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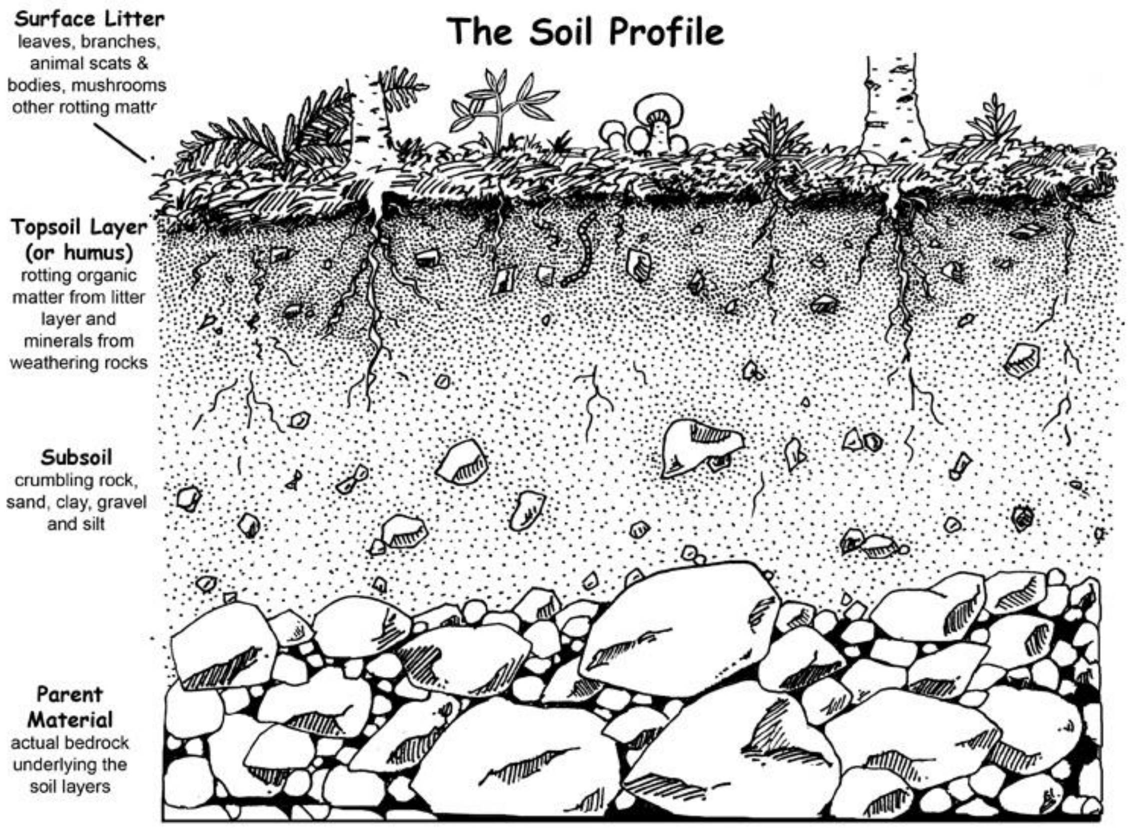
Unit Standard 22174

Demonstrate knowledge of soils and fertilisers

Version 2 Level 2 Credit 5



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Introduction

Soil is very important to New Zealand's horticultural and agricultural economy. Along with water, carbon dioxide and nitrogen from the atmosphere and energy from the sun, it provides the raw materials for all our plant and animal-based agriculture.

Soil is a natural substance consisting of a mixture of mineral and organic materials. Soils differ from one another because the materials that make up each soil type can vary considerably.

The aim of agriculture, horticulture or forestry is to produce products (plant or animal) from the soil. To achieve this, soils must be managed and maintained to ensure that products can be produced for future generations. Poor management of the soil will result in a lowering of its fertility.

This learning module is about soils and fertilisers. When you have finished this module you will be able to:

- describe the composition, texture and structure of soil
- describe how soil components and structure influence plant growth
- identify and describe major soil types in New Zealand
- describe and compare different soil types according to their use
- describe the role of fertilisers and lime for plant health and growth

Figure 1: Soils

Image from Tullottes, 2009.
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What is soil?

Soil is basically the thin layer of material on the earth's surface in which most plants have their roots.

Soil provides plants with a base to firmly fix and support them and also supplies plants with nutrients.

Soil is a mixture of broken down rocks and minerals, decaying organic matter, air and water. The proportions of these materials vary with the type of soil the environment and the plants growing in them. A good loam soil made up of:

- Minerals 45%
- Organic matter 5%
- Water 25%
- Air 25%

M**inerals** come from the breakdown and **weathering** of **parent material** or **bedrock** underground.

Organic matter consists of **humus**, plant roots, dead and decaying plant materials, animals and their litter.

Under a microscope soils appear to consist of a lot of small granules with bits of rock and dust, small bits of plant material and microbes. There is often a lot of space between the particles.

Water and **air** can fill these spaces between the soil particles.

The importance of these components to soils and plants is discussed in more detail below.

First let us take a look at how soils are formed.

Soil formation

Soil formation takes a long time and usually happens over thousands of years. Soil is formed by **weathering** of rocks and minerals, the action of plants and animals and the unique chemistry of the resulting soil.

In the early stages of soil development weathering gradually breaks down large rocks into smaller and smaller pieces (e.g. into gravel and sand). This happens in several ways.

Water falling as rain can seep into cracks in rocks and when it freezes the ice slowly expands in the cracks. This expansion can create enough pressure to split even huge rocks apart – in the same way that frozen water can burst a water pipe during winter.

Figure 2: Rock cracked by freezing ice

Image by Carlog3, 2010.
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The rivers of ice which flow down mountains as glaciers also grind over mountain bedrocks, slowly reducing them to a powder. It is this fine rock flour which gives the South Island lakes around Mt Cook their milky blue colour. Look for some images of Lake Pukaki or Lake Tekapo on the Internet to see this milky blue colour.

Wind and running water also play a part in weathering. Wind and water can carry small particles of rock which can scour against the larger rocks, gradually wearing them down. Think of the sandblasting you can get on a windy beach or the scouring cream (e.g. Jif) you can use to clean the bathroom. New Zealand's mountains are weathered (and ground down) by wind and water to form the gravels in the beds of rivers and the sand on beaches.

Water can also absorb carbon dioxide from the air which makes it acid (like vinegar). This weak acid can dissolve limestone creating holes and channels in the rock, e.g. limestone caves.

Figure 3: Limestone weathered by wind and water

Image by Jstuby, 2009.
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Over time, lichens and mosses grow on the fragments of rock and sand. The wind may blow leaves, twigs and other organic matter over the rocks. These become mixed with the rock particles.

Later, small plants may germinate in the young thin soil and these attract insects and other organisms such as earthworms. They may eat the plants and drop their litter onto the soil.

When plants and animals die their decaying remains add more organic matter. Decaying matter builds up making the soil thicker and richer. This attracts more, sometimes larger, plants and animals. This continues until the soil is fully formed. The soil may then support many different plants and animals, depending on its final characteristics.

Soil components

Minerals

Soil minerals are the tiny particles of rock formed by the breakdown of solid rock by wind, water, frost and heat from the sun. This is the process called weathering. As rocks weather they release chemical **nutrients** which plants need for growth.

As the bedrock continues to weather the mineral particles becomes gradually smaller. The size of these particles determines **soil texture**. This refers to the proportions of **sand**, **silt** and **clay** particles in the soil. This is explained in detail later in the module.

Most soil minerals come from the bedrock or **parent material** the soil formed from. Mineral content and nutrient chemistry of soils changes according to the bedrock. For example, minerals and nutrients in soils formed from **volcanic** rocks can be quite different from soils formed from **limestone**, **schist** or those formed from **greywacke** (the main type of rock in the mountains of the Southern Alps).

Volcanic basalt

Image by Kovalchek, 2010. Licenced under CC BY 2.0

Limestone

Image by Szilas, 2014. Licenced under CC0 1.0

Schist

Image by Wilkins, 2008. Licenced under CC BY-SA 2.0

Greywacke

Image by Law, 2009. Licenced under CC BY-SA 2.0

As mineral particles are ground down the nutrients contained in them are gradually released. This is caused by the action of water and weak acids released by activity of animals and plants in the soil. These nutrients dissolve in the soil water and can then be taken up and used by plants.

Rock type also determines how easily the nutrients are released from mineral particles. For example, nutrients are released from limestone more readily than from volcanic rock.

Other nutrients can be added to soils as fertiliser. However, the soil type will determine what extra nutrients are needed and how well the soil will be able to retain them for plants to use.

Plant nutrients from soil minerals

For plants, the most important chemicals in the soil mineral particles are the **inorganic nutrients** which are essential for plant growth. The main inorganic nutrients supplied by soil minerals are:

- Phosphorus (P)
- Potassium (K)
- Calcium (Ca)
- Magnesium (Mg)

- Sulphur (S)

Soil minerals also contain important **trace elements** (often called micronutrients). These are discussed in detail later in the module.

Nitrogen (N) is also an important inorganic mineral but it does not does not come from soil parent material (bedrock). It comes from the atmosphere and from breakdown of organic matter. This is explained later.

Organic matter

Organic matter is a wide range of substances which come from living and dead organisms in the soil e.g.:

- living plant roots
- living bacteria, fungi, micro-organisms and invertebrates
- remains of dead plants, bacteria, fungi, insects and worms etc.
- humus

Most of the organic matter is concentrated in the dark, rich topsoil layer, also known as the 'O' Horizon (explained below).

The soil ecosystem

The topsoil layers of most productive soils are biologically very active. In fact biological activity is essential for a natural soil to be highly productive. Soil organisms form a complex ecosystem which continuously breaks down and recycles dead and decaying organic matter and soil nutrients.

Plants push their roots into the soil, breaking up the soil and allowing air and water to move into and through the soil. They also drop litter onto the surface of the soil which become a source of nutrients for soil organisms.

Invertebrates such as insects, slaters and worms also dig around in the litter layer and topsoil turning it over and transporting nutrients into the topsoil. They also stir and aerate the soil particles keeping the soil **friable.** This creates and maintains soil air spaces (**soil pores**) and allows water to soak in into and drain through the soil.

The organisms prey on each other and consume and digest bacteria, fungi and dead and decaying plant matter. This returns the nutrients in their body tissues to the soil in their droppings.

Earthworms are particularly valuable because they turn over and mix the organic matter in the topsoil as they burrow through it. They feed on bacteria in the soil, returning their nutrients to the soil in their droppings (**worm-casts**). Their digestive system also helps to release nutrients from the mineral soil particles passing through it.

Bacteria and fungi also help to break down dead and decaying plant materials in the litter layer and topsoil, releasing their nutrients into the soil.

The result of this bacterial, fungal and animal activity is **humus.**

Figure 4: The soil ecosystem.

Image retrieved from http://nature.pagannewswirecollective.com/search/soil+ecosystem

Humus

Humus is the end product of decomposing organic material in the soil. It makes up about 80% of the total organic matter and is the most important organic material in the topsoil.

Humus is a dark, sweet smelling, jelly-like material which gives the surface layers of healthy soil (and garden compost) its characteristic dark brown colour. Humus is sticky and has a very high water holding capacity. That is why rich topsoil and well-made garden compost sticks to your boots and gardening tools.

Benefits of humus for soils and plant requirements:

- **Water retention**. Humus is the substance which helps soil to hold moisture. Humus can hold up to a hundred times its weight in water. It also acts as a 'wetting' agent which makes it easier for water to seep into soil.
- **Nutrient retention**. Humus holds nutrients in the soil but in a form that makes it easy for plants and other soil organisms to use. Humus also helps to retain nutrients in the soil and prevent them being washed out of the soil (leaching). Without humus nutrients can quickly leach away.
- **Improves soil structure**. Humus is very important for good soil structure. Humus helps to stick individual soil particles together into aggregates or crumbs. This allows air and water to penetrate into the soil more easily, improving drainage and aeration around plant roots. This is explained in more detail below.
- Helps to warm the soil. Dark humus-rich soil absorbs the sun's heat so that it warms up quickly in the morning. The air in the soil acts as insulation (like a duvet) which helps to maintain soil temperature in the evenings. This helps keep the soil temperature constant over the day.

Air

Many of the organisms living in the soil, including plant roots, need oxygen for the chemical reactions in their cells. Therefore it is important that these organisms and plants roots have access to air.

Air normally filters through the soil between the soils granules. These spaces are known as **soil pores**. The size of the pores and the amount of aeration in the soil depend on soil structure. In general soils with a crumb structure will have larger soil pores and better aeration than fine sandy or silty soils. This is explained in more detail below in the section on “soil structure”.

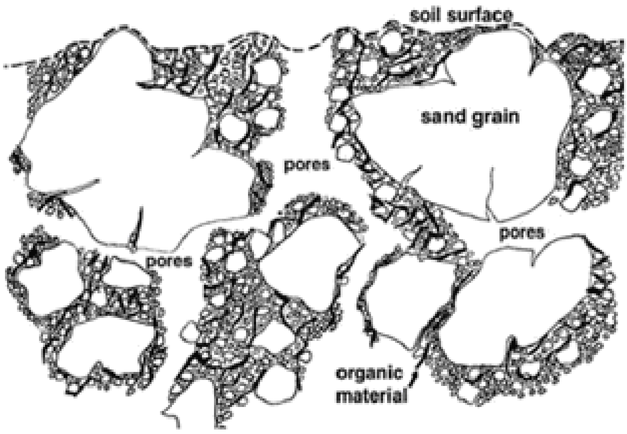


Figure 5: Pore spaces between soil

Image from http://mea.com.au/soil-plants-***climate***/soil-moisture-monitoring/learning-centre/what-is-soil-structure

For optimum plant growth the soil must be able to supply enough oxygen to meet the needs of both soil micro-organisms and plants.

Without enough air (oxygen) the soil ecosystem will gradually die. Biological activity in the soil will slow down or even stop. This will slow down nutrient recycling and release of nutrients into the soil. This reduces the soil’s natural fertility and nutrient supply for plant growth.

Cells in growing plant roots are usually biochemically very active. Root cells need to use energy to absorb nutrients from the soil. Oxygen is needed to drive the energy systems in the cells. Without enough oxygen the plants’ roots will not be able to absorb nutrients from the soil. The plants will not grow very well – whole crops may be unproductive. If oxygen is totally absent the plants will die.

Plants also need nitrogen (N) to make amino acids and proteins for growth. Some of this may come from N in the air. Plants can’t use N directly from the air. However, some soil microorganisms can take N from the air and ‘fix’ it into nutrients that they can use for their own growth. Usually they make more than they need and the surplus leaks out into the soil. Nearby plants can absorb these ‘leaked’ nutrients and use them for their own growth processes.

There are many types of free-living of bacteria in the soil which can fix nitrogen. However, some types form a special symbiotic relationship with plant roots. An example is the bacterium *Rhizobium* which lives in nodules on the roots of the clover plants. *Rhizobium* fixes nitrogen from the air in the soil pores and the clover plants can make use of any excess left over by the microorganisms.

If nitrogen-fixing bacteria can’t get enough N from the air in the soil, they will not be able to fix N and the fertility and productivity of the soil will be reduced.

The special role of N fixing microorganisms (including *Rhizobium*) in soil fertility is explained in more detail later in the module (in Nutrient requirements of plants).

Aerobic and anaerobic soils

Soils which are aerated enough to meet oxygen demands of the soil ecosystem and plants are called **aerobic** soils.

Poorly drained and waterlogged soils are often lacking in oxygen (oxygen deficient). This is because the soil pores are full of water which displaces the air. Oxygen deficient soils are called **anaerobic** soils.

For many plants if the oxygen level in the soil air drops below 10-15% the rate of root growth is reduced.

Aquatic and swamp plants are specially adapted for low soil oxygen levels. An example is rice which grows in paddy fields with their roots submerged in water.

Water

Nearly all the biological, chemical and physical processes in plants and animals rely on water.

Water, like air, is held in soil pores, the spaces between soil particles. The way water behaves in the soil and its value to plants depends mainly on the size of these pores. This is related to the texture and structure of the soil. This is explained in more detail below, in the section on soil structure.

Water is essential for plant growth for four main reasons:

1. Water is one of the essential raw materials for **photosynthesis**. This is the process in which green plants use the energy from sunlight to combine carbon dioxide from the air and water absorbed from the soil to make sugars. These sugars are then used to provide energy and raw materials for all the other biochemical processes for plant growth and reproduction. Without water photosynthesis cannot occur and plants will wither and die.

2. Plants can only absorb mineral nutrients from the soil when they are dissolved in water. Scientists call this '**in aqueous solution**'. Minerals dissolved in the soil water move through the soil along with the water to bring fresh supplies of nutrients into the plant's roots. Plants cannot absorb mineral nutrients when the soil is too dry.

3. Nearly all **biochemical reactions** take place in the water in plant cells (in aqueous solution). Water is also used to move sugars, minerals, and other nutrients and chemicals around the plants via the tubes in stems and veins in leaves. Without water these biochemical reactions and nutrient movements cannot occur.

4. Water which fills plant cells also **provides support** for plants. Many plants use water pressure to stand erect and maintain their shape. If the cells are full of water and each cell is firm (**turgid**) the plant

stands tall. If the plant lacks water the cells will collapse and the plant will wilt. If a wilted plant cannot get enough water to recover it will die.

On cropping and horticultural properties a reliable source of soil moisture improves seed germination, growth rates, flowering and fruiting of plants. In livestock farming, it improves pasture growth rates and nutritive value of the pasture. This makes livestock grow faster and produce more milk, meat and wool. It also improves reproductive performance (e.g. lambing/calving rates and survival).

Soil types

There are many different types of soil. The type and characteristics of soil in a particular place depends on:

- parent material or bedrock from which the soil was formed
- climate during the period the soil was forming
- plants growing on the soil and organisms living in the soil when it was forming
- slope of the land
- length of time the soil has been forming
- human activity (e.g. horticulture, farming, cultivation, fertiliser application)

As these factors change slowly with time so the soil characteristics also change. Soils are continuously evolving and changing and there is almost infinite variation in soil types and characteristics.

Describing and comparing soils

Soils are usually described and compared by their **soil profiles**.

A soil profile is a vertical, cross-section view down through a soil from the surface to the bedrock.

Figure 6: Soil Profile

When you look at soil profiles, many appear to be made up of more-or-less horizontal layers. Soil scientists call these layers **soil horizons**. The characteristics or features of these horizons are used to describe and classify soils. We will see more about soil classification shortly.

Soil scientists usually study soil profiles by digging a pit in the soil. Soil profiles and their horizons can often be seen on the exposed areas of road cuttings and other earthworks.

The main characteristics compared in soil horizons are:

- colour
- texture
- structure
- thickness and boundaries of horizons
- presence of roots or organisms

Figure 7: Measuring soil colour

Colour

Soil colour depends partly on the colour of the parent material. For example the fertile volcanic soils used for horticulture around Pukekohe, south of Auckland are quite red. In contrast, coastal sandy soils are often pale yellow or brown. White or light grey soils may contain a lot of silica or lime. Yellow, brown or red soils usually contain iron compounds.

Colour is also an indicator of how well water drains through the soil, i.e. its **drainage characteristics**.

- Dark soils usually contain a lot of organic matter. Organic matter holds water well but drains easily so it doesn't usually get waterlogged (unless something else is causing waterlogging, e.g. flooding).
- Grey or grey-blue colours often indicate soils which don't drain very well and are prone to waterlogging.
- Yellow brown colours generally indicate dry, free draining soils with less water holding capacity.
- Orange mottling is also an indicator of prolonged waterlogging.

Texture

Texture describes how coarse or fine a soil is. It refers to the size and proportions of mineral particles in the soil. Soil scientists often talk about **sand**, **silt** and **clay** soils. These terms refer to the size and proportions of mineral particles present in the soil.

Sand is usually described as having individual grains from 2mm down to 0.02mm (two hundredths of a millimetre). Sand and sandy soils feel gritty when you rub them between your fingers.

Silt is finer than sand, down to 0.002mm (two thousandths of a millimetre). This is finer than wheat flour or cocoa powder and does not feel gritty like sand. Silt and silty soils feel smooth and floury.

Clay is made up of even finer grains of a particular mineral which soaks up water and sticks the grains together to make a gluey paste. Clay and clay soils usually feel sticky and plastic. Clay used for pottery and sculpture is actually a clay soil which contains almost 100% clay particles.

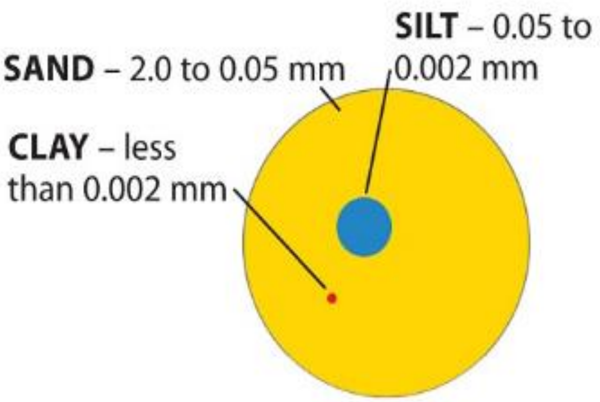


Figure 8: Comparison of particle size

Image from http://soils4teachers.org/physical-properties

Proportions of sand, silt and clay

Soil characteristics depend on the proportions of sand, silt and clay. These proportions are also used to describe and classify soils into different types.

Below is a triangular soil texture diagram which soil scientists use to describe soil texture types.

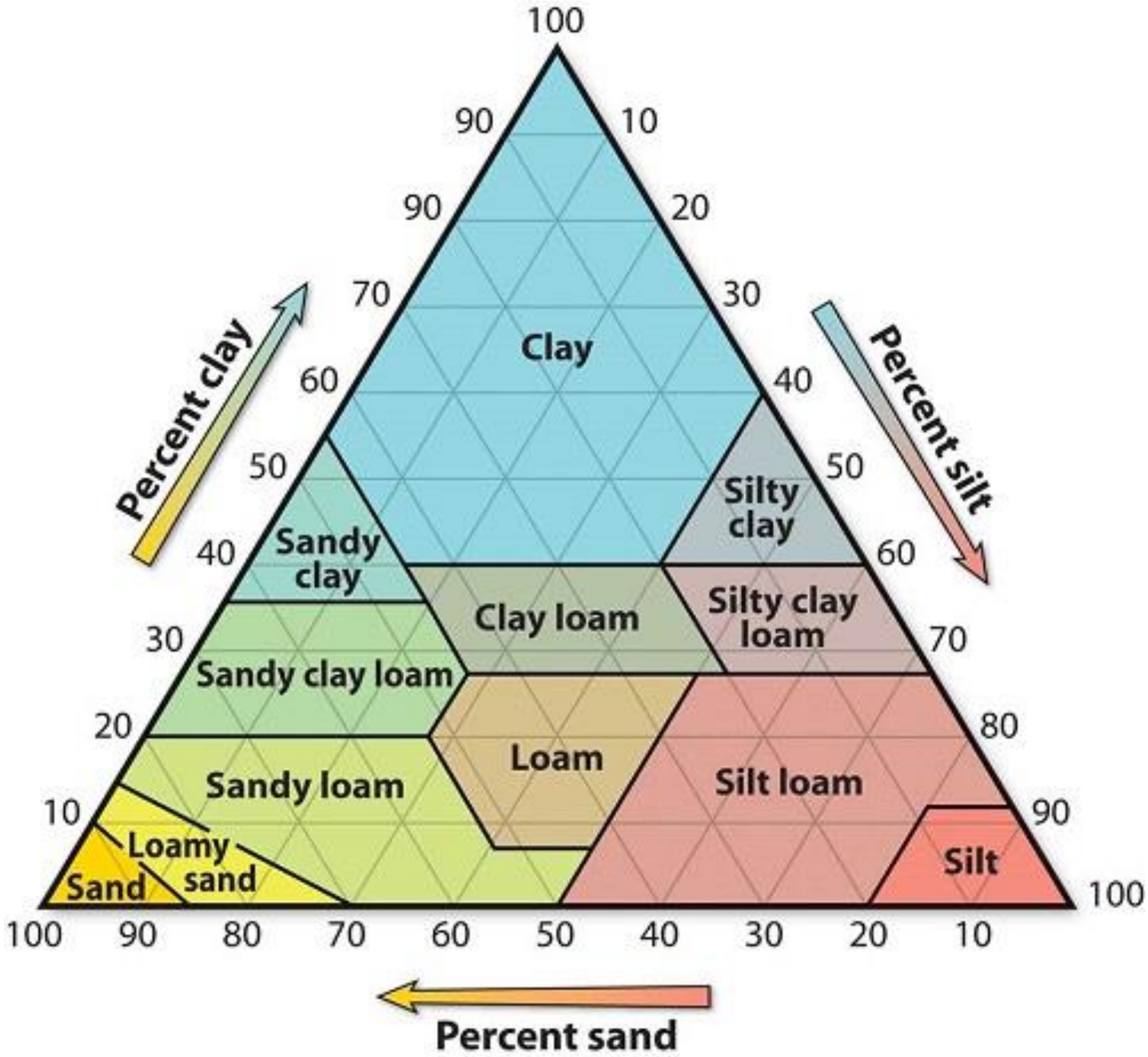


Figure 9: Soil texture types according to the proportions of sand, silt and clay

Image from http://soils4teachers.org/physical-properties

Clay soils are those which have more than 40% of their soil particles smaller than two-thousandths of a millimetre. Because of the sticky nature of clay particles, this type of soil would be sticky or gluey.

Sandy soils usually contain more than about 50% of the larger 'sand' grains. This would be less sticky and more crumbly than clay soils.

Silty soils usually contain more than about 40% silt and a low proportion of clay. It would feel smooth and gritty but not sticky.

A **loam** is a soil that contains a 'balanced' mixture of sand, silt, and clay. Loamy soils are usually more fertile than sandy soils, and hold more water.

Identifying soil texture types

It is difficult to judge soil texture using the particle size diagram without a laboratory to analyse the soil. But it is easier to identify the main soil texture types by feel. The table below describes some characteristics of the main soil types which can be judged by feel.

Sands	Consist of mostly coarse or fine sand particles, containing very little clay so that the particles do not stick together when they are wet or dry
Loamy sands	Consist of mostly sand but with sufficient clay or silt to stick particles together to make it plastic when moist.
Silt loams	Similar to sandy loams but more silt makes the soil slightly sticky, some sand present to make it feel gritty.
Clay loams	Mostly clay and silt which makes it sticky when you mould it. Still a little sand.
Sandy Clays	High proportion of both sand and clay making it gritty and very sticky when wet.
Sandy loams	Mostly sand particles by enough clay or silt to make it possible to mould in your hands without sticking to your fingers
Sandy clay loams	Mostly clay and sand making it distinctly sticky but gritty. More obvious sand content that clay loam

Another method is to use a soils texture 'key':

Activity – Identifying soil texture types by "feel"

An example of a soil texture key devised by Rutgers New Jersey Agriculture Experimental Station in the United States can be found at http://www.ndhealth.gov/wq/sw/z1_nps/pdf_files/soil_texture_feel_test.pdf. It is called **Determining Soil Texture by the "Feel Method"**.

Gather together a few different soil samples from your neighbourhood and try using the flow chart to identify the major soil texture types

We will look again at the characteristics and uses of sand, silt, clay and loam soils later when we look at soil classification.

Soil texture and water

The proportions of sand, silt and clay will also partly determine the amount of water (and air) the soil can hold, and how quickly water can soak into and drain from the soil.

If the soil is made up mostly of large grains (e.g. sand) it is likely that there will be a lot of space (**large pores**) between them (see the right side of the diagram below). Water can soak into and drain very easily through sandy soils, so they easily dry out.

In comparison, the tiny particles in clay soils pack together very tightly so the space between particles is very small (**small soil pores**). Water soaks into and drains from clay soils very slowly so that it easily becomes waterlogged. Water movement in silt soils lies between these extremes.

Soil pore size, water and air content are also affected by soil structure and organic matter content. These are explained in more detail below.

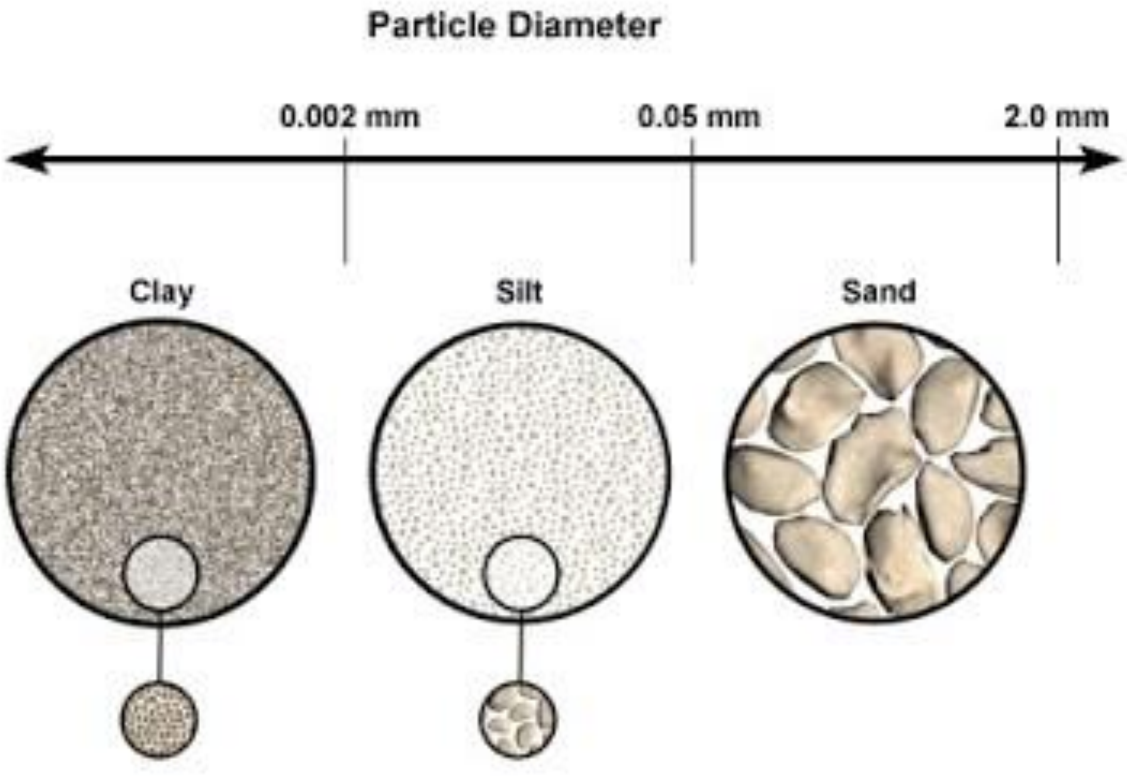


Figure 10: Shows how the spaces between soil particles changes with particle size.

Image from http://stream2.cma.gov.cn/pub/comet/HydrologyFlooding/RunoffProcessesInternationalEdition/comet/hydro/basic_int/runoff/print.htm

Structure

Structure describes how the individual particles of sand, silt, and clay become clustered together into granules and clumps. Soil scientists call these **aggregates**. The types of soil granules and clumps that we see hanging to plant roots when we pull them up are an example of soil structure.

Soil structure depends on:

- Particle size and shape, e.g. sand, silt or clay
- Type of mineral, e.g. the soil parent material or bedrock
- Organic matter content, which can act as glue and can hold water in the soil

The 4 main types of soil structure are:

1. Crumb (or granular)
2. Platy
3. Block
4. Fine

Crumb (or granular)

In crumb or granular soils the mineral particles are clumped together into granules resembling large biscuit crumbs, usually less than 0.5 cm in diameter (e.g. between the size of a rice grain and a pea). This commonly found in the surface layers of the soil where plant roots have been growing. Organic matter (i.e. sticky humus) helps to hold the soil particles together as crumbs. This helps to stabilise the soil and prevent it from being washed or blown away (**it resists erosion**).

Figure 11: Crumb (or granular)

Image from ftp://ftp.fao.org/fi/cdrom/fao_training/FAO_Training/General/x6706e/x6706e07.htm#top

Generally it is the best structure for growing plants because it holds water well but drains freely and has plenty of air spaces (pores) between the soil particles. Plant roots can easily penetrate between soil particles to get at nutrients water and air.

Platy

Platy soils are made up of flat layers particles parallel to the soil surface. They are often found in compacted soils. The pore spaces between the layers are small so they are difficult to drain and have poor aeration. Plant root systems may struggle to penetrate between the layers and may stay near the soil surface. Platy soils have less organic matter to hold the particles together so they tend to be drier and crumbly and are more likely to be affected by erosion.

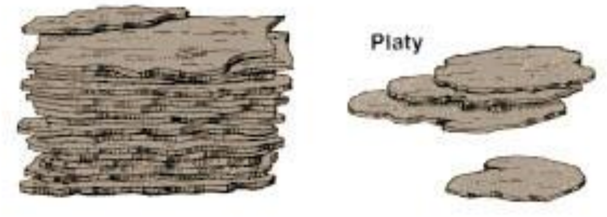


Figure 12: Platy

Image from
ftp://ftp.fao.org/fi/cdrom/fao_training/FAO_Training/General/x6706e/x6706e07.htm#top

Blocky

Blocky soils clump together into irregular solid granules or lumps (clods), usually between 1.5 – 5 cm or even larger. Water doesn't soak into the lumps and the spaces between the clumps are so large that water drains away very easily. These soils have very little organic matter and it is difficult for plants (especially small plants) to establish a good root system in blocky soils.

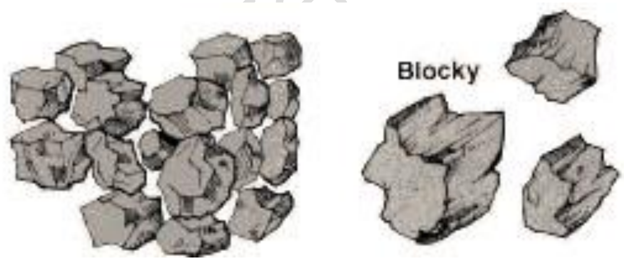


Figure 13: Blocky

Image from
ftp://ftp.fao.org/fi/cdrom/fao_training/FAO_Training/General/x6706e/x6706e07.htm#top

Fine

Fine soils are broken into individual loose grains that do not stick together. They have a very loose, flowing structure that is easily eroded. They are free draining and have good aeration but they don't hold water well. They are often lacking in organic matter so they are not very fertile. Commonly found in sandy soils.

In summary:

Soil structure affects:

- soil aeration
- water holding capacity of the soil
- the movement of air and water to and from plant roots
- nutrient cycling within the soil
- root penetration and development (in the soil pores)
- soil stability and its susceptibility to erosion
- soil temperature

Good soil structure

- improves seed germination and emergence
- allows roots to easily penetrate and grow into the soil providing plants with nutrients and a good, deep anchor
- promotes good plant growth and health
- promotes good crop quality through reduced fertiliser requirements
- encourages earthworms which improve the soil
- makes soil easier to cultivate which discourages weeds, reduces disease outbreaks and insect attacks

Horizons and boundaries

To recap, horizons are the layers we see in a vertical cross-section through the soil.

For most practical purposes soil scientists recognise 5 main horizons (layers) in a soil profile. Each horizon is identified by a letter:

O horizon

The top most layer of the soil containing mostly organic material ('O' for organic). Organic Matter collects on the surface of the soil like a rich carpet. Earthworms, other insects, invertebrates, mammals such as rabbits which burrow, and birds such as kiwis, incorporate this layer into the soil.

A horizon

If present this will be immediately below the O layer. It is commonly referred to as **topsoil**. This layer is usually the most fertile because of the organic matter which has accumulated from plant and biological activity. It is usually the 'brownest' or darkest of the layers because it contains decomposed organic matter (humus). In this layer, roots are most dense and nutrients most prevalent. This rich mix stimulates microorganisms, which results in a high biological activity.

B horizon

Immediately below the A horizon and containing less organic matter, the B horizon is often referred to as **subsoil**. It is often different in structure and texture to the A horizon. It usually has a denser structure than the A horizon, making it more difficult for plants to extend their roots. The B horizon often shows accumulations of mineral particles such as clay and salts due to leaching from the topsoil.

C horizon

Usually this is made up of broken down parent material which has not been chemically changed during soil formation. This may be the parent material (bedrock) from which the A and B horizons were formed but this is not always so. This layer may have deposits of sand, gravel, pebbles, boulders and rock in various mixtures. The original parent material could be deposits from glacial activity, from sand and silt carried by the wind, from sediments carried by flowing water, including water in flood plains, or from gravity moving material down a slope.

R Horizon

This last layer is the unchanged parent material or bedrock from which the soil originally came ('R' for rock).

The boundaries between the horizons are also important as they can provide information about how soil nutrients move through the soil. Sharp boundaries might indicate sudden changes in soil properties or chemistry which might prevent plants from taking up nutrients. They may also affect water drainage from the upper horizons.

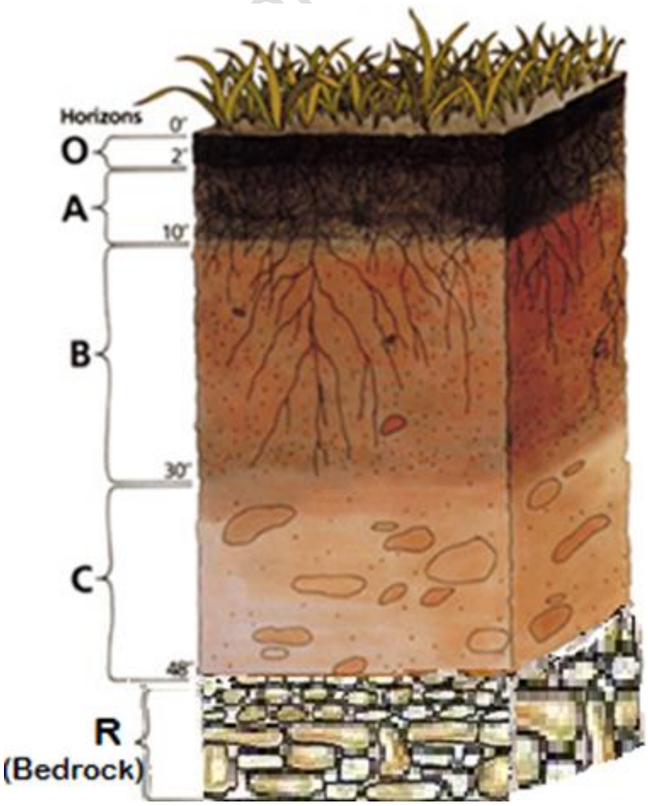


Figure 14: Soil horizons

Roots and organisms

The presence of roots and other organisms, particularly the depth and distribution of plant roots and earthworms, may highlight changes in soil properties down through the soil profile. For example, many plants normally concentrate most of their root growth where they can reach plenty of nutrients. Similarly earthworms and other soil organisms usually live in the topsoil where most of the nutrients are.

If downward root growth or evidence of earthworm activity suddenly stops at a particular soil horizon it may be a clue that the type and amount of nutrients changes abruptly at that point. Generally most pasture and crop roots will be in the topsoil. Root penetration will also depend on moisture, e.g. irrigated pasture may have a lot of shallow roots compared to deeper roots in a pasture watered more deeply but less often. Some root vegetables such as parsnips and carrots need deep topsoil horizons soil so that they can develop their characteristic edible taproots.

Self-review 1: The composition of soil

1. List the 4 main components of soil and their proportions in the soil.
2. Where do the minerals in soil come from?
3. Where does the organic matter in soil come from?
4. List the main inorganic nutrients that are supplied by soil minerals?
5. List the 4 ways organic matter (humus) benefits the soil and plants
6. Why is air important in soil?
7. List at least two reasons why soil water is important for plant growth.
8. What does the term soil texture describe about soils?
9. List the 4 main categories which are used to describe soil structure
10. List at least 4 ways soil structure affects soils
11. List the 5 main soil horizons and their main characteristics

Check your answers at the end of the module.

Soil classification

Soil classification is a way of describing and comparing different soils. It is also used for grouping together soils with similar profiles and properties. This is useful for soil management because management practices (e.g. irrigation, cultivation and, to some extent, fertiliser treatments) developed for one soil can be used on other soils with similar characteristics.

Soil classification can also be used to map similar soil types throughout New Zealand. This can then be used to determine the suitability of land for different agricultural or horticultural purposes.

There are many different ways of naming soils, but the most comprehensive scientific naming system is the New Zealand Soil Classification devised and managed by Landcare Research. You can see it on-line at the New Zealand Soils Portal (http://soils.landcareresearch.co.nz)[1].

The website explains the background of soil classification, and identifies and describes the main soil orders. It is linked to a detailed database of soil location maps so that you can find the predominant soils in your area (see the **Activity** section below).

For soil scientists the New Zealand Soils Classification involves a complex hierarchical naming system (like a family tree), similar to the way we organise and name animal and plant species (taxonomy). This system consists of orders, groups, subgroups and soil series.

However, this level of detail is not required for this learning module so, after the following activity, we will concentrate on the main soil types relevant to horticulture and agriculture in New Zealand.

[1] If you prefer, this information is also available as a book***: Hewitt A.E 1998 New Zealand Soil Classification. Lincoln Canterbury. Manaaki Whenua Press.*** This book is in the Telford Library and is usually available in most major public libraries.

Activity - The New Zealand Soil Portal

In this activity you will briefly explore some of the features of the New Zealand Soil Portal. There is a lot of information at this website, and much of it is beyond the scope of this module. However, it is interesting and in this activity we will concentrate on just the soil names and their characteristics.

Go to the New Zealand soil portal: http://soils.landcareresearch.co.nz. Or you can do an internet search for New Zealand Soil Portal and follow the links.

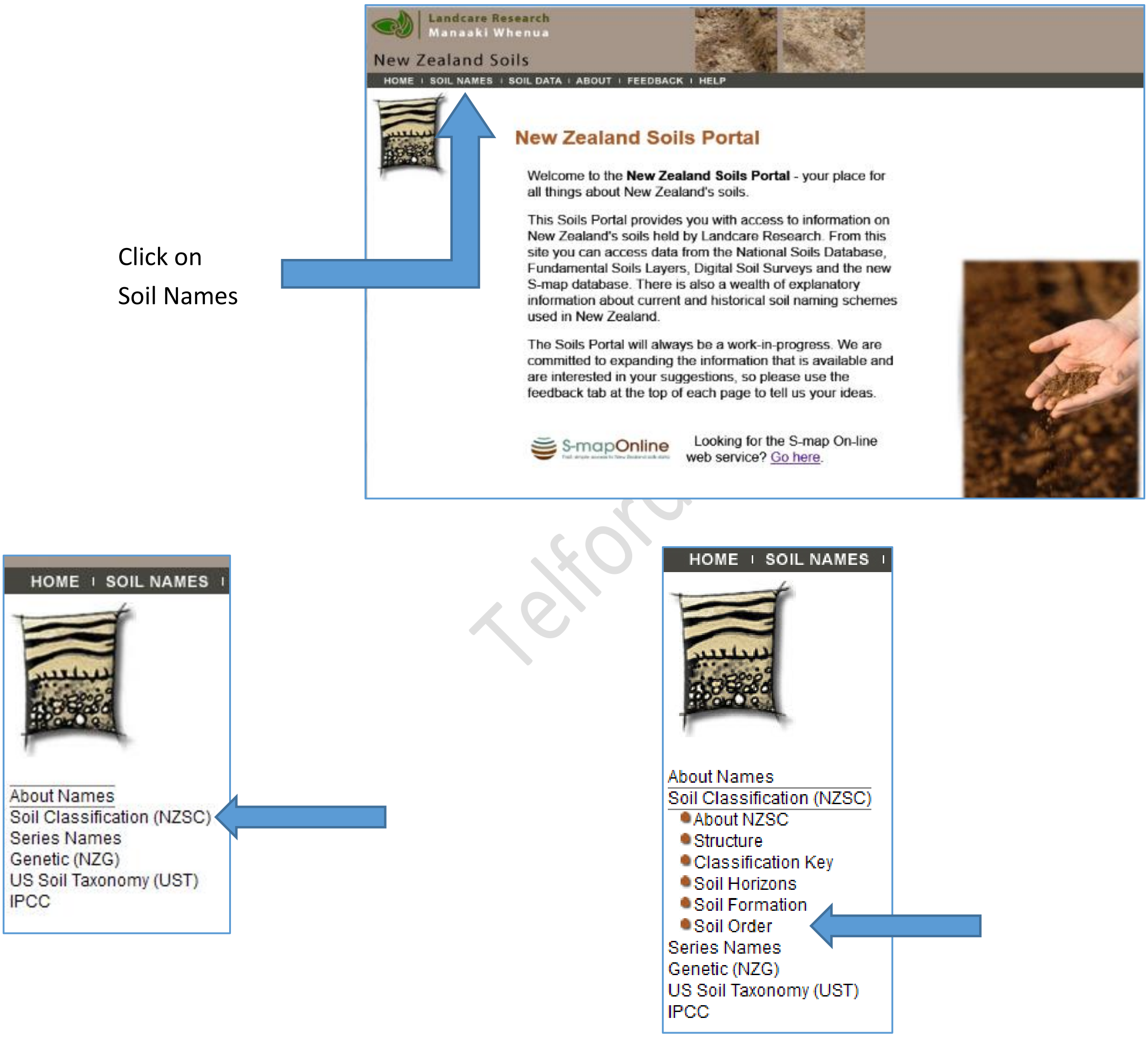


Figure 15: Activity

Image retrieved from http://soils.landcareresearch.co.nz/contents/index.aspx

This will take you to the **Soil Orders** page:

Each main soil type (the soil portal calls these orders) has a description and diagram of its soil profile. Perhaps the most interesting part of the website is the interactive map showing where different soil types occur. Use the map to zoom into your own location, horticulture block or farm and find out the local soil type.

For example the screenshot below shows the location of the Telford Farm near Balclutha in South Otago.

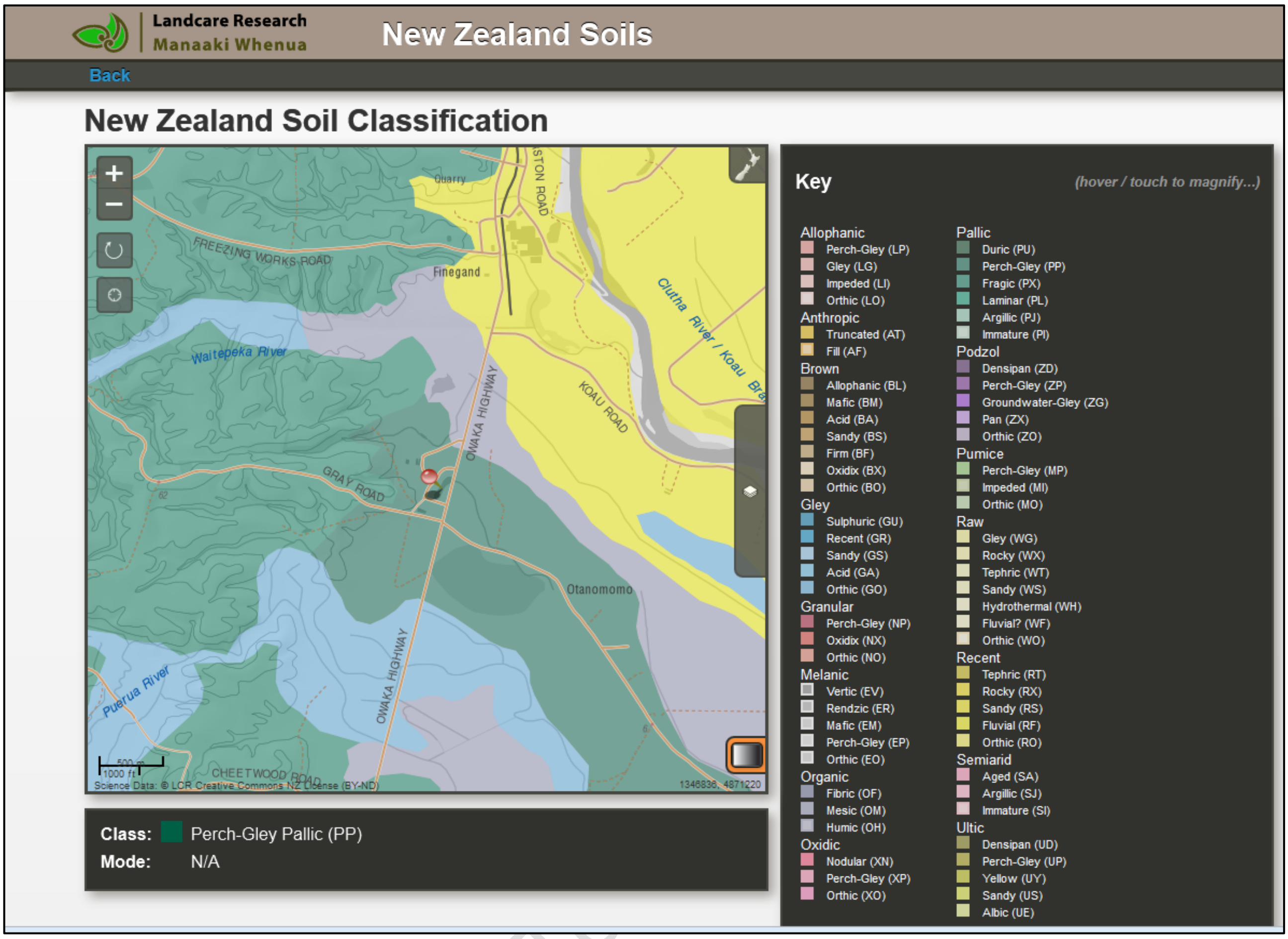


Figure 16: Telford Farm Map

Image retrieved from soils.landcareresearch.co.nz/maps/soilportal.html?Service=NZ&LayerSetName=FSL_NZSC_Layers

The map identifies that the main soil type is Perch-Gley Pallic (PP).

Go back to one page and click on **Pallic** to get information on that type of soil:

: Pallic Soils [P]

A cubic metre of some subsoils can weigh more than 1.8 tonnes.

Pallic Soils have pale coloured subsoils, due to low contents of iron oxides. The soils have weak structure and high density in subsurface horizons. Pallic Soils are dry in summer and wet in winter

OCCURENCE: Pallic Soils occur predominantly in the seasonally dry eastern part of the North and South Islands, and in the Manawatu. Parent materials are commonly loess derived from schist or greywacke. They cover 12% of New Zealand. (View map of Pallic soils.)

PHYSICAL PROPERTIES: Soils have slow permeability with limited rooting depth, and medium to high bulk density. They are susceptible to erosion because of high potential for slaking and dispersion.

CHEMICAL PROPERTIES: Soils have medium to high nutrient content (except for sulphur), high base saturation, low concentrations of secondary oxides, and low organic matter contents.

BIOLOGICAL PROPERTIES: Soils are strongly worm-mixed, at the boundary of the A and B horizons.

CLIMATE: Annual precipitation usually between 500 and 1000 mm and the climate is typically droughty in summer, and moist or wet in winter.

SOIL GROUPS:	**[PP] Perch-Gley Pallic**	periodic wetness caused by a perched water table (View map of Perch-Gley Pallic)
	[PU] Duric Pallic	silica-cemented pan in the subsoil (View map of Duric Pallic)
	[PX] Fragic Pallic	a compact pan in the subsoil (View map of Fragic Pallic)
	[PL] Laminar Pallic	clay accumulation as thin subsoil bands subsoil (View map of Laminar Pallic)
	[PJ] Argillic Pallic	clay accumulation as thin coatings on peds or in pores (View map of Argillic Pallic)
	[PI] Immature Pallic	Weakly expressed pallic soil features (View map of Immature Pallic)

Figure 17: Pallic Soils

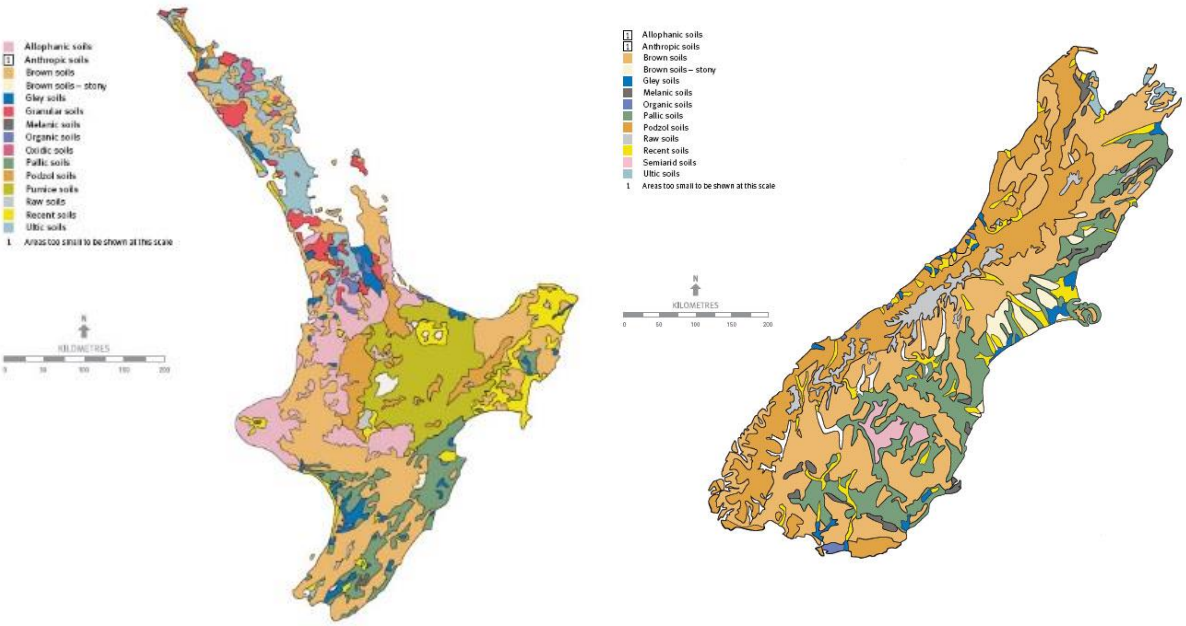
Image retrieved from http://soils.landcareresearch.co.nz/contents/SoilNames_NZSoilClassification_SoilOrders.aspx?currentPage=SoilNames_NZSoilClassification_SoilOrders&menuItem=SoilNames#P

Now explore for yourself….

Major New Zealand Soil types

In the Soil Portal activity you saw there are many different types of soils (soil orders) across New Zealand. These vary with location, the underlying geology, bedrock, climate and the way in which the land is used.

Take a look at these soil maps. These can be also be found at http://sciencelearn.org.nz/Contexts/Soil-Farming-and-Science/Sci-Media/Images/New-Zealand-soils-map



Soil Map - North Island ***Soil Map - South Island***

Figure 18: New Zealand Soil Map

See how the soil types often match the geographic regions and features of New Zealand. A good example is the pumice soils in the centre of the North Island around Rotorua and Taupo. Another is the spread of fertile organic soils which follow the major rivers in the South Island.

The keys to these maps identify about 15 different types of soil (soil orders). The main characteristics of these soils are summarised below:

Allophanic Soils

- Occur mostly in volcanic parent material.
- Topsoil and subsoil horizons are friable.
- Bulk density is low. There is little resistance to root penetration.
- P retention and phosphate fixation is high in topsoils.

Anthropic Soils

- Soils that have been altered by man
- Border dyke irrigation
- Dredgings
- Most common in urban areas or areas that have been mined

Brown Soils

- Occur in areas where summer dryness is uncommon and that are not waterlogged in winter
- The most extensive New Zealand soils
- Occur in areas where the mean annual rainfall is more than 1000mm

Granular Soils

- Soils are clayey
- They are slowly permeable
- They generally have limited root depth

Melanic Soils

- These are well structured soils with dark A horizons
- These soils have high resistance to structural damage
- Large potential rooting depths

Organic Soils

- Organic soil material is dominant.
- Soils may be up to 70% organic matter
- Peat soils fall into this group

Oxidic Soils

- Occur mainly north of Auckland
- High phosphate retention soils

Pallic Soils

- Pale colour
- Soils have slowly permeable layers
- Have water deficits in summer and surpluses in winter or spring
- Good worm mixing

Podzols

- These occur in areas of high precipitation 2000mm or above.
- They are formed under native forests.
- Podzols occur in the Catlins area of South Otago.

Pumice Soils

- These occur in the North Island, particularly in the Volcanic Plateau

Raw Soils

- Soils do not have distinct topsoil development. This is prevented by active erosion by river action or by deposition

Recent Soils

- These are young soils. They only have the beginnings of a developed soil profile

Semiarid Soils

- These soils occur in the inland basins of Central Otago where precipitation is below 500mm/yr

Ultic Soils

- These are old soils
- They are heavily leached and weathered

Not all of them are important for horticulture and agriculture in New Zealand. So for the rest of this module we will we will concentrate on the features and characteristics of the seven main soil types that are relevant to horticulture and agriculture. These are:

1. Volcanic loams
2. Brown earths
3. Coastal sands
4. Organic soils
5. Podzols
6. Pumice soils
7. Recent alluvial soils

We will look at their distribution (where they are found) their origins, properties and their main uses for agriculture and horticulture.

Volcanic loams (allophanic soils)

Soil formation: Volcanic loams are old soils formed from weathered volcanic ash from ancient eruptions such as those around Mt Taranaki and the central North Island volcanoes.

Occurrence (area and location): Occurs within 'throwing distance' of ancient or volcanoes such as Taranaki, Rotorua and the central North Island volcanoes. Bay of Plenty, King Country, Rangitikei, Waikato and Taranaki. They cover about 5% of New Zealand.

Soil texture: Sandy loam, silt loam with low-moderate clay (allophane) content.

Soil structure: Crumb to fine, sometimes blocky. They contain clay particles (allophane) which coat the sand and silt particles to make them feel greasy. Low soil strength (easy to cultivate). Little resistance to root growth.

Drainage: Excellent drainage but good water availability, resistant to pugging and impact of machinery (cultivation).

Potential for plant growth:

- Natural fertility is low with tendency for mineral deficiencies, particularly cobalt (Co) which is essential for livestock).
- But ability to retain and store phosphorus (P) is high, so regular dressing with P fertiliser will lift and maintain fertility.
- Stable and fertile topsoil and soil is resistant to erosion except on steep sites.
- Potentially very fertile. Some of New Zealand's most productive soils are volcanic loams.

Figure 19: Volcanic Loam

Allan Hewitt. 'Soils - Wet and rock type-dominated soils', Te Ara - the Encyclopedia of New Zealand, updated 8-Jul-13 URL: http://www.TeAra.govt.nz/en/photograph/12336/allophanic-soil

Uses:

- Market gardening (vegetables and fruit)
- High value horticulture (e.g. Bay of Plenty Kiwifruit and berry fruit)
- Highly productive dairy pasture
- Sheep and beef farming

Brown earths

Soil formation: formed from weathering of rocks, mainly containing silica, over a wide range of climates. The brown colour is caused by iron oxides (rust) weathered from the parent material.

Occurrence (area and location): Found in areas where soil moisture is generally reliable throughout the year and soil doesn't get waterlogged. They are the most widespread soil type covering about 43% of New Zealand (approx. 3 ½ million hectares). East Taranaki, east coast of the North Island, Wellington, Marlborough Sounds, Nelson, South Island high country, Southland

Figure 20: Brown Earth

Image from Remulazz, 2007. Licenced under CC0 1.0

Soil texture: Mostly silt loam, some sandy loam

Soil structure: Range from crumb to blocky to fine (granular). Easy to cultivate. Stable soil structure, resistant to erosion,

Drainage: Free draining and good water holding capacity.

Potential for plant growth:

- Good nutrient balance and availability
- Excellent potential for plant growth due to good soil structure and stability and high biological activity (lots of soil organisms and earthworms etc).

Uses:

- Intensive horticulture, viticulture
- Cropping
- Intensive dairy farming
- Sheep and beef farming
- Forestry

Coastal sands (sandy brown and sandy raw soils)

Soil formation: Young soils formed from weathering of parent rocks and then being transported down rivers to the coastal regions. The most common parent material is quartz.

Occurrence (area and location): Coastal regions near major rivers. Manawatu, Northland, Bay of Plenty, North Canterbury.

Soil texture: Sand and loamy sand

Soil structure: Range from crumb to fine (granular). Easy to cultivate. Soil has low strength and may be prone to erosion by water. Lacking distinct topsoil.

Drainage: Fast draining with low water holding capacity. Likely to dry out quickly.

Figure 21: Coastal Sands

Potential for plant growth:

- Low organic matter and low nutrient retention. Most sandy soils are low in phosphorus (P) and potassium (K). Needs a lot of fertiliser input.
- Limited uses in the low fertility very free draining soils while other better areas can be used for market gardening (warmer soils in early spring, less waterlogging etc.)

Uses:

- Market gardening in some better areas
- Forestry on the poorer soils
- Sheep and beef farming

Organic soils (peaty soils)

Soil formation: Formed from the partly decomposed remains of wetland plants (swamps and bogs) or forest litter. Boggy areas build up layer upon layer over time in anaerobic conditions to form peat. Some minerals are present but soil is dominated by organic matter

Occurrence (area and location): Occurs in wetland areas in most parts of New Zealand, especially areas of high rainfall and poor drainage. Waikato, Thames, Northland, Southland and Westland.

Soil texture: 'Peaty'. Fine particles of organic matter.

Soil structure: Very little structure as it contains very little mineral aggregates, mostly fine crumb. Low density, and low soil strength.

Drainage: Poor drainage. There must be more than 25% organic matter in the top 40cm of soil to be classed as an organic soil though it can be as high as 70%. This affects drainage, as peat can hold up to 20x its weight in water. Prone to waterlogging.

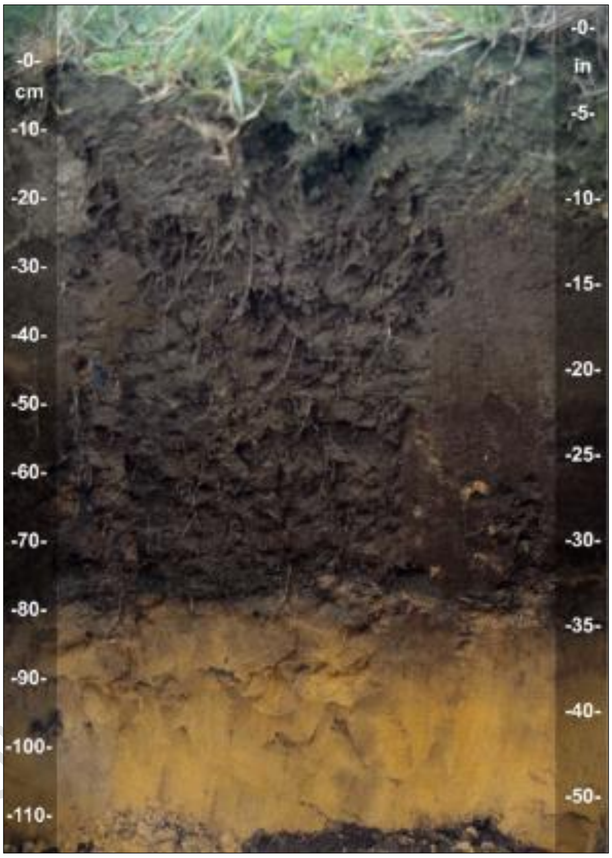


Figure 22: Organic Soils

Potential for plant growth:

- Most are deficient in N, P, K, S, and some trace elements because the soil is acid (low pH) and has low biological activity.
- Once drained they have a lot of potential for high value horticultural crops and market gardening, as well as dairy and sheep and beef farming.
- Water availability and nutrient content needs to be controlled to reach their high potential, because when peats dry they shrink and are hard to re-wet.
- Peat is used for potting mixes (a highly sought after ingredient) but mining peat is not sustainable.

Uses: The soil characteristics vary greatly so there is a wide range of uses:

- Market gardening
- High value horticultural crops
- Blueberries
- Citrus
- Dairy farming
- Sheep and beef farming

Podzols

Soil formation: Formed in areas of high rainfall (over 1500mm per annum). Underlying rock is usually silica-based. Usually has a bleached pale horizon immediately beneath the topsoil. This is where aluminium and iron oxides have washed out of the subsoil to accumulate in the brown layers below.

Occurrence (area and location): Usually under native forests in high rainfall areas with acidic soil. South Island west coast and central North Island forests. Covers 13% of New Zealand

Soil texture: Silt loam or sandy

Soil structure: Not much gradual structure as the very fine silica particles are usually cemented together into one large mass. A very hard soil to cultivate.

Drainage: Very poor drainage and difficult for plants to root into the 'cemented' subsoil.

Figure 23: Podzols

Image by Hartnup, 2005. Licenced under CC0 1.0

Potential for plant growth:

- Deficient in N, P, K, S, and some trace elements because the soil is acid (low pH) and has low biological activity.
- Poor potential for plant growth.
- The best use for podzols is native forest where the trees are adapted to growing well in podzol soils
- Areas that have been cleared and farmed need a lot of lime and fertiliser applied, but this must be carefully done because they are in high rainfall areas and fertilisers could leach or runoff to pollute waterways.

Uses: Low fertility soil suitable only for non- intensive agriculture and horticulture:

- Forestry
- Sheep and beef farming

Pumice soils

Soil formation: As with volcanic loams (allophanic soils) the parent material is **tephra** (consolidated air fall volcanic material) but is from more recent eruptions such as the very large explosion that created Lake Taupo. Pumice soils are younger and less developed than volcanic loams.

Occurrence (area and location): Mainly the central North Island Bay of Plenty, Taupo regions, Hawkes Bay. They cover about 7% of New Zealand.

Soil texture: Loamy sand, silty sand, low clay content.

Soil structure: Crumb or granular, low soil strength (easy to cultivate). Particle/granule size can range from boulders down to a fine powder.

Drainage: Excellent drainage and good water retention. Resistant to pugging but prone to erosion by water.

Figure 24: Pumice Soils

Image from http://www.nzsoils.org.nz/Topic-Regional_Soils/Soil_Resource_Materials/

Potential for plant growth:

- Not highly fertile due to young nature of soil and low reserves of major nutrients.
- Tendency for mineral deficiencies, particularly cobalt (Co) and Copper (Cu) which are essential for livestock).
- Pumice soils respond well to regular fertiliser application as they don't have much clay content to bind nutrients in the soil.
- Low organic matter with thin topsoil and low biological activity – coarse aggregate particle size not favoured by earthworms.
- The soils are porous but have high water retention so are good for deep rooted crops

Uses:

- Sheep and beef farming
- Dairy farming (regular fertiliser application and irrigation is required)
- Forestry

Recent alluvial soils (fluvial soils)

Soil formation: Sandy and silty materials being washed down and deposited on floodplains by rivers. Usually quite young soils with dinstinct topsoil but indistinct subsoil horizons. Most are less than 1000 – 2000 years old.

Occurrence (area and location): Floodplains and river terraces throughout New Zealand. They cover about 6% of New Zealand.

Soil texture: Sandy loam, silt loam, low clay content.

Soil structure: Crumb or fine crumb. Little evidence of horizon layers allows deep rooting. Generally good soil stability but prone to erosion by fast moving water during flooding.

Figure 25: Alluvial Soils

Drainage: Free draining with good water holding capacity and good water availability to plants.

Potential for plant growth:

- High natural fertility with readily available nutrients but low P retention so needs regular phosphate fertiliser application.
- Very valuable soils and land is sought after for horticulture and agriculture.

Uses:

- Market gardening
- High value horticultural crops
- Vineyards
- Arable crops
- Dairy farming

Self-review 2: Soil classification

1. Why is soil classification useful for soil management"

2. In the Soil Portal activity, you looked for the soil type at a location you chose. Name the soil type at that location.

3. Where are volcanic soils normally found?

4. What is the potential for plant growth of volcanic soils?

5. How are brown earths usually formed?

6. What are the main uses for brown earth soils?

7. How are podzols formed?

8. What are the drainage characteristics of podzols?

9. Describe the soil texture and structure of pumice soils

10. Where are fluvial soils found?

Check your answers at the end of the module.

Nutrient requirements of plants

Plant nutrients are the chemicals that are necessary for plant growth and which must be obtained from its environment. These are known as **essential nutrients**.

Essential nutrients can come from either the atmosphere, water or the soil.

Plants need carbon dioxide (CO_2) and water (H_2O) which they use in **photosynthesis** to make sugars. These are used for energy and as building blocks for other chemicals needed for growth and reproduction, e.g. proteins, enzymes, cellulose, hormones etc.

Plants also need oxygen (O_2) for **respiration** (energy production) during the night when light is not available for photosynthesis.

Carbon dioxide and oxygen are absorbed from the air through the leaves. Water is taken up by the roots from the soil or medium the plants are growing in.

Essential mineral nutrients

The soil usually supplies all the essential mineral nutrients. These are also known as **inorganic nutrients**. They are divided into **macronutrients** and **micronutrients** (or **trace elements**). This describes the amounts needed by the plants to support growth.

The main macro (+) and micro (-) nutrients for plant growth

Element		Amount (micro mol/g DM)
N, nitrogen	+	1000
K, potassium	+	250
Ca, calcium	+	125
Mg, magnesium	+	80
P, phosphorus	+	60
S, sulphur	+	30
Cl, chlorine	-	3
B, boron	-	2
Fe, iron	-	2
Mn, manganese	-	1
Zn, zinc	-	0.3
Cu, copper	-	0.1
Mo, molybdenum	-	0.001

Table 1: Average amounts of mineral nutrients found in plant dry-matter

The table on the previous page shows the average amounts of mineral nutrients found in plant dry-matter. You don't need to remember these amounts. The important thing to note is the relative difference between the 6 macronutrients N, K, Ca, Mg, P and S and the 7 micronutrients.

Macronutrients are needed in quite large amounts. They are used in the major structural chemicals such as proteins, DNA and enzymes. For example at the centre of every chlorophyll molecule is a magnesium ion which helps speed up photosynthesis.

Micronutrients (trace minerals) are needed in only tiny amounts. They may be important in speeding up enzyme reactions (**catalysts**).

Deficiency in a particular mineral usually slows down or prevents the plants from growing normally. Plants with mineral deficiencies usually show characteristic deficiency symptoms.

Functions of essential mineral nutrients for plant growth

Macronutrients

The most important of the macro nutrients are nitrogen (N), phosphorus (P) and potassium (K). Of all the macronutrients these three are the most likely to limit plant growth if they are absent from the soil. For this reason, they are commonly applied to soils as fertiliser and are usually found as a component of most mixed fertilisers. We will look at this in more detail later.

Nitrogen (N) is an essential component of all proteins. Nitrogen deficiency limits protein production and most often results in stunted growth, slow growth, and yellowing of the leaves (**chlorosis**). Nitrogen deficient plants may also show a purplish appearance on the stems and underside of leaves.

Most of the nitrogen taken up by plants is from the soil in the form of nitrate ions (NO_3^-). Under many agriculture and horticulture situation nitrogen is the main nutrient which can limit plant growth. Some plants require more nitrogen than others, such as corn (*Zea mays*).

Phosphorus (P) is important for energy metabolism in cells. Phosphorus is needed for the plant to be able to convert energy from sunlight into a chemical (**ATP** – adenosine triphosphate) that stores and carries energy that the plant can use. Since the energy carried by ATP is used in the manufacture of many other plant nutrients (e.g. amino acids, proteins and hormones) phosphorus is very important for plant growth and flower/seed formation.

Phosphorus is limited in most soils because it is released very slowly from insoluble phosphates. Under most conditions it is the limiting element because of its low concentration in soil and high demand by plants and microorganisms.

Phosphorus deficiency in plants is characterized by an intense green colour in leaves.

Potassium (K) is important because it regulates the opening and closing of pores (**stomata** -ventilation holes) in the leaves. These pores allow air and water exchange between the plant and the atmosphere so K is important in water regulation. Potassium helps to reduces water loss from the leaves, prevents wilting and increases drought tolerance.

Potassium deficiency may result in higher susceptibility to disease, wilting, chlorosis (yellowing between leaf veins) and damage from frost and heat. Potassium is very soluble in water and rapidly leaches out of sandy or rocky soils leading to potassium deficiency.

Sulphur (S) is a structural component of some amino acids, vitamins, and chloroplasts (where photosynthesis takes place in plant leaves). Symptoms of sulphur deficiency include yellowing of leaves and stunted growth.

Calcium (Ca) regulates absorption and transport of mineral nutrients into the plants' roots and is also involved in the activation of certain plant enzymes. Calcium deficiency results in stunting.

Magnesium (Mg) is an important part of chlorophyll which is essential for photosynthesis. It is important in the production of ATP (the energy molecule). Magnesium deficiency can result in leaf yellowing between the veins (chlorosis).

Micronutrients

These are elements that plants require in relatively small amounts. They include seven which are recognized as being essential for all plants: chlorine, iron, boron, manganese, zinc, copper and molybdenum.

Although these nutrients are required in much smaller quantities than macronutrients they are just as important and crop yield and quality will suffer if the plant is deficient in these nutrients. These may be added to general fertilisers where deficiencies are known to occur.

Iron (Fe) is necessary for photosynthesis and is present as an enzyme cofactor (a 'helper' molecule) in plants. Iron deficiency can result in chlorosis and cell death.

Molybdenum (Mo) is a cofactor to enzymes important in building amino acids. Mo deficiency results in stunting and slow growth and yellowing of leaves.

Boron (B) is important for the integrity of cell walls. Boron may also be involved in sugar transport, cell division, and synthesizing certain enzymes. Boron deficiency causes dead spots in young leaves and stunting.

Copper (Cu) is important for photosynthesis. It is involved in many enzyme processes. Copper is also involved in the manufacture of **lignin**, a structural component of plant stems. Symptoms for copper deficiency include chlorosis.

Manganese (Mn) is necessary for chloroplast development. Manganese deficiency may result in discoloured spots on the foliage.

Zinc (Zn) is required as a component of a large number of enzymes and plays an essential role in DNA chemistry (genes and reproduction). A typical symptom of zinc deficiency is the stunted growth of leaves, commonly known as 'little leaf'.

Chlorine (Cl) is necessary for water and mineral balance between and within cells. It also plays a role in the reactions of photosynthesis. Cl deficiency also makes plants susceptible to wilting and stunted growth

Sodium (Na) is involved in water balance inside and between cells. It can also substitute for potassium in some circumstances and can influence opening and closing of leaf pores. Sodium deficiency can make plants susceptible to wilting.

Soil types and mineral uptake

Many soil types can provide plants with adequate amounts of mineral nutrients. However in some areas, especially those under intensive agriculture and horticulture, the soil may be deficient or become depleted in one or more minerals. This will limit plant growth and productivity.

If this occurs farmers and horticulturists can usually modify soil by adding fertiliser to restore soil nutrient balance. This should restore plant growth and increase yield back to former levels. The plants are able to obtain their required nutrients from the fertiliser nutrients added to the soil.

Mineral nutrients may be added as inorganic chemical fertilisers (e.g. ammonium sulphate, urea, superphosphate and lime) or in organic form (e.g. animal manures and compost). In hydroponic horticulture all mineral nutrients are provided in chemical solution to plants growing in an inert growing medium.

We will look at fertilisers in more detail later.

The special case of nitrogen (N)

Plants need a lot of nitrogen compared to other minerals. Most plants obtain their nitrogen from dissolved nitrates in the soil which are released from decomposing organic matter such as animal manures and vegetation. Unfortunately nitrates are very soluble in water so are easily leached away from plant roots, especially on hillsides. Nitrogen deficiency is very common in agriculture and horticulture because of the huge demand on the soil by pastures and crops.

There is plenty of nitrogen in the air (the atmosphere is about 78% N), but plants are unable to use this source of atmospheric N. However some soil bacteria and fungi have evolved chemical methods of capturing atmospheric N in the soil and turning it into nitrates which they can use for their own growth. Usually they make more than they need and the surplus can diffuse out into the soil water where it can be used by other organisms including plants. Unfortunately the nitrates which diffuse into the soil are easily washed away (leached) in soil water.

Many plants form **symbiotic** (mutually beneficial partnership) relationships with bacteria and fungi in the soil to help them capture and retain soil nutrients (including N) more efficiently.

A symbiotic relationship which is particularly important to agriculture and horticulture is that between a nitrogen-fixing bacterium called *Rhizobium* and the roots of legumes (clovers, peas and beans). *Rhizobium* chemically fixes atmospheric nitrogen in nodules on the roots of legumes. Any 'fixed' N which is surplus to bacterial requirements diffuses into the nodules and is easily captured by the plant's root tissues. Very little of the fixed N escapes into the surrounding soil water, so this greatly increases the efficiency of N uptake for the clover roots. In return the bacteria obtain carbohydrates (sugars) from the host plant's root tissues for their own use.

An important application of this in New Zealand pastoral agriculture is the combination of white clover (*Trifolium repens*) with ryegrass (*Lolium perenne*) to improve grass growth in low fertility pastures. This is achieved in two ways:

1. Nitrogen fixed by *Rhizobium* improves clover growth. Animals eating the clover digest and return the nitrogen to the pasture in their dung and urine. Soil organisms and free-living soil bacteria decompose these and release nitrates into the soil water. Ryegrass (and other pasture plants) can then absorb this recycled nitrogen to improve overall pasture growth rates.

2. Organic matter in dead leaves, roots and other plant parts decomposes (as discussed earlier) recycling N into the soil.

By combining clover with ryegrass on low fertility pasture, N fixation by the clover/*Rhizobium* partnership can reduce the need for artificial N fertilisers to improve overall pasture growth.

Soil pH and mineral nutrients

Soil pH has a large influence on soil structure, soil organism activity and nutrient availability. This means that soil pH can have a large influence on plant growth.

What is pH?

pH is a measure of how acid or alkaline a solution is – i.e. a solution of something in water (an aqueous solution). In chemistry the letters pH stand for 'potential hydrogen' and represent the amount of hydrogen ions (H^+) in the soil solution which determines acidity/alkalinity.

Soil pH is measured on a scale of 0 to 14.

- A pH measurement of 7, in the middle, represents 'neutral'.
- A pH measurement *below* 7 is acidic (e.g. 0-6).
- A pH measurement *above* 7 is alkaline or basic (e.g. 8 – 14).

Essentially, the greater the number of hydrogen ions in the soil solution the more *acidic* it is. The diagram below gives an idea of the pH scale in terms of everyday items.

Table 2: pH Range

	pH range
Extremely acid	0 - 4.4
Very strongly acid	4.5 - 5.0
Strongly acid	5.1 - 5.5
Moderately acid	5.6 - 6.0
Slightly acid	6.1 - 6.5
Neutral	6.6 - 7.3
Slightly alkaline	7.4 - 7.8
Moderately alkaline	7.9 - 8.4
Strongly alkaline	8.5 - 14.0

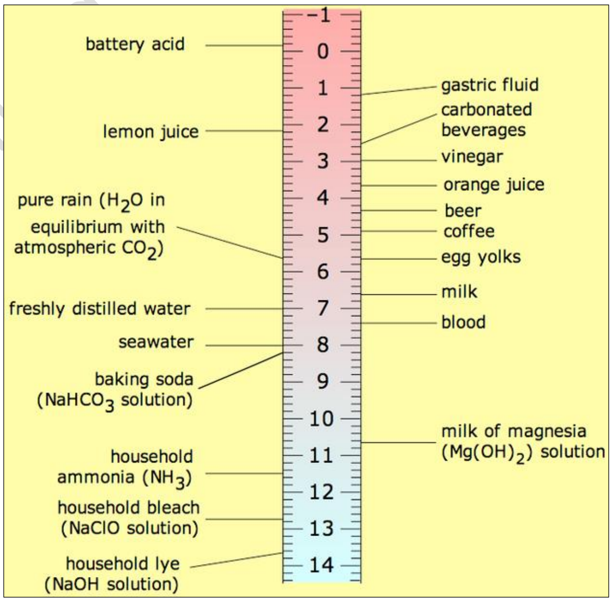


Figure 26: pH of everyday items

Image from Slower, 2006. Licenced under CC BY-SA 3.0

Many New Zealand soils have a pH ranging from about 4.5 to 6.5 but the majority of plants grow best in a soil pH of 6.0 to 7.0. Some plants are exceptions such as blueberries and azaleas which prefer a relatively acidic soil and fodder beet and asparagus that grow well in slightly alkaline soils.

Knowing the pH of soil is important because it affects the availability of nutrients to plants. This means that if the pH is not at the ideal level, no matter how much nutrient is in the soil or how much fertiliser is applied it may not be taken up by plants or they may take up toxic levels. The diagram below indicates the availability of the main macro- and micronutrients at different soil pH measurements.

Here's how to read the diagram: Choose a mineral nutrient (e.g. potassium). On the left the scale is strongly acid and on the right it is strongly alkaline. The wider the bar the more available the mineral nutrient is at that pH. The narrower the bar the less readily available the nutrient is at that pH. For example, the potassium bar gets narrower to the left of pH 6.0 which means that the availability reduces as the soil gets more acid.

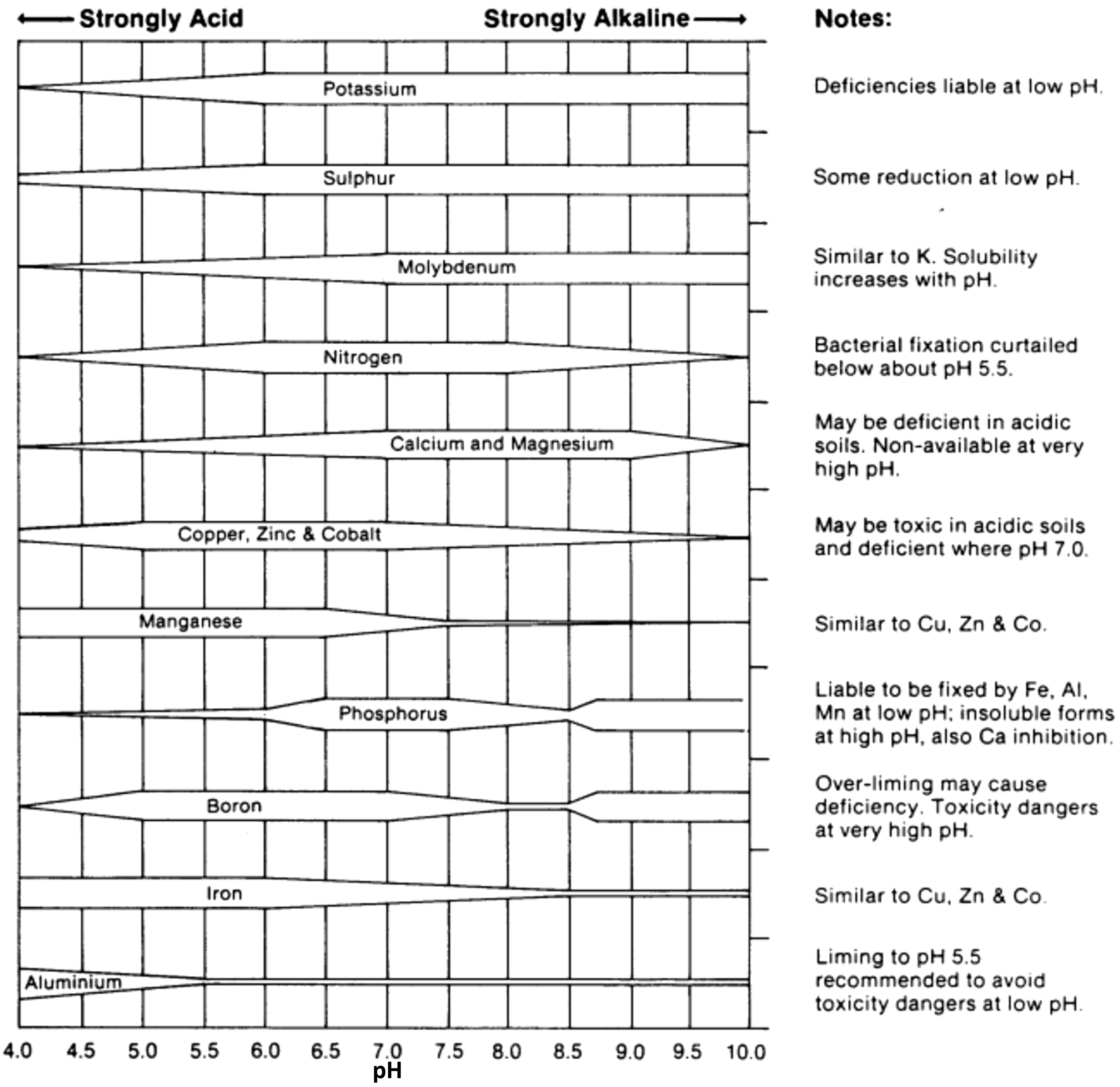


Figure 27: Diagram of Macro and Micronutrients at different soil pH measurements

Plant nutrient availability at different soil pH levels – the wide areas indicate nutrients are readily available to plants and the narrow areas indicate they are not readily available

Retrieved from: www.hill-laboratories.com

NOTE: The most important thing to note about this diagram is how most of the nutrients have high availability between pH 6.0 and 7.0. This is the optimum pH for soil mineral availability – the neutral to slightly acid range. Note also that at the far left of the diagram, (acid) nearly all the nutrients are less available (narrowing bands). The exceptions are iron and manganese which have good availability when the soil is acid.

As with plants, most soil organisms prefer a near-neutral range. Outside this range, the numbers of microorganisms and their activity decrease. This affects the levels of many important plant nutrients. For instance, as the soil pH level increases conditions become more favourable for micro-organisms. As a result they grow and multiply and release more nitrogen as they break down organic matter. This can sometimes show up as a greening of the pasture after lime is applied.

What causes soil acidity?

Anything that generates H+ adds to soil acidity. There are many types of biochemical reactions in the soil that generate acid (H+). These include:

- breakdown of soil organic matter by microbes to organic acids
- biological 'fixation' of nitrogen from the air by bacteria and fungi
- biological conversion of nitrogen fertilisers to nitrates by bacteria and fungi
- leaching (draining away in water) of clover-fixed nitrogen – leaching tends to be greater in high rainfall regions
- nutrient uptake by plants – leaving the H+ behind so that the soil is left is more acid

The net effect of all the acid-producing reactions and biological activity is that the soil pH usually declines (i.e.gets more acid) over time.

Lime and its role in increasing soil pH

Soil can be tested to determine if it has a suitable pH for plant growth. Remember that for optimum nutrient availability and plant growth soil pH should be between about 6.0 and 7.0. If the pH is too low (too acid), the most common way to increase pH is to apply ground limestone (calcium carbonate, CaCO3), commonly called lime.

The active ingredient in lime, in terms of soil acidity, is the carbonate part (CO3) not the calcium (Ca). It is the carbonate that reacts with and neutralises the acidity in the soil. Lime works in exactly the same way as antacid indigestion tablets (e.g. Quick-Eze) does to neutralise acid in the stomach which can cause indigestion pains in humans

Although lime is most commonly used, other materials also have a liming affect. These include dolomite a type of limestone which also includes magnesium, reactive phosphate rocks (RPR) and dairy farm effluent.

As a rule of thumb, 1 tonne/ha or 100 grams/m2 of lime will increase the soil pH by 0.1 pH units. So 1 tonnes/ha or 100 g/m2 of lime is required to increase the soil pH from 5.5 to 5.6. However, the exact amount needed depends on the soil type, as some soils are more resistant to changes in pH.

Applying lime to soil improves it slowly, often taking four years to have its full effect. Its effect can be reduced through leaching or reaction with organic matter.

Research shows that it does not matter whether lime is applied in small amounts often or large amounts infrequently. The reason for this is the lime is difficult to dissolve in the soil water. It takes about 12 – 18 months to fully dissolve in the soil and it has a long lasting 'residual' effect. So it is not always necessary to apply lime every year. For example, the general practice on dairy farms is to apply 2 – 2.5 tonnes/ha of lime every four to five years.

Another influence is the fineness of grinding of the lime. The finer the lime has been ground, the more even it will be spread over the soil, and it will dissolve faster than coarse lime, because fine lime has a greater surface area.

If the soil pH is already at the optimum level, then liming will have little effect to increase in plant yields.

You can test your own soils. Soil testing kits to measure soil pH (acidity) are available in local garden shops.

Optimum pH for different plants

Different plants have different optimum pH requirements. This is determined by growing plants in soils of different pH and measuring their growth and productivity. The table below gives optimum pH levels for several crops:

Table 3: Optimum pH levels

Plant	***Optimum pH***
Apples	5.8 - 6.8
Barley	5.8 - 6.5
Cabbage	5.6 - 7.0
Maize	5.3 - 6.8
Peas	5.0 – 6.0
Silverbeet	6.0 – 7.2

It is difficult, and probably unnecessary to try to get the soil pH exactly right for each crop. Note that the range for all these crops is broadly "neutral". The following table summarises some of the problems that can occur if soils are too acid or to alkaline:

Table 4: Soil problems if too acidic or alkaline

Problems in very acid soils	***Problems in alkaline soils***
Aluminium toxicity to plant roots	Iron deficiency
Manganese toxicity to plants	Manganese deficiency
Calcium & magnesium deficiency	Zinc deficiencies
Molybdenum deficiency in legumes	Excess salts (in some soils)
P tied up by Fe and Al	P tied up by Ca and Mg
Poor bacterial growth	Bacterial diseases in potatoes
Reduced nitrogen transformations	

Self-review 3: Soil nutrients

1. List the 6 essential mineral macronutrients supplied by the soil
2. What role does N play in plant cells?
3. How does N deficiency show itself in plants?
4. What role does K play in plants?
5. How does K deficiency show itself in plants?
6. List and briefly describe the function and signs of deficiency for 2 essential micronutrients.
7. How does Rhizobium help plants to obtain nitrogen in the soil?
8. What is the optimum soil pH range for most plant growth?
9. What normally happens to nutrient availability in soil as pH decreases, i.e. as soil becomes more acid?
10. How does lime help mineral availability in acid soils?
11. List three problems that can occur in very acid soils and three problems that can occur in very alkaline soils.

Check your answers at the end of the module.

Fertilisers and nutrients

What are fertilisers?

According to Wikipedia:

Fertiliser (or fertilizer) is any organic or inorganic material of natural or synthetic origin (other than liming materials) that is added to soil to supply one or more plant nutrients essential to the growth of plants.

Therefore, fertilisers are substances that add essential plant nutrients to the soil.

Note that lime is not a fertiliser! Lime is not a plant nutrient – it is not required by plants. Lime simply changes soil pH to make the other essential nutrients that are already in the soil more easily available to plant roots. Lime may be applied along with fertiliser to make sure that the pH is optimum so that the plants can use the fertiliser nutrients effectively. Limestone and dolomite are referred to as soil amendments.

Main fertiliser types

To recap an earlier section on mineral nutrients, the most important are, nitrogen (N), phosphorus (P) and potassium (K), often referred to in horticulture as NPK.

As you might expect there are three main classes of fertiliser which relate to these minerals:

1. Nitrogenous fertilisers
2. Phosphatic fertilisers
3. Potassic fertilisers

Fertilisers are often described by their NPK or NPKS rating. This is the proportion of N (nitrogen), P (phosphorus), K (potassium) and where included S (sulphur).

Nitrogenous fertilisers

Nitrogen fertilisers have been increasingly used over the last ten years for both pasture and crop production. New Zealand farmers have traditionally been reliant on legumes such as clovers for their supply of nitrogen, but increasingly nitrogen fertilisers are being used mainly to boost pasture growth when clovers are unable to 'fix' enough nitrogen from the atmosphere to support pasture growth.

The use of nitrogen fertilisers in New Zealand is mainly to:

- stimulate "out-of-season" (winter/spring) pasture growth on dairy farms
- on arable and horticultural crops
- on pasture seed crops (ryegrass and cocksfoot)
- as part of direct drilling pasture establishment
- as part of dairy effluent returned to pasture

- to correct nitrogen deficiency that often occurs on newly established pasture.

The main forms of nitrogen fertiliser available in New Zealand are:

Ammonium sulphate

Also known as sulphate of ammonia, it is the best known and most commonly used nitrogen fertiliser. It contains 21% nitrogen and 24% sulphur, and it is very water-soluble. When it is applied to the soil, it will lower the pH of the soil (make it more acid). Also because it is very soluble it is easily taken up by plants. But it also easily leaches away as water flows through the soil.

Calcium ammonium nitrate (CAN)

This fertiliser is supplied usually under a trade name. It is granular in form and contains 23 % nitrogen and 40 % lime. Can be considered as near-neutral in its effect on soil pH. For use on perennial fruit crops (where soil incorporation of lime is difficult). Contains equal parts of fast acting nitrate-nitrogen and longer lasting ammonium-nitrogen

CAN can be considered as near-neutral in its effect on soil pH - and therefore can be used on soils that have a low pH without lowering further. This also means it is most suitable for using on perennial fruit crops, where it is usually difficult to incorporate into the soi. (without damaging the roots of the trees in orchards).

CAN is a nitrogen fertiliser which contains equal parts of fast acting nitrate-nitrogen and longer lasting ammonium-nitrogen. This ensures a more continuous nitrogen supply to the crop and therefore better efficiency of use, and also makes it suitable for out-of-season application during summer or winter.

CAN cannot be used along with superphosphate as it reacts with it and binds up the N and P in both.

Urea

This is the most concentrated nitrogen fertiliser available in New Zealand, containing 46 % nitrogen. It is usually in a pelleted or granular form. It can be used for cropping, arable, pasture and horticulture. Like CAN it is not compatible with superphosphate.

Organic Nitrogen

A variable form of nitrogen. A common source of organic nitrogen is animal effluent. Because it is organic and contains organic acids it can acidify soil. It is less efficient than other nitrogen fertilisers, but is generally safe (for the crops) to use at high application rates, provided it does not pollute nearby waterways.

Table 5: Summary of Nitrogen Fertilisers

NAME	NPKS RATING	OTHER NUTRIENTS
Ammonium Sulphate	21-0-0-24	
Calcium ammonium nitrate	23-0-0-0	calcium
Urea	46-0-0-0	

Phosphate fertilisers

Phosphate fertilisers are the most commonly used fertilisers in New Zealand. A wide range of phosphate fertilisers is available

Superphosphate (also known as "super")

Two serious deficiencies of New Zealand soils are phosphorus and sulphur. Both are supplied in this fertiliser which contains 10 % phosphorus and 11 % sulphur. It is reasonably soluble in water and is often called straight super to distinguish it from other phosphate fertilisers.

Reverted superphosphate

By adding 25 % lime to superphosphate produces reverted superphosphate, with 7 % phosphate and 8 % sulphur. It is mainly mixed with seeds, as it is less harmful than straight superphosphate.

Serpentine superphosphate

Containing 25 % serpentine rock (magnesium), serpentine superphosphate has all the qualities of reverted superphosphate plus 5 % magnesium.

Granulated superphosphate

This has 10 % serpentine rock, which keeps the fertiliser free-flowing.

Partially acidulated reactive rock (PARR)

This phosphate fertiliser is made from crushed phosphate rock that has been treated with phosphoric acid.

Table 6: Summary of Phosphate Fertilisers

NAME	NPKS RATING	OTHER NUTRIENTS
Superphosphate	0-10-0-11	
Reverted super	0-7-0-8	
Serpentine super	0-8-0-8	Mg
Granulated super	0-8-0-10	Mg
PARR	0-14-0-1	

Potassium fertilisers

There are only two types of potassium fertilisers used in New Zealand to any great extent.

Potassium chloride

This is the main potassium fertiliser, containing 48 % potassium. It is a distinctive pink colour and is very soluble in water.

Potassium sulphate

Commonly known as sulphate of potash, this fertiliser supplies sulphur as well as potassium. However, it is more expensive than potassium sulphate.

Table 7: Summary of Potassium Fertilisers

NAME	NPKS RATING	OTHER NUTRIENTS
Potassium chloride	0-0-48-0	
Potassium sulphate	0-0-40-7	Sulphur

Micronutrients

Many of the more commonly used fertilisers have micronutrients added to them. This is because micro nutrients are required in such small amounts; it is much easier to add them to a macronutrient fertiliser, so that an application of this fertiliser at its normal rate supplies a suitable amount of the added micronutrient as well.

Table 8: Summary of Micronutrient Fertilisers

FERTILISER ADDITIVES	MICRONUTRIENTS SUPPLIED	RATE
Sodium borate	Boron	25 kg/t
Cobalt sulphate	Cobalt	0.5 - 2.7 kg/t
Copper sulphate	Copper	12 - 25 kg/t
Sodium molybdate	Molybdenum	0.3 - 0.9 kg/t
Magnesium sulphate	Magnesium	50 - 100 kg/t
Sodium selenate	Selenium	10g/ha

Mixture and Compound Fertilisers

Mixture fertilisers are fertilisers that have been mixed together to supply more than one nutrient to the soil. The NPKS rating of a mixture fertiliser is for the mixture itself and not the individual fertilisers that make up the mixture. Standard mixture fertilisers are:

Potash-phosphate

These range from 15 - 50 % potassium chloride mixed with straight, reverted or serpentine superphosphate.

Nitrogen-Phosphate

Most of these mixture fertilisers are made of one part ammonium sulphate and two/three parts of superphosphate.

Superphosphate-Lime

This is mainly half superphosphate and half lime.

Various mixture fertilisers are available from fertiliser manufacturers. Sometimes it is more convenient to mix fertilisers on the farm. If fertilisers are to be mixed it is important to know which fertilisers mix well and which do not.

Compound fertilisers also contain more than one nutrient. However, where mixture fertilisers are mixes of existing fertilisers, compound fertilisers are made from specially formulated materials. The best known compound fertiliser is di-ammonium phosphate (DAP).

Organic fertilisers

Interest in organic fertilisers has increased in the last few years, although there is a fair amount of misunderstanding about organic fertilisers. The term "organic" is used to indicate that they ate '"natural" and have no chemical manufacturing in their production. Most organic fertilisers break down slowly in the soil. Organic fertilisers often refer to raw or treated animal manures and industrial waste products such as blood and bone from animal slaughter premises (metalworks and abattoirs). Sulphur and reactive phosphate rock (RPR) are also used as organic fertilisers.

However, plant roots have developed in such a way that they can only take up nutrients in the inorganic (chemical) form. For plants to be able to use organic fertilisers, the fertilisers first have to be converted by soil bacteria into inorganic forms. Plants absorb nutrients as ions, whether they are from manufactured or organic fertilisers.

Organic fertilisers are also useful in improving the organic matter content in a soil.

One major problem with organic fertilisers is their variable nutrient content, which means there is often uncertainty over the actual amounts of nutrients that they contain.

Table 9: Summary of Organics Fertilisers

ORGANIC FERTILISER	***% NITROGEN***	***% PHOSPHATE***
Blood & bone	4 - 8	6 - 8
Bonedust	3 - 4	7 - 8
Dried blood	12 - 14	

Nutrient balance

It is important that all nutrients are supplied in the correct proportions.

If only one nutrient is in short supply a plant's development will still be limited by that one nutrient even if all others are present in amounts sufficient to ensure optimal plant growth. This is called the limiting nutrient. Growth can be no greater than is allowed by that one limiting nutrient.

There will be no improvement if other nutrients are added. As the concentration of the limiting nutrient increases plant growth will increase correspondingly. Once the nutrient has reached a concentration that is optimal for the plant growth and the sufficiency range has been obtained, further additions of this nutrient will not increase plant production.

However if the available nutrient concentrations increase beyond the sufficiency range the plant may take up excess nutrient and symptoms of toxicity will appear. Toxicity also leads to reduced growth and even plant death in extreme cases. Nutrients toxicity is usually confined to micronutrients.

This is shown in the a graph located at http://www.smart-fertilizer.com/articles/fertilizer-application-rates, which looks at the crop resonse to fertiliser application.

- A. the crop is nutrient deficient, adding more will increase growth rate
- B. there is just enough of the limiting nutrient to meet maximum growth requirements.
- C. there is an excess of nutrients, more than the plants can use but the plant can't grow any faster. At this stage there is no harm to the plant but the farmer is wasting money on applying fertiliser the plants can't use.
- D. the level of the nutrients becomes so high that they become toxic and poison the plants, reducing yield.

Therefore applying the right amount of fertiliser and limiting nutrients to:

- maximise yield
- minimise cost

For more information on different types of fertilisers and combination fertilisers, take a look at the Ravensdown website www.ravensdown.co.nz/products

Fertilisers – a summary

A fertiliser is defined as any material that provides a concentrated source of one or more essential nutrients needed for plant growth. Fertilising is usually necessary to replace soil nutrients lost by produce that is removed from the site.

Fertilising can also be necessary after wind or water erosion. Fertilisers can be either:

- organic: the material is plant or animal in origin
- inorganic: the material has been chemically produced or is the result of processing mineral deposits e.g. superphosphate.

Fertilisers are available as:

- straight fertilisers which supply one or two nutrients.
- compound fertilisers which provide a more complete range of elements essential for plant growth.

The object in applying fertiliser is to supplement the available nutrient reserves in the soil in order to ensure that optimum nutrient levels are available for plant growth at the right time. There are no universal standards for optimum mineral levels for all soil or crop situations.

Choosing the right fertiliser

Which fertilisers to apply and at what time of the year depend on:

- what type of plants are grown
- the type of soil they are grown in
- the existing levels of nutrients in that soil
- the climatic conditions

In recent years there has been much in the news about pollution in waterways from excessive use of fertilisers. Not only do fertilisers make plants grow on land, they are extremely good at stimulating plant growth in waterways.

This growth is not welcome as it slows the flow or streams and rivers. Plants prevent light, essential for the growth of aquatic ecosystems from entering the water. Plants also use valuable oxygen that is required by fish and other aquatic organisms.

The soil can only hold onto a finite amount of nutrient before it sheds the excess in the form of run off over the surface or leaching into ground water that finds its way into adjacent water ways.

Soil and leaf testing

We have seen how important it is to make sure that when buying an applying fertiliser you use the right type and the right amount to meet plant growth requirements.

To do this efficiently we need to check two things out:

1. the nutrient status of the plants to see what nutrients they need
2. the nutrient status of the soil and what additional nutrients might be necessary to meet plant requirements

We do this by:

1. Leaf testing
2. Soil testing

This background information helps producers to maximise growth by adjusting the right nutrient levels by the application of specific fertilisers when required. Soil and leaf testing are also valuable tools in assessing the correct amount required. This avoids unnecessary cost and helps to avoid over fertilizing which may lead to environmental pollution.

Plant leaf testing

Plant analysis is a valuable diagnostic and monitoring tool that should be used to complement soil analysis. A soil test shows what soil nutrients are available to the crop, while a plant test shows what nutrients the crop has actually taken up. In this way, plant tests provide a more reliable assessment of crop nutrient status.

Plant leaf testing involves chemical testing of plant tissue (usually leaves or leaf stems) to determine the current nutrient status of a crop or pasture. This acts as both an indicator of general plant health and also the availability of soil nutrients for uptake through the roots and leaves.

The rate of uptake of nutrients by the plant can be influenced by:

- rainfall and soil temperatures
- soil structure, drainage and pH levels
- interactions of mineral elements
- the presence of disease or insect pests

Plant leaf testing can be used in two ways:

1. To routinely monitor nutrients to help sustain optimum levels and thus avoid nutritional disorders
2. To identify nutrient deficiencies, toxicities or imbalances. Low plant nutrients are often due to low soil nutrient levels, but this is not always the case

The concentration of each element in the analysed tissue is compared with known optimum ranges for healthy, productive plants or crops of the same species.

The testing laboratory usually creates a report clearly defining both the nutrient deficiencies and/or excesses that may be limiting plant health and yield. A typical plant leaf test gives results for: nitrogen, nitrate-N, phosphorus, sulphur, calcium, magnesium, potassium, sodium, chlorides, boron, iron, manganese, copper, zinc, cobalt and molybdenum. Selenium is also usually tested for in pasture samples.

Leaf tissue is used for analysis as it plays an important part in photosynthesis and is a major site of carbohydrate and mineral storage. The mineral status of the leaves reflect the status of the rest of the plant and it is a readily accessible source of tissue for analysis.

The general rule is to sample fully developed, current season's spring flush leaves.

An example of a problem that can be identified through leaf analysis is incorrect nitrogen fertilization which can result in imbalanced nitrogen cycling. Leaf analysis can identify levels of nutrients as well as the ratios of one element with another. The balance between elements can be checked and corrected. When nitrogen levels are low, phosphorus, potassium and sulphur levels are likely to be higher than plants with adequate nitrogen levels. As one might expect, excessive levels of nitrogen are often related to low levels of the other nutrients.

Requirements for nutrients vary for individual plants.

Soil testing

Soil testing measures the amount and availability of mineral nutrients in the soil. By looking at the nutrient balance and ratios of both the micro and macronutrients it is possible to create a balanced fertiliser programme to ensure that the plants have the right nutrient supply for optimum growth and yield.

Soil testing can tell you what you need to add to correct deficiencies in the soil and what to be aware of to avoid potentially toxic nutrient levels.

Soil testing also helps avoid wasting expensive fertiliser because of improper application.

Taking soil samples

Soil samples are taken with a soil corer (Figure at right). To get a representative sample from a piece of land you need to take several core samples across the area to a depth of about 15cm (the depth many plant roots normally grow in).

Soil testing labs recommend that:

1. For horticultural samples take fifteen to twenty 15 cm soil core samples across the hort block and for a representative soil sample aim for 500g of soil.
2. For tree crops, take two 15 cm cores from the root zone of ten trees from two diagonal lines through the sample area.
3. For row crops like kiwifruit or grapes, take twenty soil cores from the plants root zone across the sample area.
4. For vegetable crops, collect twenty 15 cm soil cores across the sample area.
5. For pastures grazed by animals take fifteen to twenty 15cm core samples across the paddock

Figure 28: Soil Corer

Image from http://www.drdatedude.com/pages/s/soil-sampler/

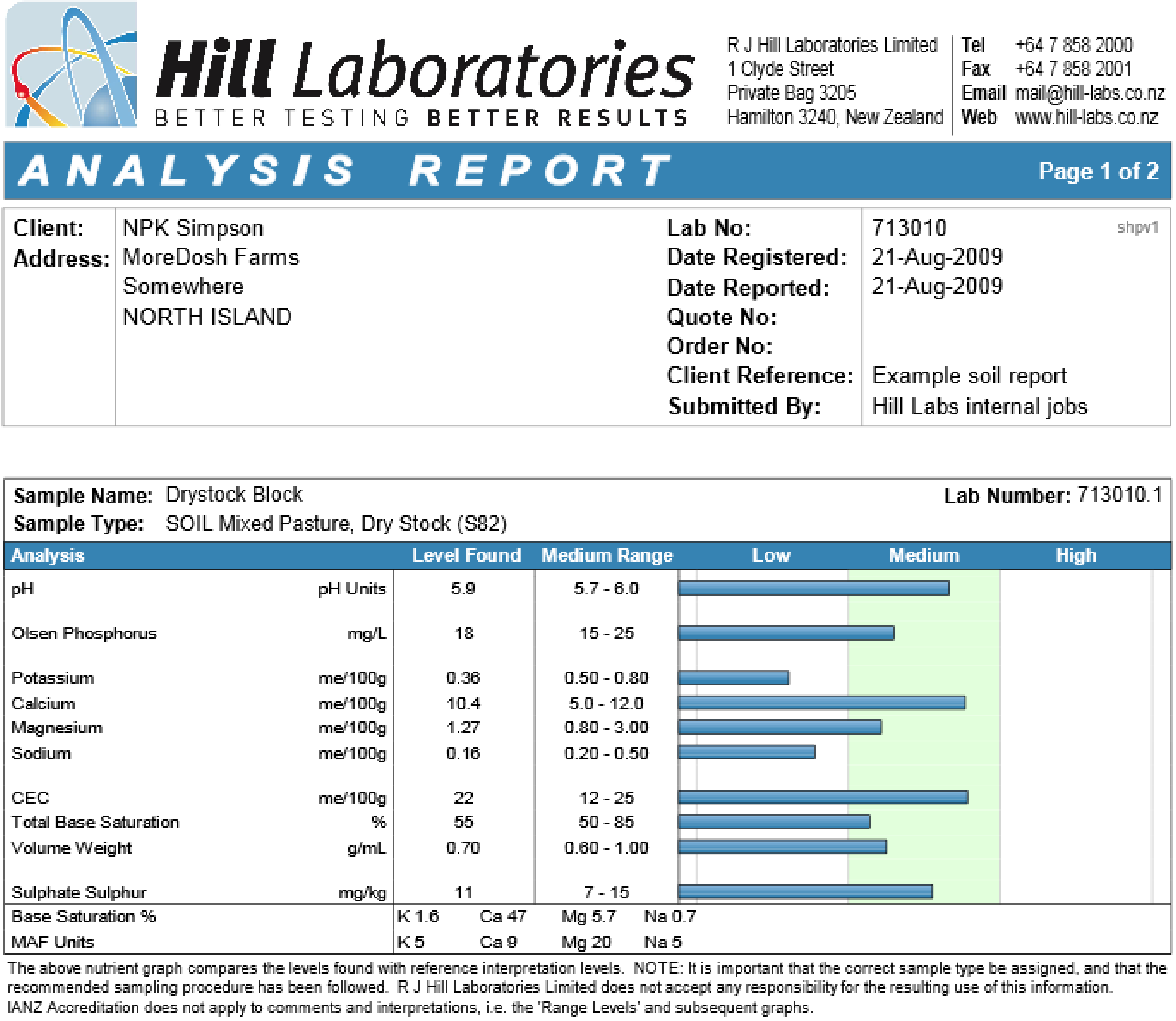
There are a few rules for getting representative samples for analysis:

- To get an accurate reading do not sample soil for 3 months after applying fertiliser or lime, as it takes this long for nutrients in the fertiliser to show up in the soil sample.
- When sampling pastures grazed by animals:
- Avoid gateways, stock camps and areas around water troughs.
- Do not sample immediately after grazing
- Where you are testing hilly areas you will need to test valleys slopes and ridges as each may have different fertility.

Reports from soil test laboratories vary greatly. On the next page is one example of a soil test report. The report lists the minerals tested and contains a chart which indicates whether the levels are low, adequate or excessive.

From this report the recipient would be able to determine what type of fertilisers and minerals to apply to the soil to correct deficiencies. In this case the soil is deficient in potassium and sodium.

This soil would benefit from dressing with a potassic fertiliser.



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ANALYSIS REPORT Page 1 of 2

Client:	NPK Simpson	**Lab No:**	713010 shpv1
Address:	MoreDosh Farms	**Date Registered:**	21-Aug-2009
	Somewhere	**Date Reported:**	21-Aug-2009
	NORTH ISLAND	**Quote No:**	
		Order No:	
		Client Reference:	Example soil report
		Submitted By:	Hill Labs internal jobs

Sample Name: Drystock Block **Lab Number:** 713010.1
Sample Type: SOIL Mixed Pasture, Dry Stock (S82)

Analysis		Level Found	Medium Range	Low	Medium	High
pH	pH Units	5.9	5.7 - 6.0			
Olsen Phosphorus	mg/L	18	15 - 25			
Potassium	me/100g	0.36	0.50 - 0.80			
Calcium	me/100g	10.4	5.0 - 12.0			
Magnesium	me/100g	1.27	0.80 - 3.00			
Sodium	me/100g	0.16	0.20 - 0.50			
CEC	me/100g	22	12 - 25			
Total Base Saturation	%	55	50 - 85			
Volume Weight	g/mL	0.70	0.60 - 1.00			
Sulphate Sulphur	mg/kg	11	7 - 15			
Base Saturation %		K 1.6	Ca 47	Mg 5.7	Na 0.7	
MAF Units		K 5	Ca 9	Mg 20	Na 5	

The above nutrient graph compares the levels found with reference interpretation levels. NOTE: It is important that the correct sample type be assigned, and that the recommended sampling procedure has been followed. R J Hill Laboratories Limited does not accept any responsibility for the resulting use of this information.
IANZ Accreditation does not apply to comments and interpretations, i.e. the 'Range Levels' and subsequent graphs.

Figure 29: Example of a soil test report

Retrieved from http://www.hill-laboratories.com/file/fileid/16907

Self-review 4: Fertilisers

1. Define fertiliser.
2. Why is lime not a fertiliser?
3. List the three main type of fertiliser in New Zealand agriculture and horticulture.
4. What are the main uses for N fertilisers in New Zealand?
5. Describe the composition of ‘superphosphate’.
6. List the two type of potassic fertiliser used in NZ.
7. What are compound fertilisers?
8. What is meant by ‘limiting nutrient’?
9. What is the reason for doing soil tests?
10. What is the reason for doing leaf tests?

Check out your answers at the end of the module.

Conclusion

Through this module we have looked at the different aspects of soil as though they are separate from one another. However soil is the end result of many interlinking processes. The parent material impacts on the texture and structure of the soil. Parent material also has an influence on the mix of nutrients that the soil can provide for plant production. The texture and structure dictate the soils ability to hold water, air and nutrients.

Human activity influences soils, especially when land is converted from natural vegetation to agricultural use. Additives of lime and fertilisers and drainage or irrigation affect soil composition. The amount of additives required is influenced by the parent material and soil texture. Cultivation techniques change soil structure which in turn dictates the availability of nutrients for plant absorption.

The identifying features of the soil profile reflect all of the above and tell the history of how the soil has been constructed, and gives clues to how best to maximise production from it.

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New Zealand Soil Classification. A.E Hewitt, 1998, Lincoln Canterbury. Manaaki Whenua Press.

Websites

There are many websites with information on soils. Check they are from reputable organisations and have relevance to New Zealand soils and farming systems. A few are listed below.

Website	Organisation
www.nzsoils.org.nz	Waikato Regional Council website 'NZ Soils' – wide range of information about soils
soils.landcareresearch.co.nz	Landcare Research site on New Zealand soils - NZ Soil Portal
www.boprc.govt.nz	Bay of Plenty Regional Council – search for 'soil'
www.orc.govt.nz	Otago Regional Council – search for 'soil'
www.fertiliser.org.nz	NZ Fertiliser Association website – Code of Practice on fertiliser use and fact sheets about sustainable and efficient use of fertiliser
vro.dpi.vic.gov.au	Australian Department of Environment and Primary Industries, Victorian Resources Online – information about soil erosion
informedfarmers.com	Australian farming website – general soil information
www.dpi.nsw.gov.au	New South Wales Department of Primary Industries – see soil section
www.ravensdown.co.nz	Ravensdown Fertiliser

Glossary

Aeration (of soil)	The process by which air within soil pores is exchanged with atmospheric air, thus preventing the depletion of oxygen and the accumulation of carbon dioxide in the soil air.
Aerobic	Containing or requiring the presence of molecular oxygen.
Allophanic soils	Soils dominated by allophone, a mineral containing aluminium and silicon that are found in soils formed from volcanic ash.
Alluvial	Sand, silt and clay deposited on land by water; may subsequently form the parent material of a new soil.
Anaerobic	The absence of, or not requiring, oxygen.
Clay (soils)	A very fine mineral particle of soil no bigger than 0.002mm in diameter; also a soil textural class, soils in which clay-sized particles predominate.
Enzymes	Protein materials which enable specific biochemical reactions to take place.
Fixation	Processes which convert plant nutrients from soluble or exchangeable forms to less soluble or exchangeable forms.
Friable	A term used to describe the ease with which a soil breaks down to a desirable, crumb structure.
Fungi	Organisms not containing chlorophyll (the green stuff in plants), which obtain their nutrients by decomposing organic materials.
Gley soil	Soil developed under conditions of poor drainage that result in predominantly grey colours and the presence of black or rusty mottles.
Horizon (of soil)	A roughly horizontal layer of soil which differs in appearance and properties from the soil above and below it.
Humus	A very stable form of organic matter which remains when most of the plant and animal residues in the soil have been decomposed by microorganisms.
Impervious	Resistant to penetration by water or roots. Often referred to as a **Pan**
Ions	Electrically charged particles formed when certain substances dissolve in water; those carrying negative charges are anions and those with positive charges are cations.
Leaching	The removal of nutrients and other soluble (dissolved) substances from the upper layers of soil by the downward flow of water through the soil profile.
Melanic soils	Soils with a dark surface horizon which are rich in nutrients such as calcium and magnesium; subsoils may contain lime and have a well-developed structure.
Mottling	Spots or patches of soil with colours that contrast with the main colour of leaf tissue or the soil.
Mulch	Any material which is applied to the surface of the soil to protect it from the weather, minimise loss of water by evaporation or suppress weeds.
Organic soil	A soil that contains more than 20% organic matter.
Pallic soils	Soils with a pale-coloured subsoil, unstable structure and a dense B-horizon.

Peat	Soil formed by the accumulation of undecompensed or partially decomposed plant residues. The material is in an anaerobic situation.
Permeability of soil	The ease with which water, gases or roots can pass through soil.
pH of soil	A measure of the acidity or alkalinity of a soil; chemically it is the measurement of hydrogen ions in the soil solution.
Plasticity	The ability to mould material into shapes which are retained after the moulding pressure has been removed.
Podzols	Strongly leached acid soils with a clearly defined bleached horizon.
Porosity (of soil)	The volume of pore spaces as a percentage of a volume of soil.
Profile (of soil)	A vertical section through the soil, exposing all its horizons, from its surface to the parent material. A soil profile is only two-dimensional.
Pugging	Destruction of surface structure of wet soils by livestock.
Silting	The deposition of water-born soil particles in a stream or lake, or on flooded land.
Soil texture	The relative proportions of solid primary particles (sand, silt and clay) in a soil.
Tephra	A general term for fragments of volcanic material such as ash.
Virgin soil	Soil that is uncultivated or disturbed by humans.
Volcanic rock	Rock derived from volcanic activity, e.g. basalt, pumice and rhyolite.
Waterlogged	Saturated with water.
Weathering	The physical and chemical changes that occur to rock materials at or near to the earth's surface.

Answers to self-reviews

Self-review 1: The composition of soil

1. List the 4 main components of soil and their proportions in the soil.
   - *Minerals 45%*
   - *Organic matter 5%*
   - *Water 25%*
   - *Air 25%*

2. Where do the minerals in soil come from?

Minerals come from the breakdown and weathering of parent material or bedrock underground.

3. Where does the organic matter in soil come from?

Organic matter consists of humus, plant roots, dead and decaying plant materials, animals and their litter.

4. List the main inorganic nutrients that are supplied by soil minerals?
   - *Phosphorus (P)*
   - *Potassium (K)*
   - *Calcium (Ca)*
   - *Magnesium (Mg)*
   - *Sulphur (S)*

5. List the 4 ways organic matter (humus) benefits the soil and plants
   - *Water retention*
   - *Nutrient retention*
   - *Improves soil structure*
   - *Helps to warm soil*

6. Why is air important in soil?

Many of the organisms living in the soil, including plant roots, need oxygen for the chemical reactions in their cells. Therefore it is important that these organisms and plants roots have access to air.

7. List at least two reasons why soil water is important for plant growth.
   - *Water is one of the essential raw materials for photosynthesis.*
   - *Plants can only absorb mineral nutrients from the soil when they are dissolved in water. Scientists call this 'in aqueous solution'.*
   - *Nearly all biochemical reactions take place in the water in plant cells (in aqueous solution).*
   - *Water which fills plant cells also provides support for plants.*

8. What does the term soil texture describe about soils?

*Texture describes how coarse or fine a soil is. It refers to the size and proportions of mineral particles in the soil. Soil scientists often talk about **sand**, **silt** and **clay** soils. These terms refer to the size and proportions of mineral particles present in the soil.*

9. List the 4 main categories which are used to describe soil structure
   - *Crumb (or granular)*
   - *Platy*
   - *Block*
   - *fine*

10. List at least 4 ways soil structure affects soils
    - *soil aeration*
    - *water holding capacity of the soil*
    - *the movement of air and water to and from plant roots*
    - *nutrient cycling within the soil*
    - *root penetration and development (in the soil pores)*
    - *soil stability and its susceptibility to erosion*
    - *soil temperature*

11. List the 5 main soil horizons and their main characteristics
    - *horizon – topmost level – organic matter*
    - *A horizon – topsoil contains accumulated organic matter and is where roots and soil organisms live*
    - *B horizon – subsoil denser than A horizon with little organic matter, foots or organisms*
    - *C horizon – broken down parent material not chemically changed during soil formation*
    - *R horizon – the unchanged bedrock on which the soil lies.*

Self-review 2: Soil classification

1. Why is soil classification useful for soil management”

Soil classification is a way of describing and comparing different soils. It is also used for grouping together soils with similar profiles and properties. This is useful for soil management because management practices (e.g. irrigation, cultivation and, to some extent, fertiliser treatments) developed for one soil can be used on other soils with similar characteristics.

2. In the Soil Portal activity, you looked for the soil type at a location you chose. Name the soil type at that location.

Example: The soil type at Telford is Pallic

3. Where are volcanic soils are normally found?

Occurs within 'throwing distance' of ancient volcanoes such as Taranaki, Rotorua and the central North Island volcanoes. Bay of Plenty, King Country, Rangitikei, Waikato and Taranaki. They cover about 5% of New Zealand.

4. What is the potential for plant growth of volcanic soils?
    - *Natural fertility is low with tendency for mineral deficiencies, particularly cobalt (Co) which is essential for livestock).*
    - *But ability to retain and store phosphorus (P) is high, so regular dressing with P fertiliser will lift and maintain fertility.*
    - *Stable and fertile topsoil and soil is resistant to erosion except on steep sites.*
    - *Potentially very fertile. Some of New Zealand's most productive soils are volcanic loams.*

5. How are brown earths usually formed?

formed from weathering of rocks, mainly containing silica, over a wide range of climates. The brown colour is caused by iron oxides (rust) weathered from the parent material.

6. What are the main uses for brown earth soils?
    - *Intensive horticulture, viticulture*
    - *Cropping*
    - *Intensive dairy farming*
    - *Sheep and beef farming*
    - *Forestry*

7. How are podzols formed?

Formed in areas of high rainfall (over 1500mm per annum). Underlying rock is usually silica-based. Usually has a bleached pale horizon immediately beneath the topsoil. This is where aluminium and iron oxides have washed out of the subsoil to accumulate in the brown layers below.

8. What are the drainage characteristics of podzols?

Very poor drainage and difficult for plants to root into the 'cemented' subsoil.

9. Describe the soil texture and structure of pumice soils
    - ***Soil texture:*** *Loamy sand, silty sand, low clay content.*
    - ***Soil structure:*** *Crumb or granular, low soil strength (easy to cultivate). Particle/granule size can range from boulders down to a fine powder.*

10. Where are fluvial soils found?

Floodplains and river terraces throughout New Zealand. They cover about 6% of New Zealand.

Self-review 3: Soil nutrients

1. List the 6 essential mineral macronutrients supplied by the soil
   - *Nitrogen*
   - *Potassium*
   - *Calcium*
   - *Magnesium*
   - *Phosphorus*
   - *Sulphur*

2. What role does N play in plant cells?

Nitrogen (N) is an essential component of all proteins.

3. How does N deficiency show itself in plants?

*Nitrogen deficiency most often results in stunted growth, slow growth, and yellowing of the leaves (**chlorosis**). Nitrogen deficient plants may also show a purplish appearance on the stems and underside of leaves.*

4. What role does K play in plants?

*Potassium (K) is important because it regulates the opening and closing of pores (**stomata** -ventilation holes) in the leaves.*

5. How does K deficiency show itself in plants?

Potassium deficiency may result in higher susceptibility to disease, wilting, chlorosis (yellowing between leaf veins) and damage from frost and heat.

6. List and briefly describe the function and signs of deficiency for 2 essential micronutrients.

Examples:

- *Iron (Fe) is necessary for photosynthesis and is present as an enzyme cofactor (a 'helper' molecule) in plants. Iron deficiency can result in chlorosis and cell death.*
- *Molybdenum (Mo) is a cofactor to enzymes important in building amino acids. Mo deficiency results in stunting and slow growth and yellowing of leaves.*

7. How does Rhizobium help plants to obtain nitrogen in the soil?
   - *Nitrogen fixed by Rhizobium improves clover growth. Animals eating the clover digest and return the nitrogen to the pasture in their dung and urine. Soil organisms and free-living soil bacteria decompose these and release nitrates into the soil water. Ryegrass (and other pasture plants) can then absorb this recycled nitrogen to improve overall pasture growth rates.*
   - *Organic matter in dead leaves, roots and other plant parts decomposes (as discussed earlier) recycling N into the soil.*

8. What is the optimum soil pH range for most plant growth?

Between pH 6.0 and 7.0

9. What normally happens to nutrient availability in soil as pH decreases, i.e. as soil becomes more acid?

Normally nutrient availability decreases as soil becomes more acid.

10. How does lime help mineral availability in acid soils?

Lime neutralises acidity in the soil and helps to make soil more neutral so that nutrient availability is increased.

11. List three problems that can occur in very acid soils and three problems that can occur in very alkaline soils.

    Examples:

Problems in very acid soils	*Problems in alkaline soils*
Aluminium toxicity to plant roots	*Iron deficiency*
Manganese toxicity to plants	*Manganese deficiency*
Calcium & magnesium deficiency	*Zinc deficiencies*

Self-review 4: Fertilisers

1. Define fertiliser.

Fertilisers are substances that add essential plant nutrients to the soil.

2. Why is lime not a fertiliser?

Lime is not a plant nutrient – it is not required by plants. Lime simply changes soil pH to make the other essential nutrients that are already in the soil more easily available to plant roots.

3. List the three main type of fertiliser in New Zealand agriculture and horticulture.
    - *Nitrogenous fertilisers*
    - *Phosphatic fertilisers*
    - *Potassic fertilisers*

4. What are the main uses for N fertilisers in New Zealand?
    - *stimulate "out-of-season" (winter/spring) pasture growth on dairy farms*
    - *on arable and horticultural crops*
    - *on pasture seed crops (ryegrass and cocksfoot)*
    - *as part of direct drilling pasture establishment*
    - *as part of dairy effluent returned to pasture*
    - *to correct nitrogen deficiency that often occurs on newly established pasture.*

5. Describe the composition of 'superphosphate'.

It contains 10 % phosphorus and 11 % sulphur. It is reasonably soluble in water and is often called straight super to distinguish it from other phosphate fertilisers.

6. List the two type of potassic fertiliser used in NZ.
   - *Potassium chloride*
   - *Potassium sulphate*

7. What are compound fertilisers?

Mixture or compound fertilisers are fertilisers that have been mixed together to supply more than one nutrient to the soil.

8. What is meant by 'limiting nutrient'?

If only one nutrient is in short supply a plant's development will still be limited by that one nutrient even if all other present in amounts sufficient to ensure optimal plant growth.

9. What is the reason for doing soil tests?

Soil testing measures the amount and availability of mineral nutrients in the soil. By looking at the nutrient balance and ratios of both the micro- and macronutrients it is possible to create a balanced fertiliser programme to ensure that the plants have the right nutrient supply for optimum growth and yield.

10. What is the reason for doing leaf tests?

Plant leaf testing involves chemical testing of plant tissue (usually leaves or leaf stems) to determine the current nutrient status of a crop or pasture. This acts as both an indicator of general plant he alth and also the availability of soil nutrients for uptake through the roots and leaves.