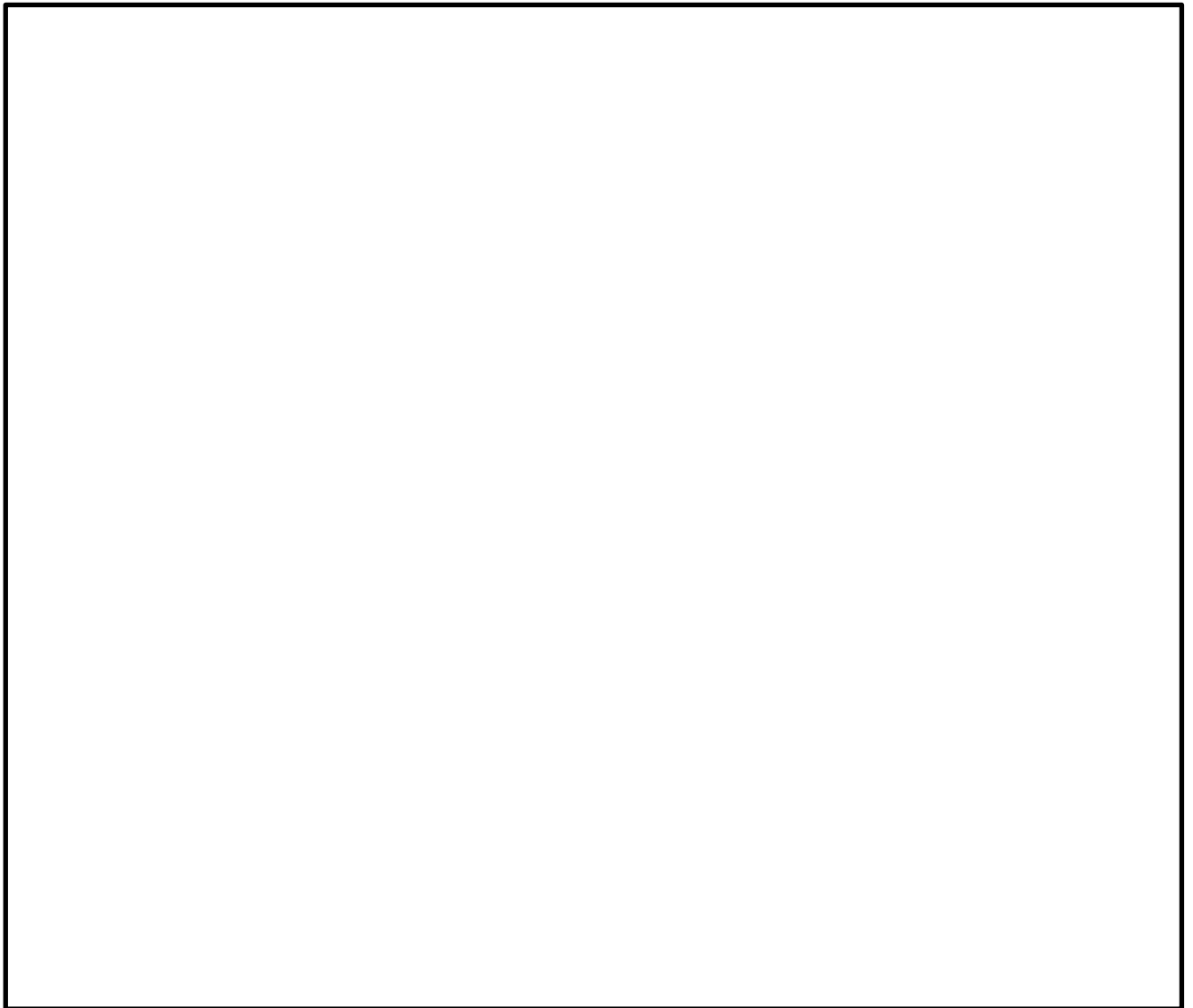
53. Complete the table to label the Carbon cycle



Carbon cycle			
A		F	
B		G	
C		H	
D		I	
E		J	

54. Explain the importance of decomposers in the carbon cycle.

55. Construct a simple, labelled diagram of the carbon cycle (land, fast carbon cycle).



Sustainable soil management

Land degradation issues

Land degradation is the decline in quality and quantity of a soil due to changes in the soil's hydrological, biological, chemical and physical properties due to human impact.

Land degradation has both on-site and off-site effects. On-site effects are the lowering of the productive capacity of the land, causing either lower outputs (crop yields, livestock yields) or the need for increased inputs. Examples of off-site effects include sedimentation of waterways, eutrophication of waterways soil and ecosystem disruption.

Land degradation is a global issue for several reasons but most significantly because productive land is finite, and one of several resources where less of it threatens our capacity to feed a growing world population estimated to be over 9 billion by 2050.

In Australia, about two thirds of agricultural land is degraded. The main types of land degradation are soil erosion (water and wind); soil salinity; soil sodicity; soil acidity and soil contamination; soil nutrient loss and soil structure decline.

Watch [American dustbowl- A man-made ecological disaster](#); to learn lessons from human-induced land degradation in America in the 1930's.



The following briefly outlines Australian land degradation issues:

- Soil erosion
- Soil acidity
- Soil sodicity
- Dryland salinity
- Soil fertility decline

Soil erosion

Soil erosion is the detachment and movement of soil particles by water, wind and gravity, As well as sediments entering waterways and dams, eroded soil carries large amounts of nutrients and organic matter which can pollute surface water (eutrophication) and reduce the productivity of paddocks. It is difficult and mostly uneconomic to move soil back to its original position. Emphasis should be on soil conservation, not remediation. There are five major forms of erosion: rill, gully, sheet, streambank and tunnel erosion.

Types of erosion



Rill erosion



Gully erosion



Sheet erosion



Stream bank erosion



Tunnel erosion

Figure 35 Types of erosion

The loss of 1 millimetre of topsoil from a paddock is equivalent to approximately 14 tonnes of soil removed per hectare. This same 1 millimetre of soil can take up to 3,000 years to form from bedrock.

Reducing soil erosion will:

- minimise the loss of valuable topsoil and nutrients, e.g. most soil phosphorus is in the top 5 millimetres of soil
- retain nutrients and organic matter in the topsoil promoting biological activity
- improve water quality in farm dams and watercourses by restricting movement of sediments and nutrients into water supplies

Best practice targets:

- Maintain more than 80 percent groundcover
- Manage erosion risk
- Fence off and remediate erosion sites

Soil acidity

A soil is acid when it has a pH below 7 (neutral). Soils with pH below 5.5 have issues with nutrient lock-up and toxicities (availability). Soil acidification is a major soil degradation issue in many Australian soils. Acidification is often a subtle process, developing slowly.

Potential indicators that soil pH is falling to critical levels include:

- reduced yields
- decline of acid sensitive species (legumes)
- lack of response to fertilisers
- aluminium toxicity.

Soil acidification may lead to a decline in groundcover and decreased farm productivity. It increases the risk of erosion and pollution of waterways. Australian soils are highly weathered and naturally acidic (pH less than 5.5). However, soil acidification has increased due to agriculture. Once the soil surface acidifies, acidity can move to depth where it is difficult to manage and reverse.

The main causes of agriculturally induced acidity are:

- Nitrate leaching below the root zone. This can happen when nitrogen fixed by legumes or nitrate fertiliser is not used by the non-legume plants present (e.g. clover dominant pastures, annual pastures, or where there has been heavy use of nitrogenous fertilisers)
- Removal of agricultural product - most agricultural products (e.g. meat, fibre, hay) are slightly alkaline. Removing these products acidifies soil. For example, lucerne hay cutting is one of the most acidifying practices
- Type of nitrogenous fertiliser - the most acidifying fertilisers are ammonium sulfate and mono-ammonium phosphate (MAP), followed by di-ammonium phosphate (DAP). Less acidifying fertilisers include: urea, ammonium nitrate and anhydrous ammonia.

A soil pH between 5.0 and 6.5 is best for most agricultural plants. If the pH drops below 5.0, plants that are highly sensitive to acidity, (such as lucerne and barley), are adversely affected. Plants that are more tolerant of acidity continue to grow normally until the pH falls below 4.6. Below pH 4.4 most introduced plants suffer a severe loss in production. Note: Many native plants have adapted to pH below 4.4 and should not be removed.

Acid soils can lower productivity due to:

- Aluminium and manganese toxicity which stunt plant root development (aluminium becomes increasingly available to plants as soil pH drops below 4.6)
- Reduced vigour and number of Rhizobia species on legume roots which fix nitrogen in the soil
- Loss of, or inability to establish, acid sensitive pasture species such as lucerne or Phalaris
- Increased weed invasion
- Declining pasture vigour

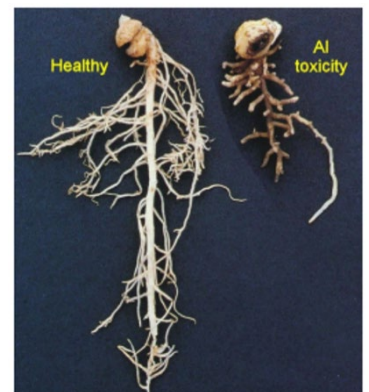


Figure 36 Al toxicity in field pea roots (legume) Source: [Excessive Aluminium in soil](#)

- Reduced solubility and availability of nutrients such as molybdenum, potassium, phosphorus, magnesium and calcium.

It is important to remember that while acidity may affect plant growth, you also need to consider other limiting factors, such as plant nutrient availability. A soil test is the best way to determine the most limiting factor affecting plant growth.

Best practice targets:

- Maintain or increase topsoil $\text{pH}_{(\text{CaCl}_2)}$ above 5.5
- Minimise the rate of further acidification
- Maintain or establish pasture species suited to your soils

Soil sodicity

Soil sodicity is a major cause of land degradation, resulting in poor pasture growth, loss of groundcover, waterlogging and gully or tunnel erosion. In Australia, about 30 percent of agricultural land is sodic. This is about five times the area of land estimated to be saline.

A sodic soil has high concentrations of sodium (Na^+) (more than or equal to 6 percent of the Cation Exchange Capacity). The sodium ions attach to clay particles and make them disperse and unstable.

Sodicity is often confused with salinity. Sodicity and salinity are both undesirable but have opposite effects on soil structure.

- sodium disrupts soil structure, causing soils to disperse if disturbed
- salt in saline soils prevents dispersion but reduces the ability of plants to take up water.

Sodicity can occur at any depth in the soil but is most common in the subsoil. Signs of sodicity may be more or less obvious depending on where it occurs in the soil profile (i.e. topsoil, subsoil or both), the climate (particularly rainfall), and slope (hilly country may be more susceptible to tunnel erosion).

Sodicity is caused by the presence of sodium attached to clay in soil. When sodium makes up more than 6 percent of exchangeable cations (positively charged ions) bound to clay particles, structural problems can occur, and the soil is said to be sodic. This is worse when soil organic matter levels are low. Soils can be naturally sodic due to a combination of climate and geology. Excess sodium can accumulate where chlorine has leached out of previously saline soils over tens or thousands of years or during soil formation from granitic and some sedimentary rocks.

Typical signs of a soil sodicity problem in the rooting zone of pastures include:

- waterlogging caused by poor structure and drainage
- increased runoff and poor water storage
- compacted soil and surface crusting
- poor emergence of pastures and crops
- loss of groundcover
- soil erosion.

Best practice targets:

- Know where the sodic soils are on your farm
- Retain topsoil and minimise disturbance and exposure of sodic soils
- Maintain more than 80 percent groundcover to improve soil structure and increase soil organic matter.

Dryland salinity

Dryland salinity is the accumulation of salt in surface soil in non-irrigated areas, usually due to rising groundwater tables. As the soil surface dries out, dissolved salts are left behind. These salts reduce the ability of plants to extract water from soil, resulting in the loss of pasture and groundcover, and subsequent erosion.

Salt is a natural part of the Australian landscape. In the last two hundred years, some land management practices have increased the extent and the effects of salinity.

All plants transpire (the passive process of water movement through a plant and its evaporation from stomates on leaves). Removing vegetation from landscapes, particularly trees and deep-rooted trees, shrubs, and perennial grasses, is a major cause of rising groundwater tables and salinity. Groundwater tables rise when water infiltrating the soil moves beyond the reach of plant roots ('recharge'). Sometimes the water table will 'discharge' above the ground surface (seen as a salt scald), at a point lower in the landscape or at the junction between two different types of rock. See Figure 37. If the groundwater is saline, the discharge will bring salts to the soil surface. Salt discharge also occurs through capillary action in soil pores as the water table rises close to the soil surface.



Figure 37 Salt scald, Source [Dryland salinity in Western Australia](#)

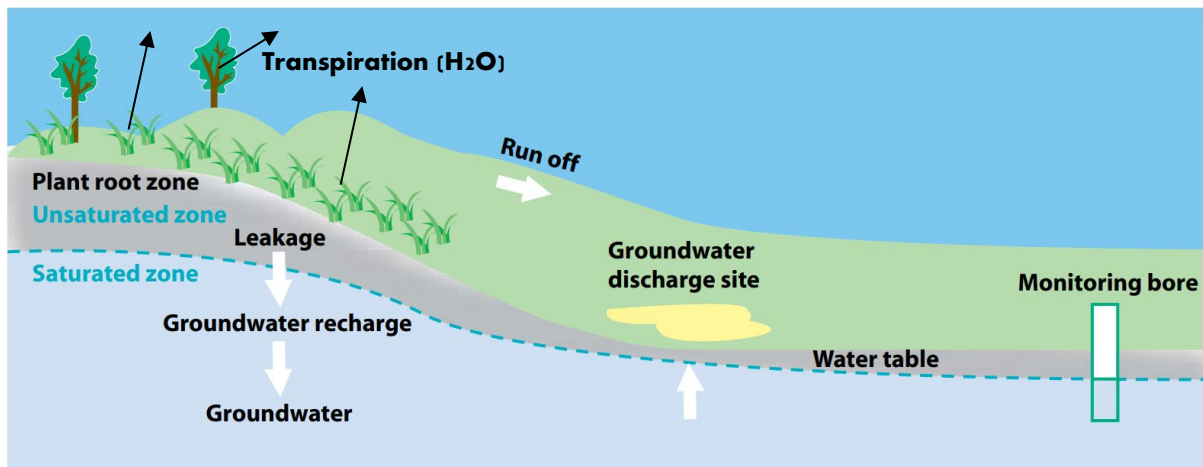


Figure 38 The groundwater system, demonstrating recharge and discharge. Source: NSW DPI Salinity Glovebox Guide 2005.

Salinity becomes a problem when high levels of salts accumulate in the root zone to reduce plant growth. Excess salts in the root zone stop plant roots from withdrawing water from surrounding soil. This lowers the amount of water available to the plant, regardless of the amount of water in the root zone. As a result, there is:

- Loss of groundcover and pasture production
- Salt deposits (scalds) on the soil surface and plant toxicity
- Increased soil erosion
- Tree death
- Increased salt concentrations in dams, streams and rivers leading to decline in water quality for human consumption, irrigation, livestock and aquatic biodiversity
- Damage to farm infrastructure such as roads, fences and buildings
- Waterlogging

Best practice targets:

- Minimise runoff and improve rainfall use
- Increase vegetation cover
- Increase soil organic carbon
- Manage saline areas and salt scalds
- Promote plant growth and use plant species that maximise soil water use
- Revegetate hills, ridge tops and other recharge areas

Soil fertility decline

Soils supply plants with essential nutrients. However, Australian soils are often deficient in phosphorus, sulfur and molybdenum, and can have low levels of organic matter.

As well as soils being naturally low in some elements, nutrients are removed in farm products (meat, wool, hay, grain); through leaching; being immobilised in stock camps and becoming bound to clays in the soil. Lack of nutrients, if not addressed, can severely restrict plant production, groundcover and livestock production.

Efficient use of fertilisers requires soil testing and nutrient budgeting. Inappropriate use of fertiliser can be costly and environmentally damaging, especially for water quality.

Maintaining soil fertility is good for productivity and the environment. Fertile soils can better maintain groundcover which will limit weed invasion and minimise erosion and contamination of waterways.

Best practice targets:

- Match fertiliser applications to plant production, environmental and enterprise needs
- Minimise nutrient waste and movement
- Encourage a healthy soil ecosystem
- Include pasture phases and legumes in crop rotations
- Adding soil amendments or fertilisers
- Using a reduced tillage system
- Keeping crop residues on site (do not burn stubble)

56. Briefly outline the following land degradation issues:

a) Soil erosion

b) Soil acidity

c) Soil sodicity

d) Dryland salinity

e) Soil fertility decline

57. Select one soil degradation issue. For your chosen issue, carry out research to compile information for a 2-page factsheet. In your factsheet address:

- Name the land degradation issue
- Define the soil degradation issue
- Identify the effect of the issue on land /water and Australian agricultural production
- Include images and diagrams
- Outline agricultural practices that have caused the issue
- Describe how the issue can be prevented through agricultural management
- Describe how to treat/reverse the issue through agricultural management

Some useful sites to assist you with your research:

- [Soil erosion factsheets](#), NSW DPIRD
- [Soil acidity](#), NSW DPIRD
- [Sodic soil management](#), NSW DPIRD
- [Dryland salinity, causes and impacts](#), NSW DPIRD
- [Soil fertility decline](#), QLD DAFF

Managing soil fertility

Farming practices constantly evolve to make best use of new technologies to manage and improve soil fertility and productivity with a sustainable focus.

Some techniques to achieve this include:

- Conservation tillage systems
- Maintenance of soil organic matter (and carbon)
- Crop rotations
- Pasture ley phases.
- Organic fertilisers
- Inorganic fertilisers

Conservation tillage

Tillage involves mechanically disturbing the soil. In an agricultural, horticultural, or forestry context, it involves managing the soil profile to change soil conditions; change plant residues (e.g. stubble or regrowth); and to control or remove unwanted plant growth (e.g. weeds). In agricultural systems, tillage is used in pasture and crop production mainly by planting, changing soil structure, incorporating fertiliser and soil amendments (e.g., lime, superphosphate, or manure), and weed control.

Conservation tillage includes any minimum tillage system that aims to reduce damaging soil structure, losing soil organic matter and water loss. It involves farming practices that improve soil organic matter levels and water conservation.

In conservation tillage cropping systems, cultivation is either reduced (reduced tillage) or eliminated (zero-tillage) and stubble (crop residue) is retained.

Conservation tillage practices include:

No till – (also called direct-drill, no-till, slot planting and zero-till) The soil is undisturbed by tillage for the entire year (crop production cycle).

Seed is sown directly into crop residues. Crop residues left on the soil surface may be disturbed in strips up to one-third of the row width for planting or drilling seed.

In row subsoiling- This reduces soil compaction to depth while conserving groundcover to minimise runoff and erosion. Equipment cuts through crop residues with minimal disturbance by non- inversion tillage in a narrow strip along the row. Seed is sown into the strip.

Strip-till – Strip or zone tillage creates a narrow, tilled planting zone, where seeds are planted, while leaving the plants, ground cover and residue between the tilled strips



Figure 39 No-till



Figure 40 Strip till

intact. It combines the benefits of both conventional tillage and no-till farming methods. It is used in cover cropping systems.

Ridge tillage - involves sowing into raised rows that remain undisturbed after establishment. One or more cultivations are then made during the early part of each growing season to improve weed control between ridges, allowing the soil to dry and warm faster, and maintaining the ridge for future planting. After ridges are established, all field traffic is controlled trafficked and confined to the furrows between the ridges which minimises compaction. Ridge tillage is common in vegetable production.



Figure 41 Ridge till

Benefits of conservation tillage systems:

- Reduced tillage reduces carbon losses (from both reduced cultivation and reduced fossil fuel usage)
- Conserve soil moisture for seed germination (due to not disturbing soil and residues reduce soil evaporation)
- Plant residues and ground cover prevent erosion (water and wind) of soil and nutrients
- Reduce operation inputs labour, time, fuel, machinery wear and tear.
- Organic matter and carbon sequestration increase and reduce carbon dioxide emissions - minimal disturbance of the soil occurs during planting and cultivation, preserving soil structure and organic matter.
- Organic matter increase- Plant residues are left on the soil surface to rot and add to the organic matter content in the soil
- Increased micro-organism and invertebrate activity through minimal soil disturbance
- Keeping the soil undisturbed keeps its structure intact, leading to better water infiltration.

Disadvantage of conservation tillage systems:

- High reliance on herbicides and chemical control of pests and weeds
- Retained crop residues can spread soil-borne diseases and harbour pests
- Initial cost of no-till equipment
- Learning curve for new practices and management techniques
- Uneven distribution of harvest residues cannot be corrected
- Volunteer seeds must be controlled with chemicals
- Wheel tracks and soil compaction cannot be mechanically repaired

58. Watch [Long-term conventional and no-tillage systems compared](#)



59. Complete the table to describe each conservation tillage system. For each give an example of a production enterprise suited to this type of plant establishment.

Strategy	Describe the conservation tillage system	Enterprise example
No till		
Strip till		
In -row subsoiling		
Ridge tillage		

Soil Organic Matter

Go to section [Soil Organic Matter and Soil Organic Carbon](#) for more detail.

Soil Organic Matter (SOM) represents organic materials both living and in various stages of decay. The most important organic matter fraction for soil fertility is humus. Humus is dark brown/black, organic material that is fully decomposed. Humus makes the upper layers of soil typically dark.

Humus is highly resistant to microbial degradation and is essential for maintaining soil physical conditions that are important for plant growth. Fresh crop residues undergo rapid microbial decomposition.

SOM can greatly improve soil processes and properties that influence nutrient availability (soil fertility). For example, increasing SOM increases soil aggregation and decreases bulk density, which improves water infiltration, air exchange, root growth, and crop/pasture productivity. SOM levels depend on soil and plant management. If management is changed, a new organic matter level is set that may be lower or higher than the previous level. Management systems should aim to continually increase SOM content and productivity. Proper nutrient management will produce high yields, which will increase the quantity of residues and soil OM.



Figure 42 Soil with high organic matter has a characteristic dark black/brown coloured A Horizon

Management techniques which increase SOM levels

- **Grow perennial pasture** - A period under perennial, grass-dominant pasture is an effective way of increasing organic matter in farm soils. Short-lived annual grasses are a source of dead roots; perennial grasses are a source of leaf, stem and root matter. Even short periods (1–2 years) under perennial pasture can improve soil structure, even though the actual increase in organic matter may be small.
- **Grow cereal crops** - Cereal crops leave large amounts of organic matter in their dead roots and stubbles after harvest which, when worked into the soil, increase organic matter content.
- **Grow green manure crops** - Green manure crops provide protective cover until they are ploughed into the soil. Initially they provide a large increase in organic matter levels, but they break down rapidly to give only a small increase in long-term organic matter levels. Also, the ploughing operation can do more harm than the good done by the organic matter.
- **Spread manure** – Bulky, organic manures will increase organic matter, but frequent and heavy applications are needed to produce significant soil changes.

- **Use organic fertilisers** - Organic fertilisers applied in large amounts can boost organic matter levels but are generally less cost-effective compared to inorganic fertilisers. Applied in small quantities, they are unlikely to have a significant effect on organic matter levels.
 - **Minimising cultivation** - Cultivation breaks down the stable aggregates, exposing humus in the aggregates to air, which speeds up decomposition. Direct drill techniques allow seed to be sown, while leaving stubble residues on top of the soil and leaving aggregates intact.
 - **Concentrate organic matter** - An alternative to increasing inputs is to make more effective use of what is already there. Retain all organic additions, whether roots, stubble or manure, close to the surface. The stability of soil structure is related to the amount of organic matter at the surface, not the total quantity present in the soil.
60. Describe how soil organic matter management can be used to alter soil fertility. Include two specific management examples.

Crop rotation and pasture ley phase

Crop rotation is the practice of planting different crops in sequence on the same paddock or area, to improve soil fertility (by increasing nutrients and water use in the soil), to combat pest, disease and weed pressure and increase soil microbial and invertebrate diversity.

Crop rotation is a vital tool of integrated pest, disease and weed management (IPWDM). Diverse rotations extend the range of farm enterprises, by buffering farm income from seasonal influences and market risk. See Table 8.

Impacts	Effects	Examples
Primary impacts	Yield increases of cereal crops due to: - N fixation from pulses or pasture legumes - break crop effects - better use of resources	Impact of a subterranean clover ley on soil nitrogen, soil structure and subsequent wheat production. Reduction of the disease take-all in cereals due to the use of lupins (WA) and canola (southern Australia). After a crop phase, use of subsoil moisture by lucerne.
Secondary impacts	Effect of break crops or pasture phases on: - weed populations - insect populations - disease incidence	Rotation of herbicide groups, reduction in seed pools, plant competition. Many pasture and crop species are unattractive to potential insect pests. Reducing the incidence of blackleg in canola with cereals and legumes
Other impacts	- water use efficiency - nutrient use efficiency - allelopathy	Wheat sown after a rice crop. Different extraction rates of N, P and S by crops. Chemical effect of plant residues on other plants, often negative.

Table 8 Agronomic impacts of crop rotations. Source: [Smart rotations: farming systems for the future, Wolfe and Cregan](#)

Rotation sequences are always flexible, and are not necessarily rotated, repeated or fixed. Depending on the farming locality in Australia, the rotation sequence may be long-phase or short phase.

- A **long-phase rotation system** involves several years of a multi-species perennial pasture phase, followed by several years of cropping (cropping phase).
- A **short-phase rotation** comprises alternating years of pasture → crop (e.g. medic → wheat) or cereal → pulse (e.g. wheat → lupin)

A ley pasture (or **pasture ley**) refers to a non-permanent pasture phase for one to several years duration, with the dual objectives of providing forage for livestock and improving soil fertility and structure. The pasture ley may contain only annual species, perennials or a mixture of both. Ley pastures in crop rotations can reverse poor soil health and structure, increase soil fertility, organic matter content and nutrient cycling, improve livestock productivity, allow for pest, disease and weed breaks, and reduce environmental problems like soil erosion and deep drainage. Pasture leys often incorporate multiple pasture legume species. Examples include lablab, Sulla, lupin, cowpeas, mung beans, chickpeas, burr medics, barrel medics, subterranean clover and lucerne to name a few. Pasture leys provide the opportunity for cover cropping.

The most important feature of pasture legumes is their ability to fix atmospheric nitrogen due to the symbiotic relationship with the soil bacteria *Rhizobium* inside root nodules. Soil nitrogen is boosted by retaining legume residues (plant tops and roots) and by the return of nitrogen in the dung and urine of grazing animals. During the pasture phase, soil nitrogen increases because the quantity of symbiotically fixed nitrogen exceeds the mineralisation of organic nitrogen. Then, during the cropping phase, nitrogen mineralised from organic matter becomes available to crops. (see more at [Nitrogen cycle](#))

Aims of crop rotation:

- **Diverse crop species:** rotating crops from different botanical families prevents nutrient depletion and increases soil biodiversity. This practice improves soil structure and fertility, soils biology and supports healthy plant growth. Examples include:
 - Legumes (*Fabaceae*) e.g. clover, medics, beans, peas, pulses, peanuts
 - Cruciferous (*Brassicaceae*): canola, brassica, kale, cabbages, broccoli, cauliflower, mustard
 - Cereals (*Poaceae*) e.g. oats, wheat, barley, rye, rice, sorghum, corn
 - Oilseeds (*Asteraceae*) e.g. sunflower, safflower, (*Brassicaceae*): canola, brassica, (*Fabaceae*) soybean.
 - Pasture grasses (*Poaceae*) e.g. Phalaris, cocksfoot, ryegrass, fescue
 - Nightshades (*Solanaceae*) e.g. tomatoes, potatoes, eggplant
 - Root crops (*Amaryllidaceae*) e.g. onions, leeks, garlic, (*Apiaceae*): beets, parsnips, celery, carrots and (*Chenopodiaceae*): beets, saltbush
- **Deep and shallow roots:** Rotate deep, tap-rooted crops like brassicas and lucerne with shallow, fibrous rooted crops e.g. cereals. This strategy maximises soil nutrient uptake, as different root depths and access various soil layers.
- **Perennial and annual crops:** Perennials improve soil health and structure, reducing erosion, and cycling nutrients with deep root systems, while annuals provide higher yields but may deplete soil nutrients more quickly. Rotating these crops helps manage pests and diseases by disrupting pest cycles, as well as controlling weeds through better ground cover from perennials and managing soil fertility.
- **Legumes and cereals:** Plant legumes (e.g., pulses) after cereals (e.g., rice) to boost soil nitrogen levels and organic matter content. Legumes fix atmospheric nitrogen (*Rhizobium* bacteria) to plant available form (nitrates), enriching the soil for subsequent crops.
- **Restorative crops:** Follow nutrient-exhausting crops like sunflower with restorative ones like legumes to replenish soil nutrients. This practice maintains soil fertility and supports long term sustainability goals.
- **Pest, disease and weed management:** Avoid planting crops of the same family consecutively to break pest and disease cycles; improve pest control and reduce

chemical pesticide use. E.g. oats → barley → wheat → oats → barley would be unsuitable as all crops are cereal species

- **Soil Pathogens and Weeds:** Grow crops susceptible to soil-borne pathogens and parasitic weeds after tolerant crops. This helps manage soil health and reduces the impact of weeds, pests and diseases.

61. Describe how crop rotations can be used to manage soil fertility. Include two specific crop rotation management aims.

62. Give an example of a long-phase rotation system:

63. Give an example of a short-phase rotation system:

64. Describe how the inclusion of a pasture ley phase can be used to manage soil fertility.

Organic and Inorganic fertilisers

Fertilisers may be classified into one of two groups:

Organic fertilisers

The addition of organic fertilisers, such as compost, manure, green manure and crop residues improve soil fertility by enhancing its structure, nutrient content, and biological activity. Organic matter increases soil aggregation, improving porosity, water retention, and aeration, which supports healthy root growth. These fertilisers also provide a slow-release supply of essential nutrients, including nitrogen, phosphorus, and potassium, promoting long-term plant growth. Organic fertilisers also encourage the growth of beneficial soil microorganisms, which help decompose organic matter, fix nitrogen, and cycle nutrients efficiently.

Furthermore, organic fertilisers enrich the soil with organic matter, improving its cation exchange capacity (CEC) and moisture retention, while also buffering soil pH, which benefits plant health. They reduce dependence on synthetic fertilisers, lowering the risk of nutrient runoff and soil degradation.

Types of organic fertilisers include:

- Manure: provide nitrogen, phosphorous, potassium and trace elements.
- Animal by-products: include blood and bone meal, bone dust etc. Organic by-products generally have a higher nitrogen content than animal manures and are high in phosphorous and calcium (bone by-products).
- Fish emulsion made from fish and fish waste (e.g. 'Charlie carp'). High in Nitrogen.

- Green manures or cover crops describe a range of temporary, fast growing leafy plants which are sown and slashed before setting seed and incorporated into the soil.
- Compost: made from decomposed plant and animal materials rich in nutrients such as nitrogen, phosphorous and potassium.

Inorganic (artificial) fertilisers

Inorganic fertilisers are chemically manufactured and contain specific ratios of essential nutrients like nitrogen (N), phosphorus (P), and potassium (K). They play a direct role in managing soil fertility by providing readily available nutrients to plants. They are often used to address specific nutrient deficiencies in the soil, ensuring that plants receive the essential elements for optimal growth. Inorganic fertilisers can be applied to meet the immediate nutrient needs of crops, leading to faster growth, higher yields, and improved quality of produce.

Inorganic fertilisers are highly concentrated, allowing for precise control over the nutrient content in the soil. They are especially useful in soils that are deficient in key nutrients or where nutrient availability is low. By using inorganic fertilisers, farmers can quickly correct deficiencies of macronutrients (such as nitrogen for leaf growth, phosphorus for root development, and potassium for overall plant health) and micronutrients (like iron and zinc). However, incorrect use of inorganic fertilisers can lead to soil acidification, nutrient imbalances, and potential environmental issues like nutrient runoff and water pollution, which is why they should be used in conjunction with sustainable practices such as crop rotation and organic matter amendments to maintain long-term soil fertility.

Go to: [Fertilisers and the environment](#) for information on environmental degradation issues caused by inappropriate fertiliser use.

Inorganic fertilisers come in various forms such as a powder, granule, liquid or gas. Some of the most widely used artificial fertilisers include:

- Superphosphate, Monoammonium phosphate (MAP), Diammonium Phosphate (DAP). These provide phosphorus.
- Sulfate of ammonia, anhydrous ammonia, ammonium nitrate and urea. These provide nitrogen.
- Potassium chloride (Muriate of Potash) and Potassium Sulfate. These provide potassium.

Both organic and inorganic fertilisers are used to provide nutrients to plants, but they differ in their nutrient content and environmental impacts. Organic fertilisers are often slower acting but can additionally improve soil structure (due to organic matter properties) and soil fertility over time. Inorganic fertilisers are rapidly available to plants

and increase soil fertility quickly but when not used correctly, can contribute to soil acidity and other environmental problems if used in excess.

65. Describe how the addition of organic fertilisers, can be used to manage soil fertility.

66. Describe how the addition of inorganic fertilisers and can be used to manage soil fertility.

Land and soil capability

Land capability is the ability of the land to sustain a range of land uses and management practices in the long term without degrading the soil, air and water. It is influenced by topography (slope), soil and climate.

Land capability is based on an assessment of the biological and physical features of the land, how these will limit a particular type of land use, and the technology that is available for the management of the land.

It provides information on the broad agricultural land uses and enterprises most suited to the soil/land. For example, intensive cropping, continuous pasture, pastoral grazing, or conservation of native vegetation etc.

Failure to manage land in accordance with its capability risks degradation of resources both on- and off-site, leading to a decline in natural ecosystems and agricultural productivity.

Using land beyond its capability may have serious consequences for the land and soil as well as environmental impacts on water, air and biodiversity. Impacts can include loss of valuable soils on agricultural land, soil acidification, structure decline, soil carbon decline and wind erosion leading to poor air quality. All these are indications of land degradation.

Land and soil capability classes (LSC) and definitions

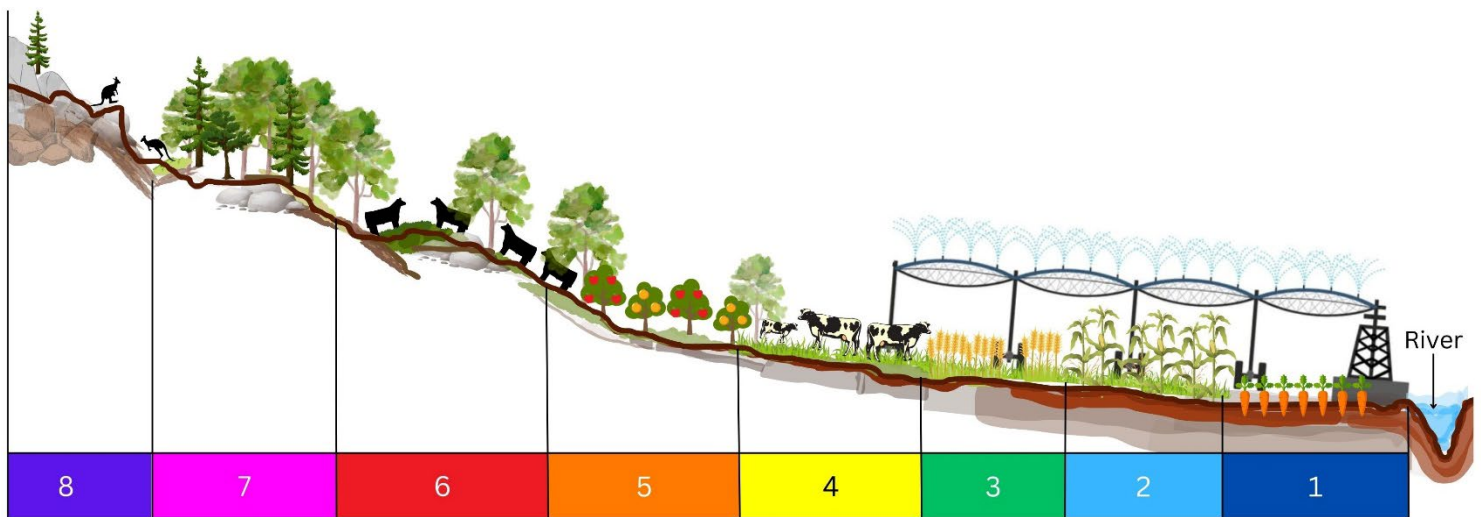


Figure 43 Example Land capability indicative enterprises across a landscape

Table 9 Land and soil capability (LSC) classes- general definitions

LSC class	Land a soil capability general definition
	Land capable of a wide variety of land uses (cropping, grazing, horticulture, forestry, nature conservation)

1	Extremely high capability land: - Land has no limitations. - No special land management practices required. - Land capable of all rural land uses and land management practices
2	Very high capability land: - Land has slight limitations. - These can be managed by readily available and easily implemented management practices. - Land is capable of most land uses and land management practices, including intensive cropping with cultivation.
3	High capability land: - Land has moderate limitations and can withstand high-impact land uses, such as cropping with cultivation, using more intensive, readily available and widely accepted management practices. - However, careful management of the land is needed for cropping and intensive grazing to avoid land and environmental degradation. <i>Land capable of a variety of land uses (cropping with restricted cultivation, pasture cropping, grazing, some horticulture, forestry, nature conservation)</i>
4	Moderate capability land: - Land has moderate to high limitations for high-impact land uses. - Will restrict land management options for regular high-impact land uses such as cropping, high-intensity grazing and horticulture. - These limitations can only be managed by specialised management practices with a high level of knowledge, expertise, inputs, investment and technology
5	Moderate–low capability land: - Land has high limitations for high-impact land uses. - Will largely restrict land use to grazing, some horticulture (orchards), forestry and nature conservation. - The limitations need to be carefully managed to prevent long-term degradation <i>Land capable for a limited set of land uses (grazing, forestry and nature conservation, some horticulture)</i>
6	Low capability land: - Land has very high limitations for high-impact land uses. - Land use restricted to low-impact land uses such as grazing, forestry and nature conservation. - Careful management of limitations is required to prevent severe land and environmental degradation <i>Land generally incapable of agricultural land use (selective forestry and nature conservation)</i>
7	Very low capability land: - Land has severe limitations that restrict most land uses and generally cannot be overcome. - On-site and off-site impacts of land management practices can be extremely severe if limitations not managed. - There should be minimal disturbance of native vegetation.
8	Extremely low capability land: - Limitations are so severe that the land is incapable of sustaining any land use apart from nature conservation. - There should be no disturbance of native vegetation.

Whole farm planning and land capability planning

A whole farm plan identifies different natural and built resources and features on a farm and matches management and enterprises to resources available and the land capabilities for sustainable production. Natural features may include soils, landforms, topography, water, historical and cultural features, native vegetation and biodiversity. A whole farm plan does not have to be complicated, but it should continuously change with time. Its overall objective is sustainable land management on the farm. Farm planning helps identify environmental issues and concerns and legislative requirements. It explores practical and cost-effective solutions, solve problems and meet targets, while minimising the impact on the environment. It is an evolving document which should be reviewed and updated annually. Keeping production, resource and performance data about the farm and its operation is essential to developing a whole farm plan.

A whole farm plan typically includes:

- Whole farm objectives
- Property map and farm history
- Natural resource inventory and assessment
- Identification of land capability across a farm
- Action plan

67. Watch: [Preparing for drought through Whole farm planning](#)



68. Watch: [The importance of Agriculture- Agricultural Land use planning](#)



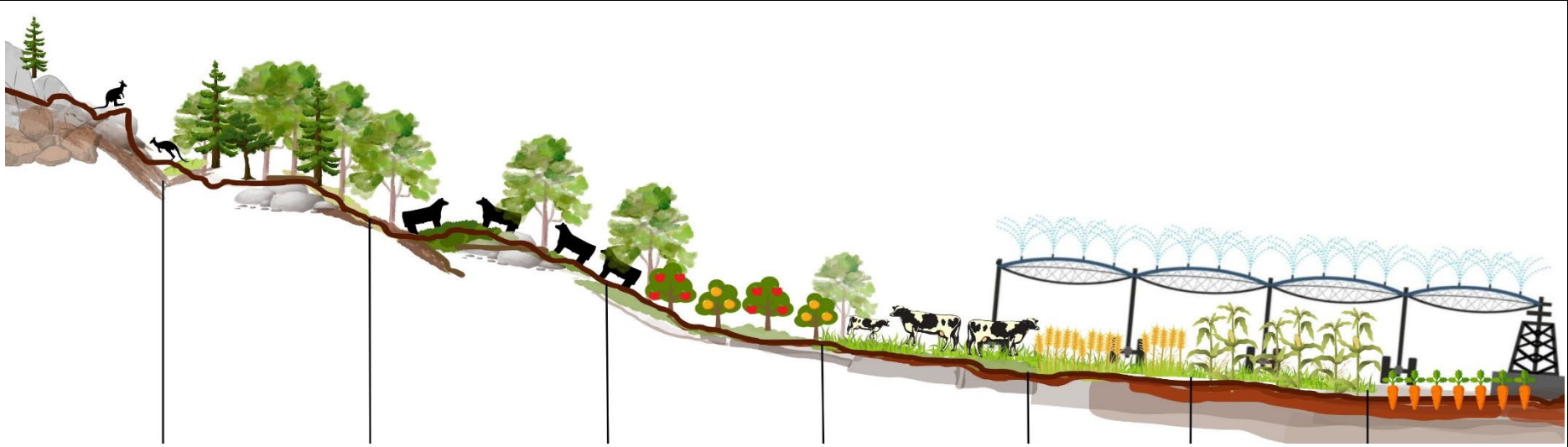
69. Go to the [Tocal Virtual Farm- Land Capability on Tocal](#), to investigate how Tocal farm enterprises are managed and set out according to Land Capabilities.

70. Define land capability

71. Explain how land capability assessment can be used to improve the long-term sustainability of Australian farms.

[illegible]

72. Complete the table to label and summarise the eight Land and Soil Capability classes. Give examples of suitable agricultural enterprises for each LSC class.

Land and Soil Capability classes, enterprises and general definitions								
Image								
	Land generally incapable of agricultural land use		Land capable for limited land uses	Land capable of a variety of land uses		Land capable of a wide variety of land uses		
LSC class	8	7	6	5	4	3	2	1
LSC Class name								

Description								
Example enterprises								

Tensions between sustainability and short term profitability

In farming systems, there is often a tension between short-term profitability and long-term sustainability. In the short term, practices like the intensive use of synthetic fertilisers, pesticides, and monocropping can boost yields and profits while reducing operational costs to meet short-term financial goals. However, these practices often degrade soil health, reduce biodiversity, and if not managed correctly deplete resources, undermining the long-term sustainability of farming systems.

Sustainable practices, such as precision agriculture, crop rotation, conservation tillage, pasture-based grazing systems and holistic farming practices, may result in lower immediate yields, infrequent cash flow, or delayed returns on investment. While these methods work to improve soil fertility, water retention, and biodiversity, they do not always generate immediate profits. This creates a conflict where producers may adopt strategies that give quick returns over practices that safeguard the sustainability of their farms.

Another area of tension lies in the intensive use of resources, such as soil and water. Short-term profit can tempt farmers to maximise production using practices that may deplete resources, e.g. soil nutrients, and organic matter content. In contrast, sustainable farming methods like water and soil conservation, precision agriculture and holistic farming practices offer long-term resilience against potential environmental stressors.

Market demands and the need to remain competitive increase this tension. Markets often favour high-yield, uniform products that meet rigid market specifications, pushing farmers toward practices that maximise immediate outputs, sometimes at the expense of long-term sustainability. Sustainable farming, which may involve diversification, holistic practices, or production of niche products, may not be as profitable in the short term as intensive production systems. This leads to a conflict between meeting market demand for producing cheap, high-volume products and farming that ensures environmental sustainability and long-term profitability.

73. Select one of the following topics

- Green manuring
- Conservation tillage practices e.g. direct drilling (zero -tillage)
- Pasture ley phase
- Matching enterprises to Land use capabilities
- Continual application of artificial N fertilisers
- Increasing pH_{CaCl} to 5.5 - 5.8

Use research to complete the following

- Briefly describe the practice
- Identify and describe the long- term effects on sustainability
- Identify and describe the short - term effects this practice has on sustainability

Soil systems careers

When you think about careers in Agriculture- the first job you think of is a farmer, right? Thank again.

There are hundreds of jobs which, quite literally, could change the world in which we live.

From scientific breakthroughs to designing autonomous robots, campaigning for change in parliament, to environmental engineering careers in Agriculture are at the forefront of Innovation.

Of course, farming remains at the heart of the industry, but the job of a farmer is massively different from the stereotypical image of an old man chewing straw.

Agriculture is in an exciting time of change globally. It is now one of the most fast paced and dynamic industries to work in, giving young people plenty of options to pick from.

Technology development is enabling agriculture to lead the way in tackling many global challenges, such as feeding a growing world population. Battling climate change and protecting the environment.

A career in Agriculture also offers a great quality of life, the chance to help others, to make a difference and it can pay generously.

There really is more to agriculture than you think!

Think Careers? Think Agriculture.

Source: [This is agriculture](#)



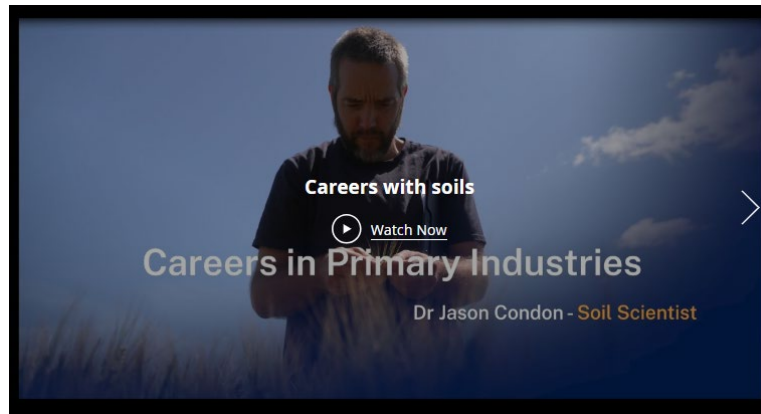
If you like being outdoors, problem solving, gardening, insects, getting your hands dirty, plants and science, a career working with soils may be ideal for you!

Soil scientists focus on maintaining the overall health of soil by working to understand the environment, soil conditions and what is living within it.

Duties and tasks as a soil scientist

- Conduct field studies, collect and evaluate data, and formulate reports on soil health and conditions
- Provide recommendations for general wildlife conservation and for ways to control soil pollution
- Consult large organisations and government looking to maintain soil health and productivity
- Find ways to protect the environment, reduce pollution and keep the soil healthy
- Study the physical, chemical and biological makeup of soil

Watch:



[Careers with soils- Soil scientist](#)

The following is a list of NSW Department of Primary Industries and Regional Development roles associated with soil

- Agronomist
- Biometrician
- Biosecurity officer
- Chemist
- Climate researcher
- Crop development officer
- Crop Physiologist
- Data scientist
- Ecologist
- Entomologist
- Environmental scientist
- Farm assistant
- Farm manager
- GIS mapping specialist
- Grazing officer
- IT technician
- Land use Planning Officer
- Mechanical/trade engineer
- Plant pathologist
- Soil hydrologist
- Soil scientist
- Soil technical officer
- System developer
- Water scientist

74. Use the internet and other sources to investigate a soils systems related career of your choosing. For this career find out the following:

- Title of the career/job
- Role description
- Personal qualities
- Skills required (if formal courses or education is required, find out where you could train and the timeframe to complete the course)
- Salary or wage range
- Identify opportunities for job progression in the role

Useful sites to help you with your research include:

- [Soils Science Career Resources](#)
- [Jobs and careers at the Soil Conservation Service](#)
- [Career Harvest](#)
- [Explore careers in soil science](#)

Syllabus links

NSW Syllabuses

Agriculture Stage 6 Syllabus (2013)

Outcomes:

P2.1 describes the biological and physical resources and applies the processes that cause changes in plant production systems

P5.1 investigates the role of associated technologies and technological innovation in producing and marketing agricultural products.

H1.1 explains the influence of the physical, biological, social, historical and economic factors on sustainable agricultural production

H2.1 describes the inputs, processes and interactions of plant production systems

Students learn about:

Preliminary Agriculture

Plant Production

Animals, climate and resource interaction

- Effects of soil texture, structure, pH and fertility on plant production
- inorganic and organic fertilisers
- cultivation and grazing practices
- management for sustainable production

Students learn to:

- measure and describe the features of soil including colour, texture, structure, pH, organic matter, parent material and water holding capacity
- identify macro and micro nutrients important for plant growth
- select appropriate tillage implements and/or techniques to establish a crop or pasture
- recognise sustainable management practices including crop rotation, green manuring, minimum tillage and mulching

Students learn about:

HSC Agriculture

Soil, nutrients and water

- chemical and physical characteristics of soil
- the role of soil nutrient cycles in Australian agricultural systems including the nitrogen cycle and the carbon cycle
- the role of microbes and invertebrates in the decomposition of organic matter

Factors contributing to the degradation of soil and water

- farming practices that have contributed to soil degradation such as salination, acidification, soil structure decline, loss of soil organic matter and erosion and the effects of these on soil and water

Sustainable resource management

- sustainable techniques to maintain and/or improve soil fertility including alternative strategies to the application of inorganic fertilisers
- tension between sustainability and short-term profitability in farming systems

Students learn to:

- describe chemical characteristics of a soil including soil pH, ion exchange capacity, soil carbon and nutrient status
- describe physical characteristics of a soil including soil structure, texture, porosity and bulk density
- perform a first-hand investigation to analyse and report on the physical and chemical characteristics of a soil
- illustrate the nitrogen cycle and the carbon cycle
- research using secondary sources the importance of microbes and invertebrates in decomposition and nutrient cycling
- investigate using secondary sources the practices that have led to one important soil degradation problem, the outcomes of these practices on the land/water system and current recommended procedures to alleviate the problem
- describe techniques used to manage soil fertility including conservation tillage systems, maintenance of soil organic matter (or carbon), crop rotations, organic fertilisers, inorganic fertilisers and pasture ley phase
- assess the factors involved in long-term sustainability of agricultural systems including Australian land classification/capability and whole-farm planning
- identify tensions between sustainability and short-term profitability in farming systems

Agriculture Technology 7-10 Syllabus (2019)

Outcomes

AG5-2 Explains the interactions within and between agricultural enterprises and systems

AG5-4 Investigates and implements responsible production systems for plant and animal enterprises

AG5-8 evaluates the impact of past and current agricultural practices on agricultural sustainability

AG5-9 Evaluates management practices in terms of profitability, technology, sustainability, social issues and ethics

AG5-11 designs, undertakes, analyses and evaluates experiments and investigates problems in agricultural contexts

AG5-14 Demonstrates plant and/or animal management practices safely and in collaboration with others

Content

Core A- Introduction to Agriculture

- research a range of current and future employment opportunities in agriculture
- research an agricultural problem and develop possible solutions, for example: dryland and irrigation salinity (ACTDEP048)

Plant Production 1

- implement soil-management operations for a chosen plant enterprise (ACTDEK046)
- investigate and analyse soil quality indicators, eg soil texture, structure, pH and soil profiles
- evaluate current agricultural methods relevant to the chosen plant enterprise in terms of environmental sustainability, for example: minimum tillage/tramlining (ACTDEK044)
- evaluate the social and ethical issues that would be confronted in the chosen plant enterprise, for example: chemical use; urban sprawl/land use conflicts (ACTDEK040)
- select and use appropriate software to analyse and present agricultural data related to the plant enterprise (ACTDEP052)
- plan and undertake procedures in the management of a plant enterprise (ACTDEP048, ACTDEP050)
- work collaboratively to perform plant enterprise management activities (ACTDEP050, ACTDEP052)

Core B: Agricultural Systems and Management

- investigate the effect of beneficial and harmful microorganisms and invertebrates on plant and/or animal production
- identify opportunities provided by the agricultural sector, both as an employer and as a user of products
- evaluate different production techniques for a chosen agricultural system or enterprise, for example tramline farming
- design and conduct a controlled agricultural experiment, for example: (ACTDEP049) e.g. soil testing to determine the influences on plant growth

Plant Production 2

- evaluate the impact of current technologies on sustainability, for example: (ACTDEK041, ACTDEK044, ACTDEP051) controlled traffic farming, precision farming
- compare short-term and long-term effects of agricultural production systems on sustainability, for example: (ACTDEK044) e.g. growing a green manure crop may reduce short-term profit but will improve soil structure and fertility in the long term; continual application of artificial fertilisers may increase short-term yields but may adversely affect soil pH in the long term
- draw conclusions from evidence and the analysis of data, for example: identify fertilisers for optimal plant growth (ACTDEP051)

ACARA- Australian Curriculum

Year 10 Science: Australian Curriculum V9.0

- **AC9S10U04** use models of energy flow between the geosphere, biosphere, hydrosphere and atmosphere to explain patterns of global climate change
- **AC9S10H02** investigate how advances in technologies enable advances in science, and how science has contributed to developments in technologies and engineering
- **AC9S10I02** plan and conduct valid, reproducible investigations to answer questions and test hypotheses, including identifying and controlling for possible sources of error and, as appropriate, developing and following risk assessments, considering ethical issues, and addressing key considerations regarding heritage sites and artefacts on Country/Place
- **AC9S10I02** plan and conduct valid, reproducible investigations to answer questions and test hypotheses, including identifying and controlling for possible sources of error and, as appropriate, developing and following risk assessments, considering ethical issues, and addressing key considerations regarding heritage sites and artefacts on Country/Place
- **AC9S10I03** select and use equipment to generate and record data with precision to obtain useful sample sizes and replicable data, using digital tools as appropriate
- **AC9S10I04** select and construct appropriate representations, including tables, graphs, descriptive statistics, models and mathematical relationships, to organise and process data and information

- [AC9S10I07](#) construct arguments based on analysis of a variety of evidence to support conclusions or evaluate claims, and consider any ethical issues and cultural protocols associated with accessing, using or citing secondary data or information
- [AC9S10I08](#) write and create texts to communicate ideas, findings and arguments effectively for identified purposes and audiences, including selection of appropriate content, language and text features, using digital tools as appropriate.

Year 11-12 Earth and Environmental Science: Australian Curriculum V8.4

- [ACSES030](#) Identify, research and construct questions for investigation; propose hypotheses; and predict possible outcomes
- [ACSES031](#) Design investigations including the procedure/s to be followed, the information required and the type and amount of primary and/or secondary data to be collected; conduct risk assessments; and consider research ethics
- [ACSES032](#) Conduct investigations, including using map and field location techniques and environmental sampling procedures, safely, competently and methodically for the collection of valid and reliable data
- [ACSES033](#) Represent data in meaningful and useful ways; organise and analyse data to identify trends, patterns and relationships; qualitatively describe sources of measurement error, and uncertainty and limitations in data; and select, synthesise and use evidence to make and justify conclusions
- [ACSES034](#) Interpret a range of scientific and media texts and evaluate processes, claims and conclusions by considering the quality of available evidence; use reasoning to construct scientific arguments
- [ACSES035](#) Select, construct and use appropriate representations, including maps and other spatial representations, diagrams and flow charts, to communicate conceptual understanding, solve problems and make predictions
- [ACSES036](#) Communicate to specific audiences and for specific purposes using appropriate language, genres and modes, including compilations of field data and research reports
- [ACSES038](#) Biological soil crusts are formed by living organisms such as cyanobacteria, lichen or algae and their byproducts, creating a crust of soil particles bound together by organic materials. Biological soil crusts are found globally in arid and semiarid environments, and are common in Australia. They play an important role in soil fertility and protect the soil surface from erosion and evaporation. The cyanobacteria in soil crusts are photosynthetic and research indicates that they are important for fixing and storing soil carbon; they also secrete compounds that increase the bio-availability of phosphorus and nitrogen
- [ACSES056](#) Energy is stored, transferred and transformed in the carbon cycle; biological elements, including living and dead organisms, store energy over relatively short timescales, and geological elements (for example, hydrocarbons, coal and kerogens) store energy for extended periods
- [ACSES077](#) Ecosystems provide a range of renewable resources, including provisioning services (for example, food, water, pharmaceuticals), regulating services (for example, carbon sequestration, climate control), supporting services (for example, soil formation, nutrient and water cycling, air and water purification) and cultural services (for example, aesthetics, knowledge systems)
- [ACSES093](#) Land clearing and farming practices have led to significant salinity issues for Australian land and water resources. Dryland salinity currently affects over 5 million hectares of land and the National Land and Water Resources Audit predicted that up to 17 million hectares may have high potential for development of dryland salinity by 2050. Historically, land clearing for agriculture was supported by governments as an important measure to increase national economic prosperity, but since the 1980s the rate of land clearing has declined as awareness increases and attitudes change
- [ACSES097](#) Salinity causes loss of agricultural land and remnant native vegetation and has a significant impact on public resources such as water supplies, roads, buildings and biodiversity. Mitigation activities include tree planting, planting of deep rooted crops such as lucerne, or salt-adapted species such as salt bush. Using remote sensing technologies to develop models of regional hydrogeology, scientists are increasingly able to predict sites most at risk from salinisation so that preventative measures such as tree planting can be taken

Design and Technologies - Australian Curriculum V9.0

- [AC9TDE8K04](#) analyse how food and fibre are produced in managed environments and how these can become sustainable
- [AC9TDE10K04](#) analyse and make judgements on the ethical, secure and sustainable production and marketing of food and fibre enterprises

Geography 7-10 - Australian Curriculum V9.0

- [AC9HG9K01](#) the distribution and characteristics of biomes as regions with distinctive climates, soils, vegetation and productivity
- [AC9HG9K02](#) the effects on environments of human alteration of biomes to produce food, industrial materials and fibres
- [AC9HG9K04](#) challenges to sustainable food production and food security in Australia and appropriate management strategies
- [AC9HG7K01](#) classification of environmental resources and the way that water connects and changes places as it moves through environments
- [AC9HG9S02](#) collect, represent and compare data and information from primary research methods, including fieldwork and secondary research materials, using geospatial technologies and digital tools as appropriate

Periodic table of elements

1

H

Hydrogen

1,008

2

He

Helium

4,003

3

Li

Lithium

6,941

4

Be

Beryllium

9,012

11

Na

Sodium

22,990

12

Mg

Magnesium

24,305

19

K

Potassium

39,098

20

Ca

Calcium

40,078

37

Rb

Rubidium

85,468

38

Sr

Strontium

87,620

55

Cs

Cesium

132,906

56

Ba

Barium

137,327

87

Fr

Francium

223,000

88

Ra

Radium

226,000

1

H

Hydrogen

1,008

1

Atomic number

1

Element symbol

1,008

Element name

1,008

Atomic weight

1

2

3

4

5

6

7

8

9

10

11

12

Noble gases

Reactive nonmetals

Halogens

Metalloids

Post-transition metals

Transition metals

Lanthanoids

Actinoids

Alkaline-earth metals

Alkali metals

Metals

Nonmetals

13

B

Boron

10,811

14

C

Carbon

12,011

15

N

Nitrogen

14,007

16

O

Oxygen

15,999

17

F

Fluorine

18,998

18

Ne

Neon

20,180

21

Sc

Scandium

44,956

22

Ti

Titanium

47,867

29

Y

Yttrium

88,906

30

Zr

Zirconium

91,224

57-71

Lanthanides

72

Hf

Hafnium

178,490

89-103

Actinides

104

Rf

Rutherfordium

261,000

31

Ga

Gallium

69,723

32

Ge

Germanium

72,640

33

As

Arsenic

74,922

34

Se

Selenium

78,960

35

Br

Bromine

79,904

36

Kr

Krypton

83,800

41

Nb

Niobium

92,906

42

Mo

Molybdenum

95,938

43

Tc

Technetium

98,000

44

Ru

Ruthenium

101,070

45

Rh

Rhodium

102,906

46

Pd

Palladium

106,420

49

In

Indium

114,818

50

Sn

Tin

118,710

51

Sb

Antimony

121,760

52

Te

Tellurium

127,600

53

I

Iodine

126,905

54

Xe

Xenon

131,293

61

Pm

Promethium

145,000

62

Sm

Samarium

150,360

63

Eu

Euroium

151,964

64

Gd

Gadolinium

157,250

65

Tb

Terbium

158,925

66

Dy

Dysprosium

162,500

67

Ho

Holmium

164,930

68

Er

Erbium

167,259

69

Tm

Thulium

168,934

70

Yb

Ytterbium

173,040

71

Lu

Lutetium

174,967

72

Hf

Hafnium

178,490

73

Ta

Tantalum

180,948

74

W

Tungsten

183,848

75

Re

Rhenium

186,207

76

Os

Osmium

190,230

77

Ir

Iridium

192,217

78

Pt

Platinum

195,078

79

Au

Gold

196,967

80

Hg

Mercury

200,590

81

Tl

Thallium

204,383

82

Pb

Lead

207,200

83

Bi

Bismuth

208,980

84

Po

Polonium

209,000

85

At

Astatine

210,000

86

Rn

Radon

222,000

87

Fr

Francium

223,000

88

Ra

Radium

226,000

89-103

Actinides

104

Rf

Rutherfordium

261,000

105

Db

Dubnium

262,000

106

Sg

Seaborgium

266,000

107

Bh

Bohrium

264,000

108

Hs

Hassium

277,000

109

Mt

Meitnerium

278,000

110

Ds

Darmstadtium

281,000

111

Rg

Roentgenium

282,000

112

Cn

Copernicium

285,000

113

Nh

Nihonium

284,000

114

Fl

Flerovium

289,000

115

Mc

Moscovium

290,000

116

Lv

Livermorium

293,000

117

Ts

Tennessine

294,000

118

Og

Oganesson

294,000

101

Md

Mendelevium

258,000

102

No

Nobelium

259,000

103

Lr

Lawrencium

262,000

104

Rf

Rutherfordium

261,000

105

Db

Dubnium

262,000

106

Sg

Seaborgium

266,000

107

Bh

Bohrium

264,000

108

Hs

Hassium

277,000

109

Mt

Meitnerium

278,000

110

Ds

Darmstadtium

281,000

111

Rg

Roentgenium

282,000

112

Cn

Copernicium

285,000

113

Nh

Nihonium

284,000

114

Fl

Flerovium

289,000

115

Mc

Moscovium

290,000

116

Lv

Livermorium

293,000

117

Ts

Tennessine

294,000

118

Og

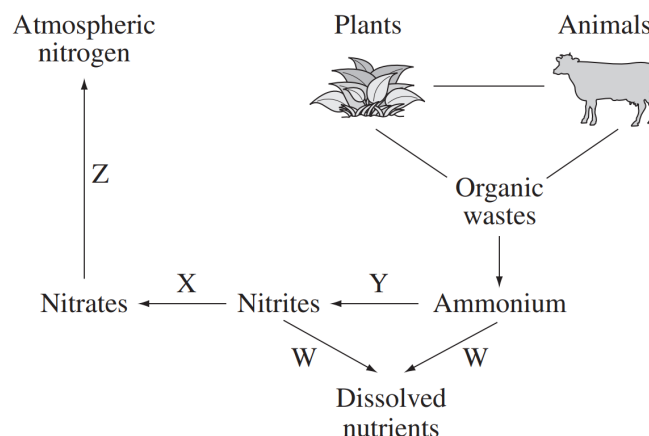
Oganesson

294,000

Soils revision – past HSC questions (2013-2023 papers)

Past HSC questions and answers are sourced directly from the [NSW Education Standards Authority, Agriculture HSC exam packs](#).

- Which of the following statements is true of early European land management practices in Australia? ([2013 HSC Exam pack Q1](#))
 - They did not affect natural waterways.
 - They led to an increase in soil degradation issues.
 - They did not involve the burning of plant material.
 - They encouraged the establishment of a more diverse range of native plant species.
- Which term is used to describe the arrangement of particles in soil? ([2013 HSC Exam pack Q3](#))
 - Bulk density
 - Porosity
 - Structure
 - Texture
- The diagram shows a summary of the nitrogen cycle ([2013 HSC Exam pack Q19](#))



Which process in the diagram does NOT involve microbial activity?

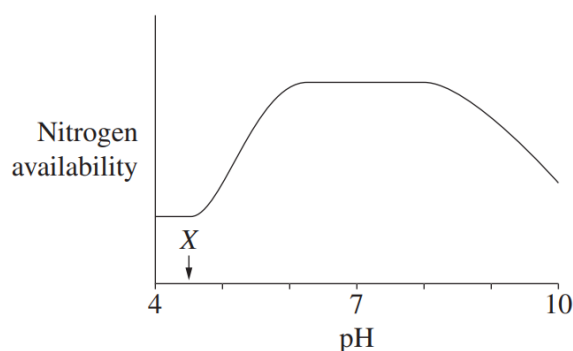
- W
 - X
 - Y
 - Z
- A soil test determined that the pH of a soil was 4. What does this pH level indicate? ([2014 HSC Exam pack Q5](#))
 - This soil is too saline for seeds to germinate and grow.
 - This soil is too alkaline (basic) for most plants to grow well.
 - The most important soil nutrients are available to plants at this pH.
 - Plants could access a greater range of nutrients if the pH was raised.

5. What is most likely to result from the loss of organic matter (soil carbon) from a soil over time? ([2014 HSC Exam pack Q7](#))
 - a. A change in soil texture
 - b. An increase in soil salinity
 - c. A breakdown of soil structure
 - d. An increase in water-holding capacity
6. How do Australian land capability assessment systems encourage more sustainable farming? ([2014 HSC Exam pack Q14](#))
 - a. They regulate what farmers can and cannot do on their land.
 - b. They enable the financial capability of land to be calculated.
 - c. When land is used according to the assessed capability, land degradation issues are reduced.
 - d. Farmers can change the capability of their land and ensure their financial sustainability
7. Which of the following is a feature of a soil with a high bulk density? ([2014 HSC Exam pack Q16](#))
 - a. High level of porosity
 - b. Low mechanical strength
 - c. High levels of organic matter
 - d. Closely packed soil particles
8. Which characteristic of a soil would give the best indication of its chemical fertility? ([2014 HSC Exam pack Q17](#))
 - a. Acidity
 - b. Ion exchange capacity
 - c. The arrangement of soil particles
 - d. The proportions of sand, silt and clay
9. What is being determined by the test shown in the diagram? ([2015 HSC Exam pack Q1](#))



- a. Bulk density
- b. Porosity
- c. Structure
- d. Texture

10. The long-term fertility of sandy soils is best maintained by: ([2015 HSC Exam pack Q19](#))
- applying gypsum.
 - applying a chemical fertiliser.
 - conserving organic matter (soil carbon).
 - regularly using the land to grow organic crops.
11. The graph shows the availability of nitrogen to plants growing in a soil. The soil was tested and the pH is shown at point X in the diagram ([2015 HSC Exam pack Q20](#))



Tonnes of material required to alter soil pH

<i>Material</i>	<i>Tonnes/Ha</i>	<i>pH change (+ or -)</i>
Gypsum	5	0.3
Lime	3	1
Nitrate fertiliser	0.3	1
Organic mulch	10	0.2

The best strategy to make nitrogen more available to plants growing in this soil is to apply

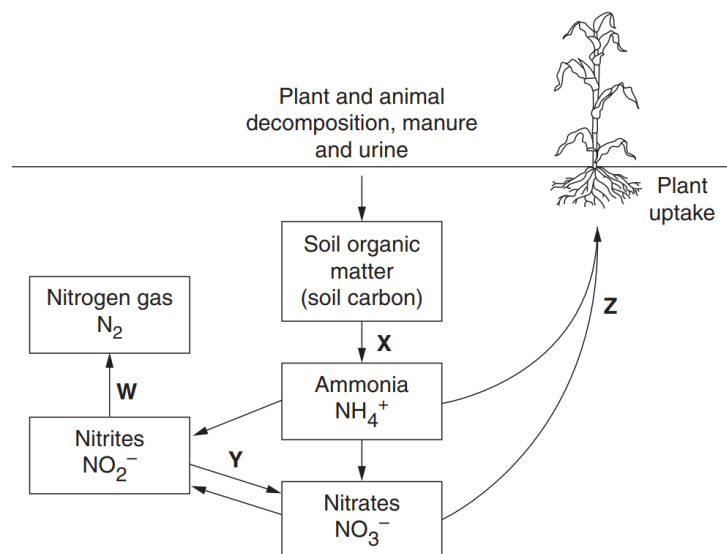
- gypsum.
- lime.
- nitrate fertiliser.
- organic mulch.

12. A student carried out the following procedure on a sample of dry soil. ([2016 HSC Exam pack Q11](#))

1. Weighed the soil sample
2. Heated the sample at high temperature (400°C) in an oven for six hours
3. Re-weighed the sample

What characteristic of the soil was the student measuring?

- a. pH
 - b. Texture
 - c. Bulk density
 - d. Organic matter content
13. Which of the following soil textural classes would be most likely to have the highest ion exchange capacity? ([2016 HSC Exam pack Q12](#))
- a. Loam
 - b. Clay loam
 - c. Sand
 - d. Sandy loam
14. The diagram shows part of the nitrogen cycle. ([2016 HSC Exam pack Q13](#))



Which arrow in the diagram represents the process of nitrification?

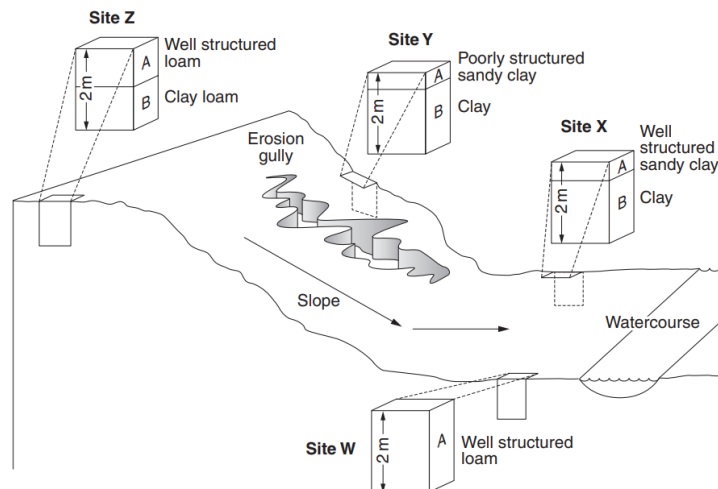
- a. W
- b. X
- c. Y
- d. Z

15. What does weight per unit volume of soil measure? ([2017 HSC Exam pack Q7](#))
- Porosity
 - Structure
 - Bulk density
 - Ion exchange capacity
16. Which row of the table of soil characteristics best describes a sandy soil? ([2017 HSC Exam pack Q8](#))

<i>Soil characteristics</i>				
<i>Row</i>	<i>Moisture holding capacity</i>	<i>Bulk density</i>	<i>Structure</i>	<i>Ion Exchange Capacity</i>
a)	High	High	Blocky	Medium
b)	Medium	Medium	Crumb	Low
c)	High	High	Massive	High
d)	Low	Low	Single grains	Low

17. Which of the following is a chemical characteristic of soil? ([2018 HSC Exam pack Q1](#))
- pH
 - Porosity
 - Structure
 - Texture
18. Which statement is INCORRECT in relation to the process of decomposition in soils? ([2018 HSC Exam pack Q4](#))
- It is the process of rotting or decaying.
 - It involves the total loss of nitrogen by the action of microbes.
 - It involves the breakdown of plant/animal material to form organic matter.
 - It involves the change of a complex substance into simpler substances through the action of microbes
19. Which pair of characteristics describes soil with a high bulk density? ([2018 HSC Exam pack Q5](#))
- Poor drainage and poor aeration
 - Poor drainage and good aeration
 - Good drainage and good aeration
 - Good drainage and poor aeration

20. The diagram shows a cross-section of a part of a farmer's property and four sites (W, X, Y, Z) with their soil profiles displayed. (2018 HSC Exam pack Q17)



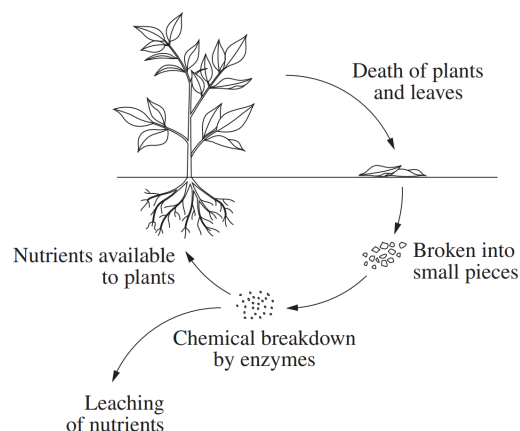
The table shows descriptions for some of the Australian land capability classes.

Land not suited to agriculture except light grazing. Major environmental constraints to production.	Land suited to cropping but not regular cultivation. Improved pasture using minimum tillage. Moderate constraints to sustainable production.	Arable land suited to regular cultivation such as field crops. Some constraints to sustainable production.	Arable land suited to continuous cultivation such as intensive horticulture or field crops. Constraints are minor or absent.
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Which sequence of sites best matches the sequence of descriptions in the table (from left to right)?

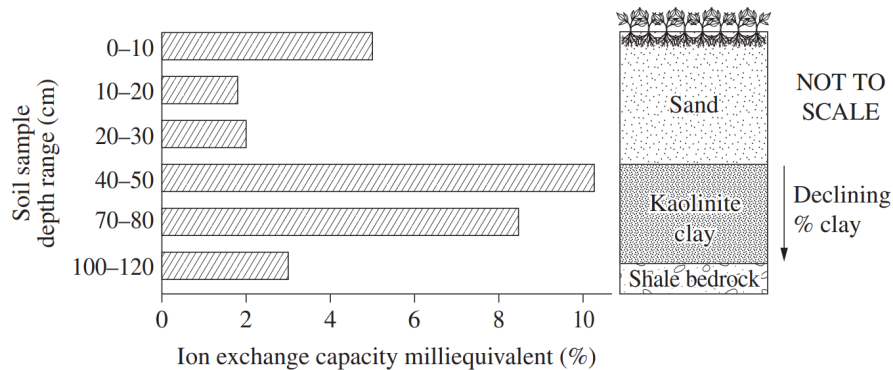
- Y X W Z
- Y Z X W
- Y X Z W
- Y Z W X

21. The diagram shows some steps in a nutrient cycle. (2019 HSC Exam pack Q9)



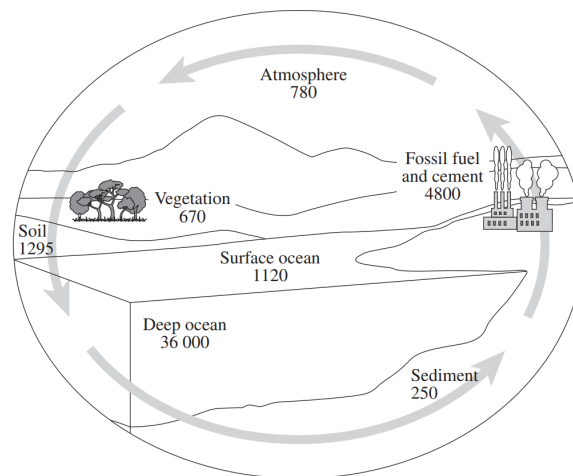
Which of the following shows a pair of steps in the cycle where both steps involve soil invertebrates?

- a. Broken into small pieces and leaching of nutrients
 - b. Leaching of nutrients and nutrients available to plants
 - c. Broken into small pieces and chemical breakdown by enzymes
 - d. Chemical breakdown by enzymes and nutrients available to plants
22. The diagram shows the ion exchange capacity of random soil samples taken from a duplex soil with an upper sandy layer and a clay layer beginning at a depth of 40 cm. The surface is densely vegetated and rich in organic matter ([2019 HSC Exam pack Q17](#)).



Which pair of factors most influences this soil's ability to retain nutrients in a form available to plants?

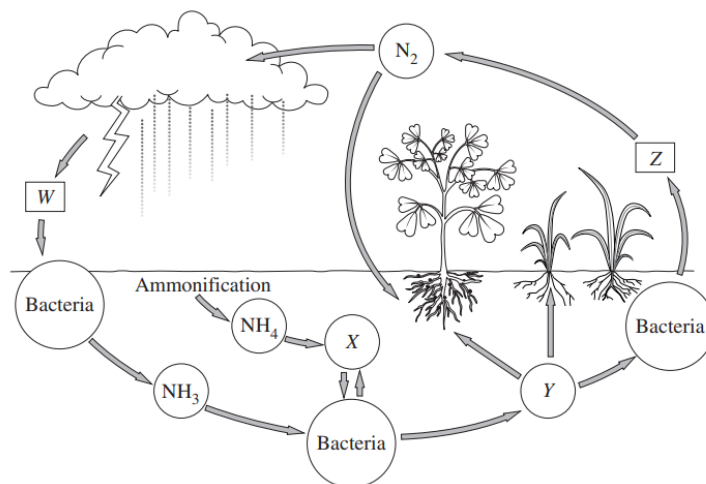
- a. Soil depth and percentage of clay particles
 - b. Soil depth and percentage of sand particles
 - c. Organic matter and percentage of clay particles
 - d. Organic matter and percentage of sand particles
23. The diagram shows a carbon cycle and the mass of carbon, in gigatonnes, in each component. ([2020 HSC Exam pack Q1](#))



Based on the diagram, which of the following shows carbon sinks in decreasing order of mass?

- a. Soil, surface ocean, vegetation, sediment
 - b. Vegetation, surface ocean, soil, deep ocean
 - c. Sediment, soil, deep ocean, fossil fuel and cement
 - d. Deep ocean, fossil fuel and cement, vegetation, soil
24. Which of the following features of soil cannot be changed by management practices? ([2020 HSC Exam pack Q2](#))
- a. Water-holding capacity
 - b. Nutrient status
 - c. Structure
 - d. Texture
25. A soil has a measured pH of 5.1 Which treatment would be the most effective in making this soil more productive? ([2020 HSC Exam pack Q3](#))
- a. Deep rip the soil to at least 40 cm.
 - b. Spread lime onto the soil and incorporate it into the soil.
 - c. Add organic matter to the soil by incorporating a green manure crop.
 - d. Add gypsum to the soil and allow the gypsum to incorporate naturally over time.
26. Soil microorganisms have various roles in the soil. In which of the following are three of these roles listed? ([2020 HSC Exam pack Q11](#))
- a. Build humus, lock up nutrients, improve soil texture
 - b. Break down humus, create soil structure, promote plant growth
 - c. Build organic matter, leach nutrients, glue soil minerals together
 - d. Return nutrients to mineral form, break down organic matter, fix nitrogen
27. A student assesses the size, shape and arrangement of soil peds in a sample. What characteristic of the soil is being assessed? ([2021 HSC Exam pack Q5](#))
- a. Texture
 - b. Porosity
 - c. Structure
 - d. Bulk density
28. Which soil characteristic is NOT influenced by the level of organic matter in the soil? ([2021 HSC Exam pack Q9](#))
- a. pH
 - b. Texture
 - c. Structure
 - d. Ion exchange capacity

29. The diagram shows a nitrogen cycle, with four of the components labelled W, X, Y and Z. (2021 HSC Exam pack Q20)



Which row of the table correctly names components W, X, Y and Z ?

	W	X	Y	Z
A.	Denitrification	Nitrite	Nitrate	Nitrification
B.	Denitrification	Nitrate	Nitrite	Nitrification
C.	Nitrification	Nitrite	Nitrate	Denitrification
D.	Nitrification	Nitrate	Nitrite	Denitrification

30. A student is conducting a test on soil and is using universal indicator and barium sulphate. For what soil characteristic is the student most likely to be testing? (2022 HSC Exam pack Q8)
- pH
 - Texture
 - Porosity
 - Organic matter
31. The space in soil between mineral particles, which may contain either air or water, is called: (2022 HSC Exam pack Q2)
- texture.
 - porosity.
 - structure.
 - bulk density

Short Answer responses

32. ([2014 HSC Exam pack](#) Q21) (8 marks) Answer parts (a), (b) and (c) in relation to an identified soil degradation problem

Name of a soil degradation problem.....

- a) Outline an effect of this soil degradation problem on agricultural production. 2 marks

- b) Explain how a farming practice can lead to this soil degradation problem 2 marks

- c) Describe procedures which can be used to alleviate or prevent this soil degradation problem. 4 marks

33. ([2015 HSC Exam pack](#) Q22) (6 marks)

- a) Describe the effect of organic matter (soil carbon) on a physical characteristic of soil. (2 marks)

- b) Explain how conservation tillage assists in maintaining soil fertility. (4 marks)

34. ([2015 HSC Exam Pack](#) Q23) (8 marks)

- a) Explain how soil texture influences the water-holding capacity of soils. 2 marks

- b) Explain how land capability assessment can be used to improve the long-term sustainability of Australian farms. 6 marks

35. ([2016 HSC Exam Pack](#) Q22) (7 marks)

- (a) Describe TWO techniques that farmers can use to improve or maintain soil organic matter (soil carbon) levels. 4 marks

36. ([2017 HSC Exam pack](#) Q22) (7 marks)

- a) Outline the beneficial roles played by microbes in soils. 3 marks

- b) Explain how TWO soil management techniques can increase the population of microbes in the soil (4 marks)

37. ([2017 HSC Exam pack](#) Q23)

- c) Explain an advantage and a disadvantage of ONE method farmers can use to improve soil moisture. (4 marks)

38. ([2018 HSC Exam pack](#) Q21-C)

- c) Explain ONE strategy that can be used to alleviate a soil degradation problem. 4 marks

Name the soil degradation problem

39. ([2019 HSC Exam pack](#) Q22) (6 marks)

- a) Name TWO physical characteristics of soil. (2 marks)

- b) Describe a method that can be used to test ONE specific physical or chemical characteristic of soil (4 marks)

40. ([2019 HSC Exam pack](#) Q24-C)

- c) Explain how TWO techniques are currently used to sustainably manage soil fertility on farms. (6 marks)

41. ([2020 HSC Exam pack](#) Q21) (9 marks)

Answer parts (a)–(c) with reference to a soil degradation problem you have studied.

Name of problem.....

- a) Outline the named problem (2 marks)

- b) Explain how a land use practice has led to this problem. (3 marks)

- c) Explain how a sustainable management practice can alleviate this problem (4 marks)

42. [\(2021 HSC Exam pack Q21\)](#) (6 marks)

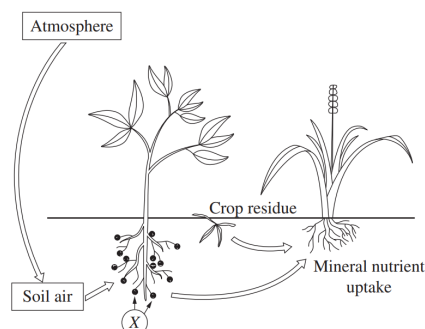
- a. Outline how ONE management practice has contributed to a soil degradation problem. 2 marks

- b. Explain how ONE procedure alleviates a soil degradation problem and ensures the long-term sustainability of the soil. 4 marks

43. [\(2022 HSC Exam pack Q21\)](#)

- a. Describe the role of ONE invertebrate in decomposition within the soil. 3 marks

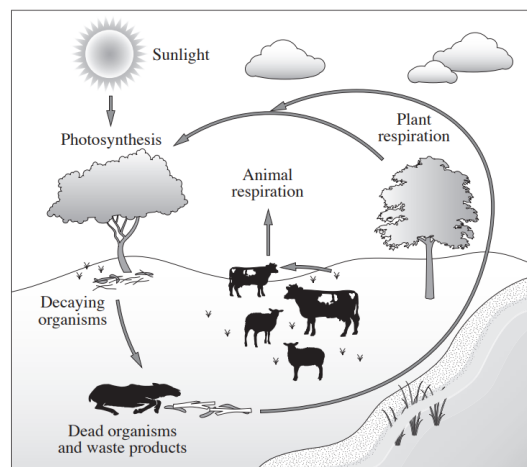
- b. The following diagram depicts part of a nutrient cycle.



Identify the process occurring at X and explain how this process contributes to the cycling of the nutrient. 4 marks

44. ([2023 HSC Exam pack](#) Q21)

Use the diagram to answer parts (a) and (b)



a) Identify the nutrient being cycled in the diagram. (1 mark)

b) Outline the role of soil nutrient cycles in agriculture. (2 marks)

c) Describe the importance of invertebrates in both decomposition and nutrient cycling. (3 marks)
