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Understanding Your Soils

Soil booklet for Southland Farmers

Roger McLenaghen, Jim Moir and Leo Condron

AB LIME

INTRODUCTION

AB Lime is focused on providing our customers with accurate and appropriate knowledge about the soil that supports their business. We believe that without a good understanding of what is going on under your feet, it's impossible to determine with confidence what you need to keep your farming business growing and profitable. As such, we asked Lincoln University soil scientists to provide you with appropriate information on the properties and management of Southland soils.

This booklet was prepared by Mr Roger McLenaghen, Associate Professor Jim Moir and Professor Leo Condron from the Faculty of Agriculture and Life Sciences at Lincoln University.

As a farmer, your soil is the foundation of your business — your most important asset. Do you know it as well as your best piece of equipment? Do you spend the same amount of time considering your fertiliser investment as you do before investing in a new tractor? Would you let a salesman buy a tractor for you?

There is an increasing, and almost overwhelming number of fertiliser options out in the market place these days all claiming to be what your farm needs. Only you as the farm owner really know your farm needs. And this starts with knowing your farm's soil requirements.

It's really simple – all it needs is to be in good physical condition and able to provide appropriate nutrients to your crop or pasture.

Conventional agriculture, organic agriculture, alternative agriculture, chemical agriculture, industrial agriculture, eco-agriculture - these labels create strong reactions and can be a source of controversy and much debate. However there are important underlying similarities among these farming systems.

The great thing about most soil is that under good management it thrives. When soil is looked after microbes thrive and flourish, organic matter builds, nutrients cycle and water drains. Plants grow and animals fatten. This isn't a fantasy, this is normal. All you need to do is balance the losses from product removal (feed it if it needs it) and treat it gently when you turn it up, when it's wet and when it's carrying weight.

Get to know your soil. It's unique to your farm and its needs are unique to your business. Read this booklet, use the resources mentioned and apply it to your property. Start with a good informative soil test and make sure you understand the results, and test annually! When a sales rep comes knocking, be prepared. Remember knowledge is power – power to ensure your business is working for you.

Good Management = Good Soil

CONTENTS

PHOTO ACKNOWLEDGEMENTS:

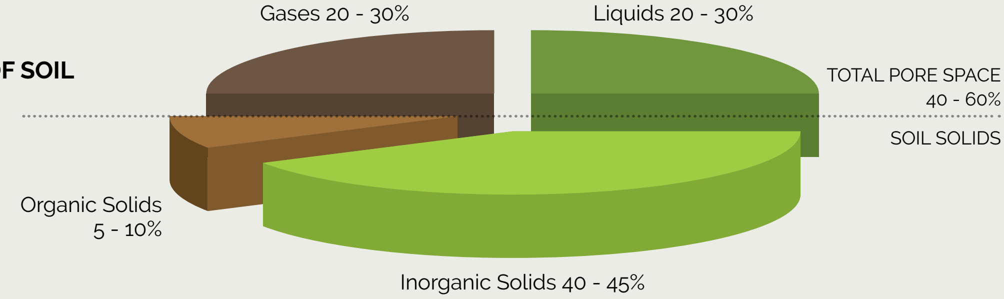
- Soil plates – Dr Sam Carrick, Lincoln University
- Pugging damage – Prof Keith Cameron, Lincoln University
- All others – Lincoln University, Agriculture and Life Sciences Faculty Collection

THE SOIL RESOURCE

Soil is made up of inorganic solids (derived from rock) and organic material combined into a medium that also contains a network of open voids (pore space).

FIGURE 1

THE COMPONENTS OF SOIL



The relative proportions of soil components are shown in *(Figure 1)*.

THE COMPONENTS OF SOIL

Inorganic solids

- Inorganic solids in the soil vary in size from large stones through to gravels, sand and silt ending with fine clay particles.
- Material greater in size than clay is mostly inert and therefore doesn't affect nutrient availability. This material is very important for ease of cultivation, drainage and available water storage (silt is optimum).
- Clay sized particles (<2 μm) are important for nutrient retention, water storage and drainage, ease of cultivation and soil structure formation.

Organic solids

- Soil Organic Matter (SOM) varies in content depending the age of the soil and the climate in which the soil formed. Most SOM is found in the top 10-15cm with contents in the order of 4-15%, which is equivalent to 50-250 tonnes/ha.
- SOM is extremely important for both nutrient retention and nutrient cycling as well as the soils physical conditions.

For good soil growth a continuous network of a range of pore sizes is optimal.

The soil pore space

- The soil pore space varies in size from large pores (macro-pores) that are greater than 50 μm to extremely small pores that are less than 0.2 μm.
- Macro-pores are important for water infiltration and drainage, aeration and gaseous exchange, root penetration and space for living organisms.
- Pores between 0.2 and 50 μm are essential for water storage, nutrient transfer and uptake by plant roots and space for living micro-organisms.

SOIL PHYSICAL PROPERTIES

Soil Texture

Soil texture is the size and abundance of the inorganic solids in the soil. Material that is < 2mm in size is referred to the fine earth fraction and is made up of mineral grains. The relative proportion of sand silt and clay in a soil determines the textural class of that soil.

In New Zealand we use six main textural classes:

- Clay
- Clay loam
- Silt loam
- Sandy loam
- Loamy sand
- Sand.

The texture of a soil can be easily determined using the field texture method described in a number of textbooks, field guides or web pages.

PLATE 1: GOOD SOIL STRUCTURE

Soil Structure

Soil structure represents the way that the mineral particles have been grouped together with organic matter to form larger units and pore spaces. These larger units are referred to as peds or aggregates. In well aggregated soils, the voids between aggregates are important for providing a continuous network of macro-pores for water infiltration, drainage and aeration. The small pores within individual aggregates are for water storage. Thus soil structure and aggregation results in a dual system of soil pores *(Figure 2).*

Soil structure is formed by physical processes such as freezing/thawing cycles; shrinking and swelling; plant roots pushing past particles, and earthworms. The stability of structural aggregates refers to the soils ability to resist rain-drop impact, cultivation and animal compaction. Structural stability depends on:

- The amount and type of clay and the presence of calcium to flocculate the clay
- Fresh decomposing organic matter producing sticky gums
- Iron and aluminium oxides produced by weathering.

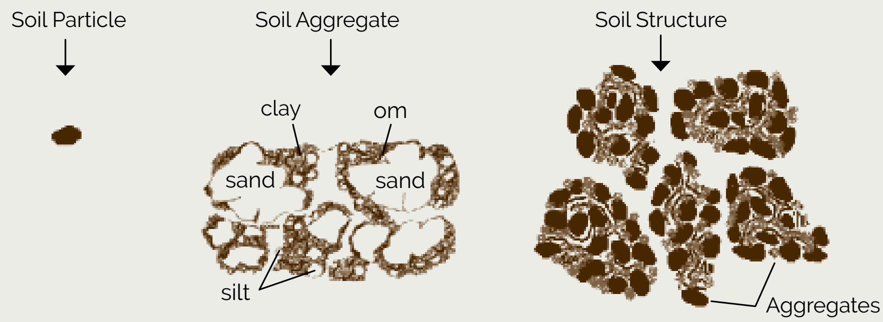
The stability of soil structure can be assessed by placing small aggregates into a saucer of water and observing them after about half an hour. If the aggregates completely collapse and the water starts to go cloudy then the structure is very unstable. Partially stable aggregates may show material starting to break off so that the aggregate starts to break-down into a pile of smaller units. Stable aggregates remain intact. After initial observations it is useful to gently shake the saucer to provide more energy for breakdown, similar to rain-drop effects.

A number of textbooks and web pages are available to describe the visual appearance of soil structure.

Generally, the more structural aggregates (2 - 10 mm) that can easily be gently disrupted from a block of soil; the better the structure (*Plate 1*).

FIGURE 2

SOIL STRUCTURE DEVELOPMENT



Soil Consistence

Soil consistence describes how the soil will behave if compressed or disturbed by cultivation. Consistency depends on the soil texture, amount of organic matter and water content of the soil. As the soil water content increases, soil consistency changes across the following terms:

- **Hard** when the soil is dry. Indicating considerable resistance to cultivation force
- **Friable** to indicate moist soil that is easy to cultivate
- **Plastic** if the soil is wet and will deform and compress when cultivated
- **Liquid** when the soil is very wet and may start to flow.

Soil that is moist and friable are relatively safe to cultivate. For wetter plastic soils there is a danger that cultivation or animals will compress the soil, damaging the soil structure. Soils may smear when cultivated forming a plough-pan or animals can pug the soil surface.

Soil consistency can be easily estimated by taking a sample of soil, crushing down and removing most plant roots, then moulding and trying to roll out a worm 2 - 3 mm in diameter. If the worm forms without breaking the soil is plastic and can be easily damaged.

Soil Drainage

In well-structured soils, the interconnecting system of macro-pores between the aggregates of 2 - 10 mm diameter will allow for excess water to drain. This will mean that the soil is well aerated and plant roots will be able to penetrate deeper to extract water and nutrients.

The indicators of poor drainage are often very visual and include:

- Grey and/or mottles colours in the soil profile *(Plate 2)*
- Poor structural development
- Presence of rushes etc. in the pasture
- Excessive stock/vehicle damage
- Nitrogen deficiency (yellowing of plant leaves).

PLATE 2: POOR DRAINAGE

"Waterlogged soils use twice the amount of heat to warm 1°c compared to dry soils which delays spring growth."

The reasons for poor drainage and therefore the management strategy employed can be related to the following:

- Impervious layer (pan or poor structural development) in fine textured soils creating a perched water-table. If drainage below is adequate then subsoiling may be appropriate
- High ground-water table in basin positions in the landscape. May require extensive drainage system utilising both drainage ditches and sub-surface drains such as tile, nova-flow, and mole
- Toe-slope positions in the landscape where water from the hill meets flat land. An interceptor drain can be effective at draining a considerable distance from the slope.

The impact of poor drainage is:

- Decreased root growth and microbial activity due to anaerobic conditions
- Colder soil temperatures delaying plant growth/ germination/microbial activity
- Easy damage to surface soil structure by vehicles and stock hooves
- More fertiliser nitrogen is required.

Pugging damage on wet soils

In pugged soils, the top 4-8cm acts as a seal and prevents further rain from infiltrating into the soil. Pugged areas, especially in the clay and clay loam soil types, may not fully recover until well into the second spring if not renovated or over sown.

The severity of pugging depends on factors such as the physical properties of soil such as soil type, soil drainage, rainfall, and soil moisture content. All of these affect soil consistence *(refer to page 7)*. Stock type, number of stock, the length of time they are left there and the pasture cover are also factors that alter the severity of pugging.

This damage can range from light, requiring little or nil repair work, to very severe, necessitating a full re-sowing program. Pastures and animals must be restored as soon as possible to return to higher profitability.

What are the effects of pugging and wet weather?

- Reduced pasture growth by 20 - 80%, depending on pugging severity.
- Reduced pasture utilisation by 20 - 40%.
- Reduced clover content.
- Delayed spring growth - waterlogged soils use twice the amount of heat to warm 1˚C compared to dry soils.
- Delayed and reduced silage/hay yields.
- Reduced nutritive value of this fodder.
- Uneven paddocks.
- Possible animal health problems.

Pugging damage may be minimised by utilising specific management options, dependent on different circumstances. To preserve the main source of feed for their stock, farmers should aim to **avoid pasture damage at all costs**.

PLATE 3: PUGGING DAMAGE

Options to prevent or reduce pugging damage are:

- Try not to move stock onto the paddock if the soil consistence is in the plastic range
- Don't graze wet soils if the pasture cover is short
- Graze blocks rather than strips. Stock tends to walk backwards and forwards more in a long narrow strip. This is accentuated if hay or silage is fed on this strip
- Graze from the rear of the paddock using temporary lane ways for access to the block. Don't allow stock access to previously gazed areas
- Allow stock access to only about 2/3 of the 24-hour grazing allocation throughout the day, and the remaining 1/3 at night. This stops contamination of the nightly allocation by mud, urine and dung. The stock will have a clean feed for the night so that less walking (pugging) will occur. They will feed quickly and then tend not to move so much for the rest of the night
- For dairy cows, options include the use of feed pads, feeding in the milking shed before moving stock onto the paddock and also during winter having run-off blocks or sacrifice paddocks to feed out onto.

SOUTHLAND SOILS

Soils vary in nature depending on changes in the soil forming factors (parent material, climate, relief, time and organisms). Most of the variability in Southland is due to changes in the climate and parent material.

In Southland the rainfall of between 800 and 1600mm is evenly distributed throughout the year. The wettest areas are at higher elevation and near the coast. Warmer temperatures are at low elevation and on sunny slope faces. Lower temperatures are at higher altitude and shady faces. The rainfall and temperature strongly influence the weathering and leaching of the soil parent material and therefore has a direct influence on soil fertility.

The soil parent material of the Southland region can be divided into the following 4 groups:

- **Bedrock** - tuffaceous sandstone and mudstone with minor loess cover
- **Windblown loess** that blankets the existing landscape
- **River alluvium**
- **Peat** (organic matter).

The soils of Southland can be divided into the following physiographic groups:

- Catlins, Hokonui Hills and Takitimu Mountains formed on rocks of the Southland syncline *(Plate 4).* These areas comprise of alternating ridges of resistant sandstone, and subdued valleys cut into the less resistant mudstone. Varying thickness of loess blanket (0 - 1m) over the underlying rock material
- Soils on the ridges and hill slopes with this loess cover are usually classified as either Podzol Soils, Allophanic Soils or Brown Soils. The key factor determining overall soil properties is the depth to bedrock
- Rolling loess covered (> 1 m) hills North East of Gore are typically Pallic Soils due to the lower rainfall. As you move South West towards Invercargill the soils are more weathered and leached and are classified as Brown Soils
- Adjacent to the main rivers (Aparima, Oreti and Mataura) there are major deposits of stony alluvium formed either from the last glaciation or beforehand. More recent deposits (Recent Soils and Gley Soils) of finer alluvium are also to be found near these rivers and on the floodplains
- Peat soils (Organic Soils) are found in low lying areas with the main area South East of Invercargill.

PLATE 4: SOUTHLAND SYNCLINE

SOIL MAPS AND RESOURCE INFORMATION

There are some published maps of the Southland region available at various scales. Some local maps at a scale of 1:10,000 are rarely available and none cover the Southland area. A regional map, such as the Soil Map of Southland Region (NZ Soil Bureau Map 207/1) is at a scale of 1:500,000, and is inappropriate at the farm scale.

Web based map resources are now available in a number of regions. Fortunately Landcare Research provides a map service called 's-map'. When completed this will provide digital soil map coverage for the whole of New Zealand. S-map is designed to provide soil map information right down to the farm scale. The Landcare s-map link is as follows:

http://smap.landcareresearch.co.nz/home

First time user will need to register. Registering is quick and easy, and completely free. Once registered, click on the Maps & Tools button, and then Maps. Search for your location, then zoom into the area of your farm (Plate 5). The Soil Summary tab allows you to get soil summary factsheets. Click onto the soil units and this will link you to factsheets on the various soil types.

At time of print, more than 50% of Southland region is available using the s-map website (Plate 5). In the not too distant future it is hoped that most of the region will be covered by s-map.

PLATE 5: S-map generated map of the area NE of Gore at a scale of 1:25,000

PLATE 6: S-MAP GENERATED

AB Lime also hold hard copies of soil maps for the Southland Region.

GENERAL SOIL PROPERTIES

0.5M

1.0M

Allophanic Soils

Allophanic soils are typically found on the Takitimu Mountains and between Lake Te Anau and Lake Wakatipu.

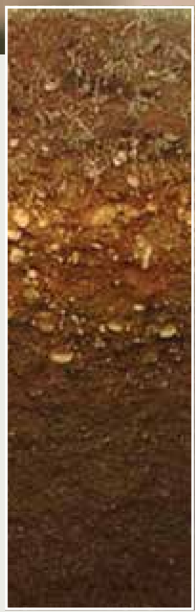
They are characterised by the presence of the mineral allophane and therefore have very high phosphorus retentions (> 85%). These soils are well drained to imperfectly drained and have porous low density subsoils.

0.5M

1.0M

Brown Soils

Brown soils are normally associated with higher rainfall areas (> 900mm) or older stony deposits. They are characterised by having yellowish brown subsoils and a well-structured topsoil. Brown soils are normally well drained to imperfectly drained and have low to moderate fertility.



0.5M

1.0M

Stony Brown Soils

Stoney brown soils are formed in alluvial gravel with the depth to gravel being less than 45cm. The depth of fines over gravel is the key factor that determines the water holding capacity of the soil. If the gravel is plugged with fines or translocated clay, permeability can be restricted.

0.5M

1.0M

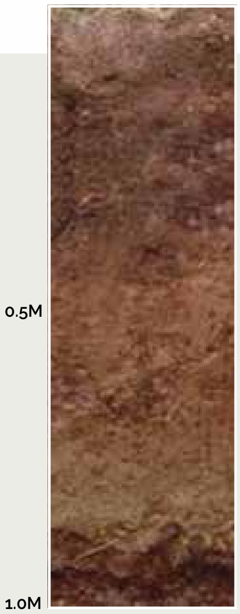
Gley Soil

Gley soils are found in low lying flood plain areas and depressions in the landscape. Gley soils are characterised by their grey coloured subsoil indicated they have formed under saturated conditions for prolonged periods. The limited oxygen at depth leads to anaerobic/reducing conditions. Subsoils are often poorly structured, sometimes clay rich, leading to poor to very poor drainage and permeability.

Pallic Soils

Pallic soils are formed in a weaker weathering/leaching environment having been formed under a 650 - 900mm rainfall.

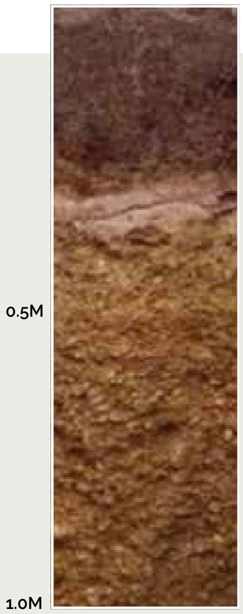
They are characterised as having a dense, slowly permeable fragipan that limits rooting depth and water holding capacity. Soil drainage is also restricted, so that these soils are imperfect to poorly drained. These soils are vulnerable to water logging, structural compaction and pugging damage. Artificial drainage of these soils is recommended.



Podzol Soils

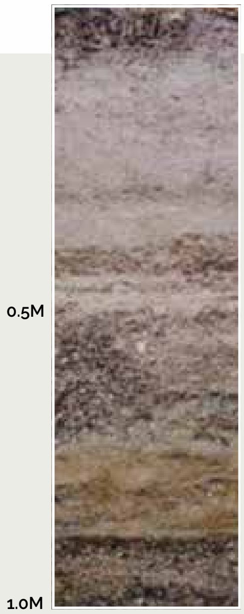
Podzol soils are extensively mapped in the Catlins area. They are characterised by being strongly leached, acid and of low fertility. They are well to poorly drained and sometimes have an iron pan present.

Subsoils have accumulations of aluminium and organic complexes. The E horizon may be absent depending on erosion and/or ploughing.



Organic Soils

Organic soils occur in wetlands, with the dominant area in Southland being south of Invercargill. These soils were formed in swamp positions with very high water tables. The plant remains did not decompose rapidly and therefore peat has formed. Organic soils have very low bulk densities and low load bearing strength. They are strongly acidic and deficiencies of N, P K, S and trace elements are common.



Recent Soils

Recent soils are formed in young fresh alluvial sediments. They have distinct topsoil and weakly developed subsoil, showing limited signs of soil-forming processes. Typically these soils are well to imperfectly drained, which is a reflection of the type of alluvial sediment. As these soils are young, they have undergone limited leaching; therefore soil fertility is moderate to high.

NUTRIENT CYCLING IN GRAZED PASTURE

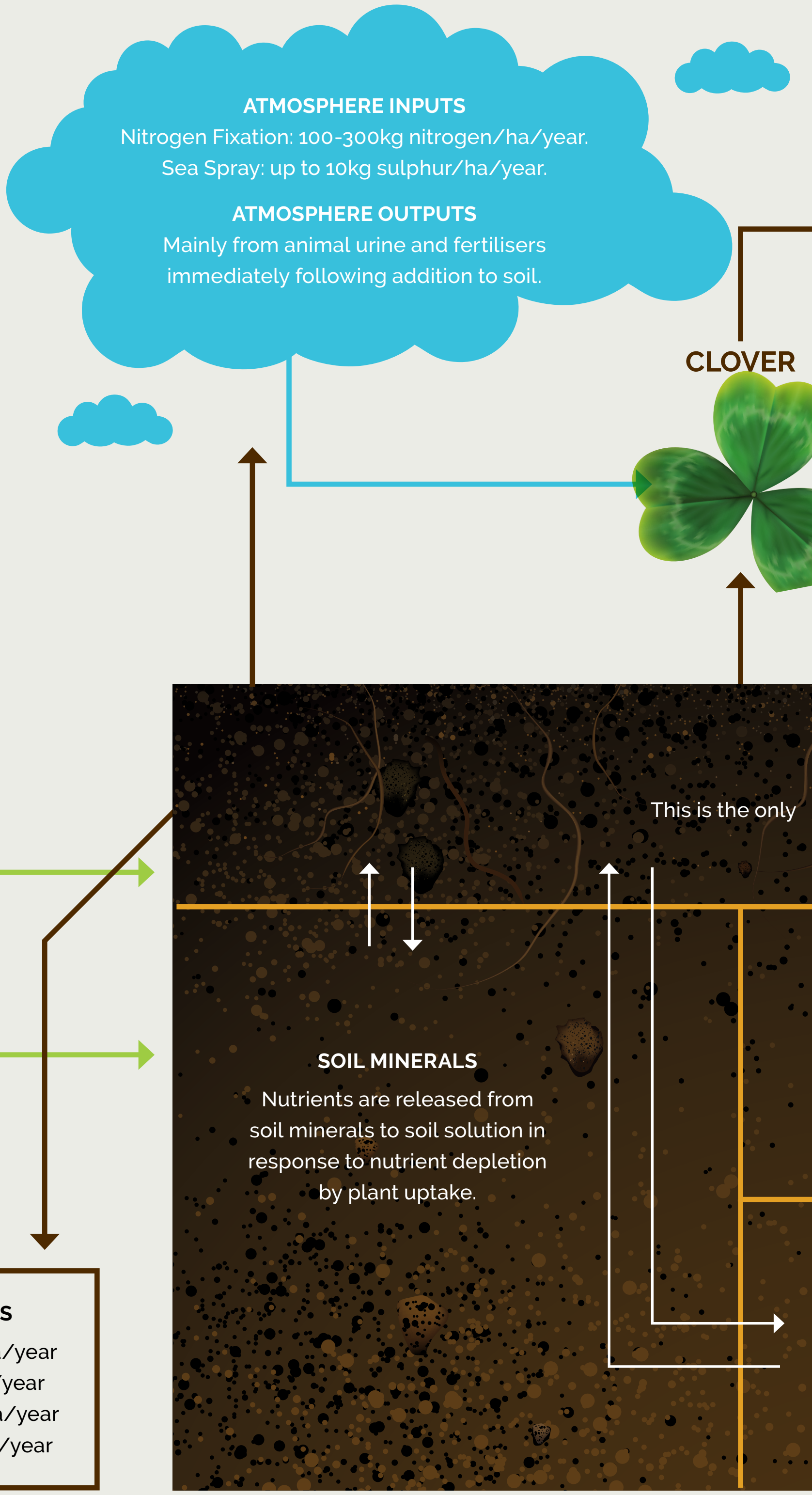
Nutrient cycling involves the growth and decomposition of organic matter back into mineral chemicals. There are losses and gains in and out of this system, but overall nutrient cycling is the movement of nutrients which is driven by living organisms.

Three different living organisms drive nutrient cycling:

1. Soil organisms
2. Pasture plants; and
3. Grazing livestock.

They all work together to produce good quality soils, which in turn produces good quality pasture. An efficient pasture system efficiently cycles nutrients as they move through various soil organisms and pasture plants then through grazing animals and back to the soil again as manure and urine.

By understanding the functions of the plants and animals living in and on the soil you can effectively manage soil fertility. Soil organisms make nutrients plant available and these same minerals can be recycled several times in a growing season if the soil ecosystem is healthy and plant cover is optimal. With good management nutrients can cycle quickly with minimal losses to air and water.



FERTILISER INPUTS

Most fertiliser nutrients are applied as water-soluble granules which dissolve readily in contact with soil solution. Other fertiliser materials dissolve slowly in soil.

DRAINAGE LOSSES

Nitrogen: 20-100kg/ha/year
Sulphur: 15-25kg/ha/year
Potassium: 50-70kg/ha/year
Phosphorus: 1-2kg/ha/year

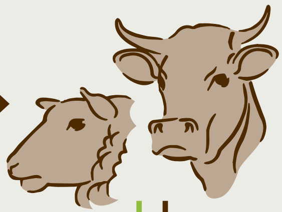
OFF-FARM LOSSES

FORAGE & PRODUCE/ LIVESTOCK

For hill country sheep & beef 8-13% of nutrients ingested by animals is removed in produce, compared with 15-24% under dairying.

GRASS

ANIMALS



WITHIN-FARM TRANSFERS

For hill country sheep & beef up to 40% of nutrients ingested by animals is transferred by stock, compared with only 7-9% under dairying.

SOIL SOLUTION

source of soil nutrients for plants.

RESIDUE RETURNS

Plant: 10-70% of nutrients taken up by plants

Animal: 50-90% of nutrients ingested by animals

SOIL BIOMASS

In topsoil (0-7.5cm) the weight of biomass is approximately 1% of organic matter, which is equivalent to 300-1100kg/ha.

SOIL ORGANIC MATTER

Topsoil (0-7.5cm) contains 4-15% organic matter, which is equivalent to 30-110 tonnes/ha.

NUTRIENT CYCLING IN GRAZED PASTURE

Pasture plants require three factors for growth and reproduction: light, water, and nutrients. Plant nutrients are chemical elements. They are mostly absorbed by plant roots as inorganic chemicals dissolved in the soil solution. These nutrients are also used by other forms of life and go through many biological transformations. Having some understanding of the biological and the chemical processes in the soil is important to effectively and efficiently provide plants with nutrients. Use the diagram on pages 14 & 15 to help understand the relationships of the following sections of information.

ATMOSPHERE INPUTS

Nitrogen Fixation:
Conversion of atmospheric di-nitrogen (N_2) to proteins by bacteria (Rhizobia) associated with clover roots (100-300kg nitrogen/ha/year).

Sea Spray:
Mainly sulphate-sulphur in coastal areas (up to 10kg sulphur/ha/year).

ATMOSPHERE OUTPUTS

Gaseous losses of nitrogen in the form of nitrous oxide (N_2O), di-nitrogen (N_2) and ammonia (NH_3) mainly from animal urine and fertilisers immediately following addition to soil.

FERTILISER INPUTS

Most fertiliser nutrients (nitrogen, phosphorus, potassium, sulphur) are applied as water-soluble granules (e.g. urea, superphosphate, diammonium phosphate) which dissolve readily in contact with soil solution and rapidly equilibrate mainly with the mineral pool. Other fertiliser materials such as phosphate rock, elemental sulphur and lime dissolve slowly in soil and become part of the mineral pool when applied.

PLANT AND ANIMAL RESIDUE RETURNS

Plant:
Return of nutrients to soil from pasture plants in herbage and root litter, which represent 10-70% of the nutrients taken up by plants.

Animal:
Return of nutrients to soil in animal urine and dung, which represent 50-90% of the total nutrients ingested by the grazing animal.

SOIL SOLUTION

Soil solution is the water content of soil, which is a solution containing various gases, organic matter, and minerals. This is the only source of soil nutrients for plants and microbes. Amounts of nutrient present in soil solution at any one time are extremely small and are constantly replenished from a combination of the soil mineral, biomass and organic matter pools.

SOIL MINERALS

Soil matrix (<2mm) comprised of sand, silt and clay particles. Nutrients are held on mineral surfaces (e.g. phosphorus, ammonium, calcium, magnesium, potassium) or contained in discrete sparingly soluble minerals (e.g. apatite [phosphorus], illite [potassium]). Nutrients are released from soil minerals to soil solution in response to nutrient depletion by plant uptake.

SOIL ORGANIC MATTER

Derived from carbon-rich plant and animal residues added to soil which are broken down by the biomass to release energy and nutrients over timescales ranging from hours to millennia. Calcium, magnesium and potassium (and ammonium) ions are also mainly held on soil organic matter surfaces, and are released to soil solution in response to nutrient depletion by plant uptake. Topsoil (0-7.5cm) contains 4-15% organic matter, which is equivalent to 30-110 tonnes/ha.

SOIL BIOMASS

Comprised mostly of bacteria and fungi (>90%), together with larger organisms such as protozoa, nematodes, mites, springtails and earthworms. Obtain energy and nutrients from breakdown of organic matter, and the activities of the different organisms are closely interlinked (soil food web). Biomass activity involves exchange of nutrients with soil solution, which in turn has a major influence on nutrient supply and availability to plants. In topsoil (0-7.5cm) the weight of biomass is approximately 1% of organic matter, which is equivalent to 300-1100 kg/ha.

DRAINAGE LOSSES

Removal of nutrients from soil in surface runoff and by leaching (nitrogen: 20-100kg/ha/year; sulphur: 15-25kg/ha/year; potassium: 50-70kg/ha/year; phosphorus: 1-2kg/ha/year).

OFF-FARM LOSSES

Removal of nutrients from plant and animals products, including forage (silage, hay), meat, wool, milk and livestock. For hill country sheep-beef 8-13% of nutrients ingested by animals is removed in produce, compared with 15-24% under dairying.

WITHIN-FARM TRANSFERS

Removal of nutrients from source areas mainly by livestock movements associated with transfer (rotation, laneways) and congregation (camps, water troughs, gateways, dairy sheds), but also includes forage transfer. Nutrients transferred to dairy sheds can be returned via effluent irrigation. For hill country sheep-beef up to 40% of nutrients ingested by animals is transferred by stock, compared with only 7-9% under dairying.

FERTILISER & SOIL

FERTILITY MANAGEMENT

Plants require many key nutrients in order to photosynthesize, grow, reproduce, and in the case of legumes, fix atmospheric nitrogen. Even if only one nutrient is deficient, plant function and growth can be limited.

The quantities of nutrient required by plants vary for different elements, and between plant species and cultivars. Elements required in large quantities are called 'macro' or elements, and those required in small quantities are called 'micro' or 'trace' elements. Essential macro elements include: nitrogen (N), phosphorus (P), sulphur (S), potassium (K), calcium (Ca) and magnesium (Mg), while micro elements include boron (B), cobalt (Co), copper (Cu), iron (Fe), molybdenum (Mo), manganese (Mn) and zinc (Zn).

SOIL CHEMICAL PROPERTIES

Soils are comprised of both mineral (derived from rock) and organic (carbon-based) materials. Soil organic matter often refers to the 'dead' carbon present in the soil.

The mineral particles vary vastly in size, in the order of clay <silt < sand < gravel < stones and boulders. The organic matter content of soils also varies considerably, and is determined by a combination of factors including soil type, soil age and management history.

In pastoral soils, most organic matter is present in the surface 10 cm of the profile. As soil macro and micro biological organisms require carbon as a source of energy (in decomposition processes), these organisms mostly reside in this soil layer. Nutrient cycling (turnover) in a soil/plant/animal farming system is strongly influenced by the quantities and activities of soil organisims.

The 'cation exchange capacity' (CEC) is the ability (quantity) of the soil to hold positively charged 'ions'. The CEC of soil is mainly determined by the organic matter and clay contents, and pH. CEC increases with increasing organic matter and clay.

The nutrient ions held by soil in this way include potassium, magnesium, calcium, sodium and also iron and aluminium. These 'cations' are termed as being 'exchangeable', because they can easily move into soil solution from the surface of the soil particle, and can then be taken up by plant roots.

Soils which have a high CEC have a large capacity to store and release these nutrient cations, while the reverse is true for low CEC soils. As such, the CEC of a soil is an extremely important nutrient storage mechanism. The CEC also strongly influences the extent to which a soil can resist changes in soil pH, e.g. when liming.

Soils with high CEC will generally have a high ability to resist or 'buffer' changes in pH ('high pH buffering capacity'). Conversely, soils with low CEC will have a low pH buffer capacity, and therefore a low ability to resist pH changes. As a result, high CEC soils require more lime per ha to shift the soil pH test by 1 pH unit than low CEC soils.

SOIL FERTILITY & NUTRIENT AVAILABILITY (INCL. LIME & PH)

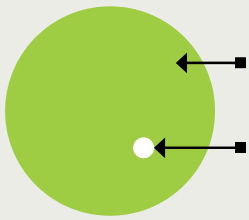
Soil fertility is a key driver of productivity at any one site, or farm. Nutrients are present in either inorganic or organic forms in soil. Some nutrients are mostly stored in inorganic forms, while others are mainly in organic forms. For example, soil nitrogen and sulphur are mainly stored in organic forms, while potassium and magnesium are mainly in mineral (inorganic) form. Phosphorus is stored in both inorganic and organic forms.

In terms of productive agricultural systems, 'soil fertility' often refers to the quantity of plant available nutrient in a soil, often in the plant root zone. Scientists would refer to this as being the size of the **plant available nutrient pool.** The 'plant-available' portion of a nutrient represents only a small fraction of the 'total' amount of the nutrient present in the soil *(Figure 3)*.

FIGURE 3

AN EXAMPLE OF SOIL 'TOTAL' AND 'PLANT-AVAILABLE' (LABILE) NUTRIENT POOLS

Olsen P - A soil test which estimates the amount (size) of the plant-available (labile) phosphorus pool in soil.



Total Soil P Pool
e.g. 1000 μg P/mL

Labile Soil P Pool
(Olsen P) e.g. 20 μg P/mL
[Typically 1-10% of Total Soil P]

PLATE 7: NITROGEN FIXING NODULES ON A WHITE CLOVER PLANT

The exchange of nutrients to and from plant-available and non-plant-available forms in soil differs for different elements. These exchange processes are critical to nutrient cycling, are extremely complex, and in some cases, are not fully understood.

Several factors influence the availability of soil nutrients to plants, including soil pH, soil nutrient cycling and development, nutrient concentrations in soil solution and plant effects.

pH has a profound effect on nutrient availability to plants and soil organisms. For example, P availability is strongly affected by pH. At low soil pH (acid; < pH 6.0) soil P can form insoluble compounds with aluminium, iron and manganese. At high pH (alkaline > pH 7.0), P forms insoluble calcium and magnesium phosphates. Therefore both low and high soil pH can have a large effect on the plant-availability of P, and therefore plant growth and yield.

Trace elements such as boron also have low availability at high pH. Also, nutrient cations (K, Mg, Ca, Na) are often low in acid soils, because acid cations (H and Al) have displaced these. Nitrogen availability may also be low in acid soils, and also molybdenum, a critical trace element used by legumes to fix N.

The quantity of nutrients, and nutrient availability, of a soil can also be affected by soil development. The age of a soil, the climate that it formed in, vegetation type (species, rooting depth and density etc.) and soil parent material are all contributing factors. Whether or not the nutrients are cycled back to the soil, or are transported away, will have major effect.

Atmospheric N_2 'fixation' by pasture legumes (often clovers) is a vital component of N input and cycling in grazed pasture systems. A large proportion of the N required for grass growth in the sward is often provided by the clovers (where N fertiliser rates are low).

This N, 'fixed' by bacteria in legume root nodules, becomes available slowly over time to the grass in pastures after it is released into the soil. This N transfer occurs by several mechanisms, including the mineralisation (decay) of old legume through exudates from legume roots and in excreta deposition (especially urine) by grazing animals.

In addition to plant nutrient availability considerations, soil aluminium (Al) is also a major issue for pasture and crop production. Al begins to become soluble below pH 5.8, and is toxic to plants, especially legumes such as Lucerne and clovers. Grasses are less sensitive to Al toxicity, but are still affected. Plant growth and development can be severely limited by Al toxicity in acid soils. In general, a soil test value for 'exchangeable Al' of 2 mg/kg or greater should be considered harmful to plants.

The exact mechanisms of how Al affects plants are not fully understood. However, we do know that plant root systems are severely affected (restricted/stunted, cell damage), and can even grow horizontally in the soil upon contact with an acid soil layer due to Al toxicity. Legume nodulation, N fixation and plant N nutrition are also likely reduced.

Soil acidity problems are widespread on NZ soils. To offset increased soil acidity, lime must be applied, and where this cannot be done, soils may be too acidic for legumes and pasture productivity declines sharply. The main goal of liming is therefore to reduce the effects of Al toxicity, and to improve nutrient availability to plants. Agricultural lime is the product most commonly used, which contains the active ingredient calcium carbonate ($CaCO_3$). As a natural ground rock product, all lime deposits vary in the content of the active ingredient $CaCO_3$. A high $CaCO_3$ content (80-90%) is desirable. The amount of lime applied will depend partly on the soil pH target level. This will be driven by the requirements of your crop or pasture.

Secondly, the rate applied will depend on how much lime is required to shift the pH on your soil, and also on the initial soil pH. How much lime is required is driven by the 'pH buffer capacity' of your soil. In general, many NZ 'mineral' soils (soils formed from sedimentary parent materials) will shift 0.1-0.2 pH units for every 1 tonne lime/ha applied.

Other soil types, such as volcanic ash soils or peats will require more lime/ha to achieve the same shift in pH. Placement of lime, e.g. surface applied or incorporated into the soil, is also an important consideration. In this respect, knowledge of pH variation down the soil profile can be valuable.

SOIL TESTING & PLANT RESPONSE

We can quantify the soil fertility status, or amount of plant available nutrient in a soil, using simple soil analyses in a laboratory test.

Different lab tests are used to test for different elements. For example, in New Zealand, we commonly use the 'Olsen P' test to determine the plant-available soil P status, and the 'sulphate-S' or 'organic-S' tests to determine plant-available soil Sulphur status. These tests are standardised, and used by the major commercial soil and plant testing labs in New Zealand.

Plants vary in their nutrient requirements. Therefore the 'optimum' soil nutrient requirements of one species may be above or below optimum levels for a different species. For example, in pastoral systems, legumes often have a higher optimum soil fertility requirement than grasses. Likewise, some legumes have higher nutrient requirements than other legumes species. The same is true for different types of grasses.

Selected farm paddocks should be soil tested at least every 2-4 years to determine soil fertility status. Ideally, the same GPS locatable 'transects' should be sampled each time. This adds real value to soil fertility monitoring, adding higher accuracy to changes in soil fertility over time. Soil sampling should be undertaken by skilled personal with professional experience.

Soil test values are only useful where they have been scientifically 'calibrated' against plant growth indicators e.g. pasture yield. Without such calibration, the link between the soil fertility measurement and the plant measurement is of little value.

The relationship between a soil fertility measurement and plant yield will often produce a typical 'diminishing returns' curve *(Figure 4)*. At the steep part of the curve, where soil fertility is low, the plant growth response to increased soil fertility is high. At a fixed higher level of fertility, the response curve will 'tip over' (flatten off). At this point, increasing soil fertility further will not result in further increases in plant yield. It is important to realise that this calibration curve will change for different regions, due to different soil types and climates.

You should consult your local nutrient management advisor for information on appropriate soil fertility requirements for your district, farming system, and your own farm/business objectives. Likewise the calibration curves change for different nutrients, due to the plant requirement for the specific nutrient, and the local environment. It should be noted however that calibration curves do not guarantee 'precise' responses at given soil test levels, but give 'average' or 'likely' responses only, within a range of soil test values.

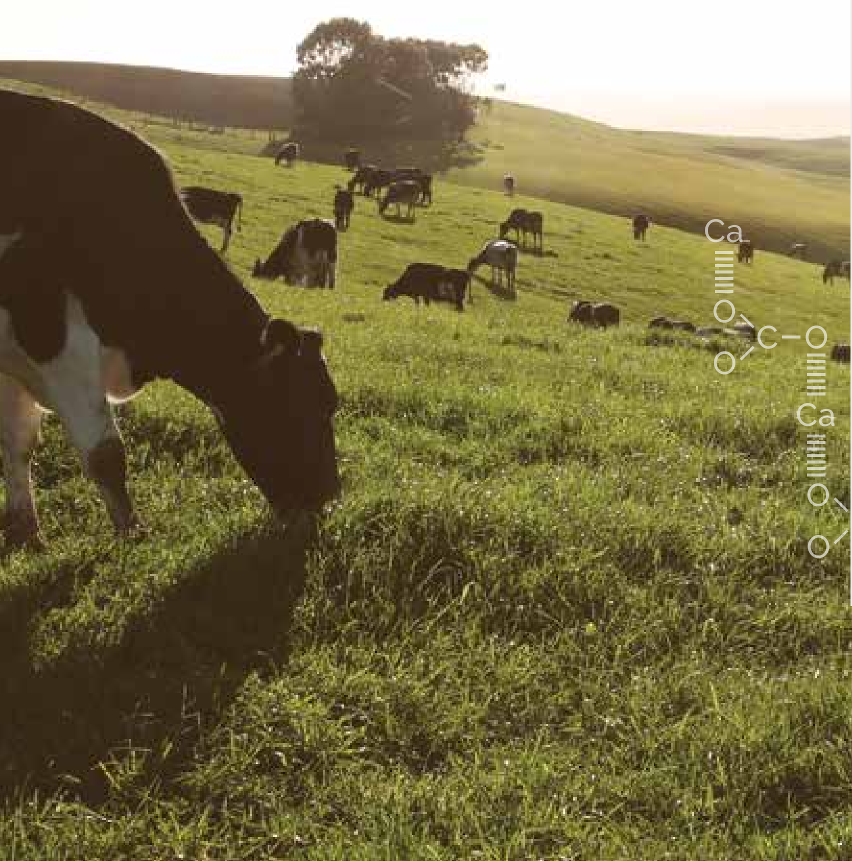
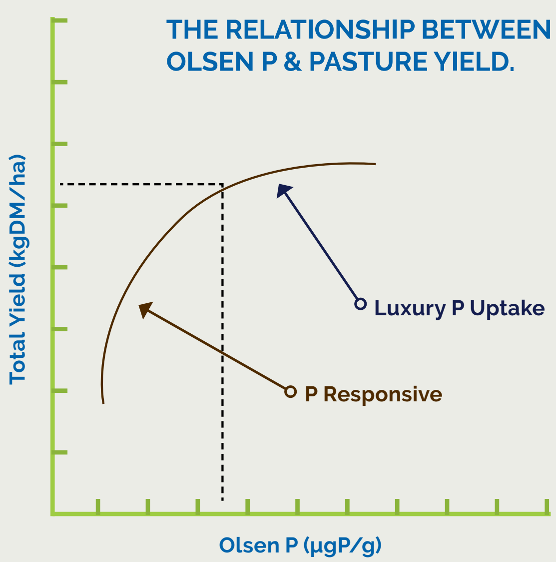


FIGURE 4



FERTILISERS AND EFFECTIVE NUTRIENT MANAGEMENT

Nutrients are essential for healthy plant and animal production, and managed nutrient inputs are often required to maintain and enhance productivity. We have the ability to change soil fertility by applying fertilisers and lime.

'Best practice' nutrient management often involves changing soil fertility status to meet the requirements of the pasture or crop, while at the same time using nutrients efficiently and keeping nutrient losses to a minimum. The principle factor limiting plant growth at a site must be taken into account when fertilising and/or liming.

Scientific computer models which can predict on farm nutrient cycling requirements are often used to calculate fertiliser requirements, and aid in compiling farm nutrient management plans. In order to be relevant and accurate, such models must have a strong scientific basis, including scientific knowledge from many regions, climates, landscapes and farming system types. They are complex and involve site - specific data input and calculations.

A nutrient budget model commonly used for this purpose is the OVERSEER® model. Such models quantify the inputs and losses of key nutrients for a defined farming system. An important output from these models is the quantity of each nutrient required to maintain current soil fertility status, and production.

This quantity of nutrient is often referred to as 'maintenance' or 'maintenance fertiliser', and is expressed as kg/ha/yr. Maintenance fertiliser rates (kg/ha) are strongly driven by the type of farming system, stocking rates, topography and soil types. A larger quantity of fertiliser, applied with the objective of raising soil fertility and production is called 'capital fertiliser'.

In theory, nutrient budget models can be used for scenario analyses, and therefore predictions of changes in soil fertility and production can be projected for different rates of nutrient input. This is a very useful application of the models. In general, for phosphorus, an application of 5 kg P/ha (above maintenance) will increase the soil Olsen P by 1 unit on sedimentary soils. In some situations, such as in dairy conversion, the P requirement to shift the soil test P will often be much higher. Likewise, soils derived from volcanic ash will also require more P.

An effective fertiliser programme will involve matching fertilisers to meet the maintenance nutrients requirements of the farming system. Over-applying nutrient may lead to environmental impacts and economic losses, while under applying may limit production and lead to nutrient 'mining' of the soil nutrient resource, which is an unsustainable practice. Therefore once maintenance requirements have been determined, as an annual rate in kg/ha, fertilisers can be matched. Important considerations include the choice of fertiliser type and timing of application. In terms of fertiliser product, manufacturers/retailers must, by law, supply information on the concentrations (%) of (N-P-K-S) in fertilisers e.g. single superphosphate is typically (0-9-0-12).

The choice of fertiliser type depends on: nutrients it contains; concentration of nutrients; form of nutrient; the rate at which the nutrient becomes available to plants; cost /kg of nutrient; and the risk of damage to sensitive plants. The nutrient form controls rate at which nutrient becomes available e.g. superphosphate = water soluble P and S, Reactive phosphate rock (RPR) = slow release P.

You must also be aware that the presence of potentially harmful components. For example, chloride may damage roots of some vegetable seedlings, but is OK for most pasture and crop species e.g. potassium chloride (KCl) and potassium sulphate (K_2SO_4).

Good fertiliser use should be based on soil tests, plant analyses, nutrient budgets (e.g. OVERSEER®) and local trials. Soil tests should be done frequently, in an appropriate manner. You should also use fertilisers efficiently, in order to reduce production costs, avoid wastage of non-renewable resources, avoid pollution of groundwater and the environment and to improve your efficiency of production.

It is critical that fertilisers and lime should be compared on the basis of cost/kg of nutrient (or active ingredient for lime):

$$\textit{Cost/kg nutrient} = \frac{\textit{Cost/tonne fertiliser}}{\textit{(10 x \% nutrient in fertiliser)}}$$

You should also consider that the effectiveness of different kinds of fertilisers is not always the same. For example, the cheapest plant nutrient is not necessarily the best for all situations e.g. $ per kg P in reactive phosphate rock (RPR) may be cheaper than P in superphosphate (but P in rock phosphate is much less available to plants).

You should also consider that the 'cost on the ground' also includes transport and spreading costs. 'Compound fertilisers' may also be more expensive, or cheaper, than mixed fertilisers.

Fertilisers should generally be applied during periods of rapid plant growth, especially spring and autumn, to maximise plant uptake. As such, fertiliser application should be timed to achieve maximum plant uptake to maximise production response and minimise losses.

The amount of rainfall and/or irrigation expected should also be considered. In cropping, lime or phosphate fertiliser application is usually done during soil cultivation. Also, N fertiliser should not be applied when soil temperatures are 6°C or less, or will soon fall to that level i.e. the late autumn/winter/late winter periods. This is because plants stop taking up N at low temperatures due to limited plant growth and the N can be lost out of the system via leaching.

Economic returns on fertiliser and lime applications depend on several factors. These include:

- **The stage of pasture growth**
  High digestibility (young pastures) verses Low digestibility (mature or old pasture due to increases in fibre content and lowering protein content).
- **Grazing management**
  Periodic or continuous grazing produces young regrowth with high digestibility.
- **Seasonal effects**
  Spring herbage = high digestibility. Early winter or sometimes mid-summer herbage = low digestibility.
- **Pasture species**
  Legume herbage = high digestibility.
- **Crop quality**
  protein, carbohydrate (CHO), fibre contents, colour etc.

In the long run, the economically optimum fertiliser strategy for capital fertiliser should be to immediately raise soil fertility to the optimal level and then apply the appropriate maintenance rate. However in many cases the large initial expenditure on capital fertiliser applications will take a number of years to recapture in improved returns. Optimal fertility level depends critically on the gross margin per stock unit (SU) : fertiliser cost price ratio.

FINAL WORD

We hope that you have found this booklet helpful. Good soil quality is essential for the environmental and economic sustainability of farmland. Poor soil quality impacts on pasture and crop production, food quality and animal health, nutrient losses and farm costs.

To sum up:

"To be a successful farmer, one must first know the nature of the soil."

400 BC

Want to know more?
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