MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

FARMED
LANDSCAPES
RESEARCH
CENTRE

MASSEY UNIVERSITY

AN INTRODUCTION TO NUTRIENT MANAGEMENT IN AGRICULTURE

Reading material and self-assessment

Contact Details:

Farmed Landscapes Research Centre
School of Agriculture & Environment
Massey University (PN 432)
Private Bag 11 222
Palmerston North 4442, New Zealand
Phone: (06) 356 9099
Email: J.A.Hanly@massey.ac.nz
http://flrc.massey.ac.nz

Revised January 2021

Table of Contents

1. Introduction to Nutrient Management for Dairy Farms

2. Introduction to Soils Used for Dairy Farming in New Zealand

3. Nutrient uptake by pasture from soils

4. Introduction to Fertiliser Materials

5. Introduction to Soil Physical Properties

Introduction

Aim of this guide

To prepare your background knowledge on soils, fertilisers and nutrient flows in grazing systems in preparation for undertaking the Professional Development Course, Sustainable Nutrient Management in New Zealand Agriculture.

Analysing farm nutrient budgets and developing nutrient management plans to enable the efficient use of nutrients on farms are skills required by farm consultants, fertiliser company field officers and regional council staff.

The Farmed Landscapes Research Centre (FLRC) at Massey University in conjunction with the Fertiliser Association of NZ and AgResearch have developed courses in Sustainable Nutrient Management (SNM - Intermediate and Advanced) that provide rural professionals with skills and training in the operation and interpretation of nutrient budgeting software.

Preparing a nutrient budget for a farm requires use of nutrient budgeting software such as OverseerFM[1], and a good knowledge of the properties and distribution of New Zealand soils, pasture nutrition and how farm management influences the cycling of nutrients in grazed pasture systems. An introductory level of this knowledge is required for those attending the Intermediate Sustainable Nutrient Management course, in New Zealand Agriculture. This introductory level of knowledge is normally gained either through tertiary study of soil science, pasture agronomy and land resource management, or “on the job experience”.

If you are a rural professional wishing to embark on the course of study for a Massey University Certificate of Completion in Sustainable Nutrient Management in New Zealand Agriculture, it is advisable that you use this ‘Introduction to nutrient management in agriculture’ and the self-assessment to refresh and enhance your knowledge in the following areas:

1. **Introduction to Nutrient Management**
2. **Introduction to Soils Used for Dairy Farming in New Zealand**
3. **Nutrient uptake by pasture/crops from soils**
4. **Introduction to Fertiliser Materials**
5. **Introduction to Soil Physical Properties**

---

[1] Download or register for online use at https://www.overseer.org.nz/overseerfm

The way to use these study notes

Sections 1 and 2 contain information that you are required to be familiar with on nutrient flows (Section 1) and New Zealand soils and their properties (Section 2). Sections 3 to 5 provide the background knowledge to understand Sections 1 and 2.

We assume that most people embarking on the Intermediate SNM course are already familiar with some aspects of soil fertility, fertilisers and plant and animal nutrition. If this is the case with you then read the Sections from 1 to 5. If however, you have limited understanding of soils, fertilisers and nutrient uptake, you may wish to read Sections 3-5 first before reading Sections 1 and 2.

Learning objectives and question and answer sections

Learning objectives are clearly stated at the beginning of each section. Questions to assist learning are placed at the end of each section with appropriate answers listed at the end of the study notes.

Multichoice self-assessment

You can ‘self-test’ by completing the multichoice test at the end of each section in this guide. An answer score sheet is provided on the final page.

You should be able to gauge from how well you answer the questions at the end of each section and your outcome in the self-assessment whether you need to undertake more study before you progress to the Intermediate Sustainable Nutrient Management Course.

Other study options

If you decide these introductory notes are a starting point that is too advanced for your current level of experience or understanding, you are welcome to enquire about other study options, both formal and informal, that you can embark on to allow you to progress to the Professional Development courses offered by FLRC. Please email James Hanly: J.A.Hanly@massey.ac.nz

SECTION 1

1. Introduction to Nutrient Management

Key Learning Objectives

After studying this section you should be able to:

1. Describe 4 ways nutrients enter a New Zealand farm and 2 ways they leave.
2. Explain what is meant by a capital fertiliser application.
3. Explain the nutrient losses that are commonly used to calculate a maintenance fertiliser requirement.
4. Describe 3 soil tests useful for indicating the plant supply of nutrients in soils.
5. Describe the range of values of the Olsen P test that may indicate surplus, inefficient use of Phosphorus (P) inputs.
6. Explain why nutrient budgeting software is required to estimate nutrient losses from farms or paddocks and calculate maintenance fertiliser requirements.
7. Describe how patterns of grazing and excretion lead to inefficient recycling of nitrogen (N) in grazed pastures.

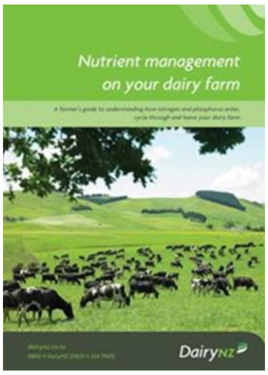
1.1 Introduction to farm nutrient balances

Inputs, transformations and losses from the soil-plant- animal system

Read the following section in conjunction with the following reading to apply nutrient balances to a dairy farm:

https://www.dairynz.co.nz/environment/nutrient-management/

"Maintaining healthy waterways is beneficial for the dairy sector, its international reputation and for all current and future New Zealanders."



Dairy farming is one of New Zealand's more intensive uses of our lowland, high quality soils. To be profitable, dairy farms must operate near optimum soil fertility. Increasing milk production on traditional 'all grass' New Zealand dairy farms has required the regular use of lime, fertilisers and/or manures to maintain and improve the soil's ability to supply the nutrients phosphorus (P), sulphur (S), nitrogen (N), potassium (K) and to a lesser extent calcium (Ca), magnesium (Mg) and trace elements (Figure 1.1).

Addition of nutrients through fertiliser can fulfil two requirements:

(a) a **capital application** that raises the plant-available pool of a nutrient in the soil to a level that does not inhibit grass and clover (pasture legume) growth. Vigorous clover (legume) growth is required to provide the major input of nitrogen through biological fixation.

(b) a **maintenance application** of nutrients that replaces losses of major nutrients created by the farming system. These include (Figures 1.1 and 1.2) losses in produce (milk and meat), leaching of nutrients in drainage waters and within-farm transfer of nutrients to non-productive areas (e.g. deposition of cattle excreta on raceways and yards and deposition of cattle excreta or crop residues on land areas with soil fertility status already greater than optimum). The maintenance fertiliser rate will increase with increasing soil fertility and farm productivity (see later explanation).

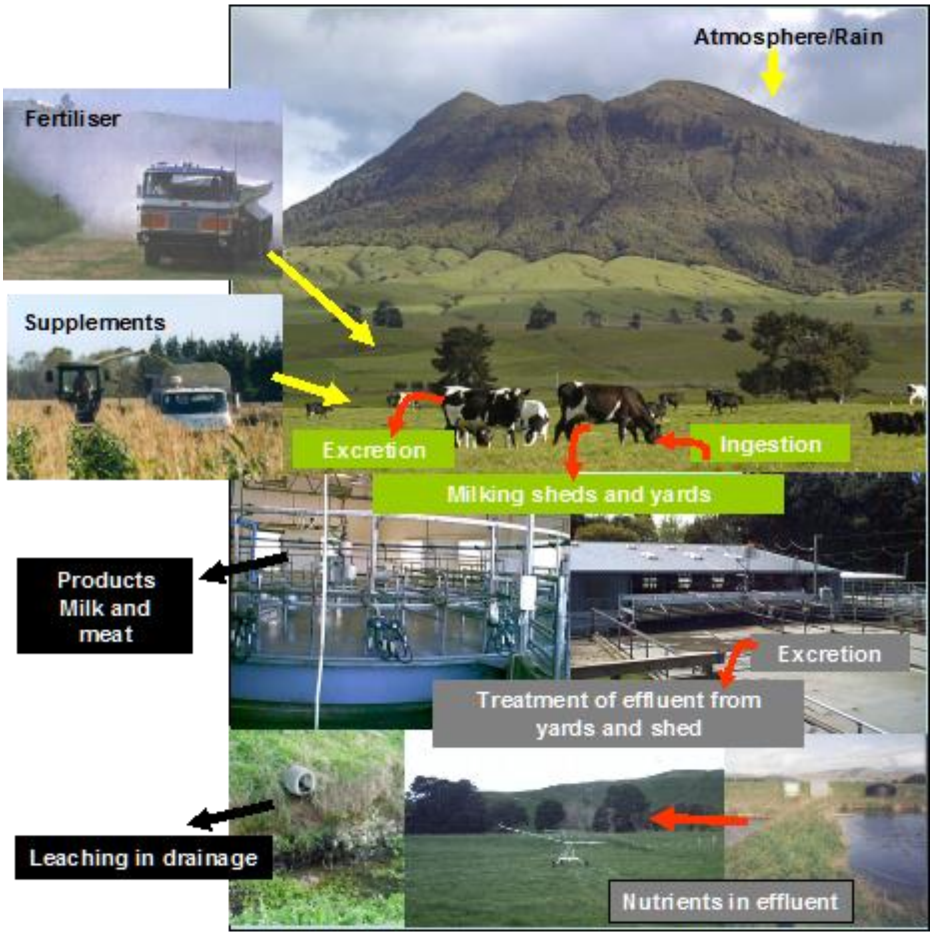


Figure 1.1 The physical attributes that contribute to inputs (—), transfers (—) and losses (—) of nutrients from the soil-pasture system on a typical dairy farm.

Using capital applications of fertiliser to raise the plant available pool of nutrients in the soil to near optimum levels increases pasture growth and nutrient concentration, stock carrying capacity per hectare, and the amounts of nutrients lost in produce and returned in excreta (Figure 1.2). Buying in supplementary feeds such as hay, silages and concentrates can also increase farm stocking rates and productivity. Nutrients brought onto the farm in supplementary feeds enter the soil's available nutrient pool through the animal's excreta (Figure 1.2, dung and urine excreted on the paddock plus farm dairy and feed pad effluent re-applied in spray irrigation).

The capacity to recycle nutrients is controlled by the complex relationship between the quantities of nutrient applied in fertiliser and returned in excreta (Figure 1.2) and the ability of the soil to hold available nutrients for re-use by actively growing pasture. Key factors are the soil's physical, chemical (see Sections 2 and 3) and biological condition and the interaction of the soil-plant system with the weather (see Section 5). Warm, moist conditions lead to rapid excreta decomposition, rapid nutrient uptake and pasture growth; cool, wet conditions may lead to nutrient loss in drainage and runoff, slow nutrient uptake and slow pasture growth.

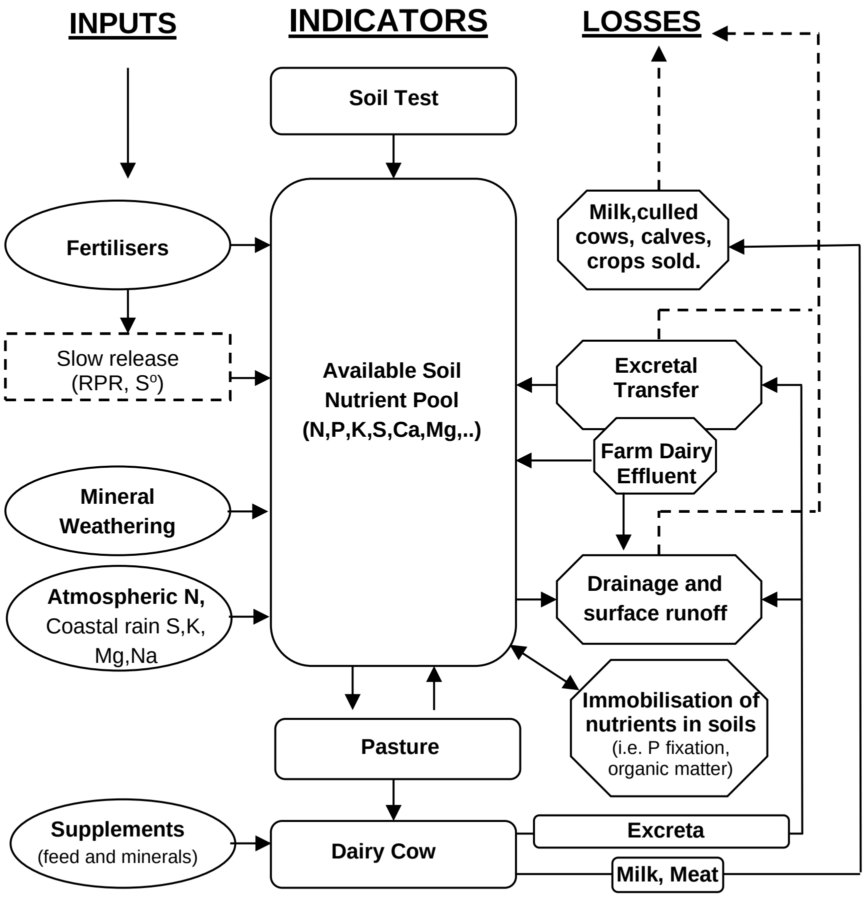


Figure 1.2 Inputs, transfers and losses of nutrients from the soil-pasture system on a standard dairy farm.

Exceeding the capacity of the soil-plant system to hold and recycle nutrients

Productivity gains through the use of capital fertiliser and/or supplementary feeds increase the effective stocking rate and increases the rate of nutrient cycling per land area unit. Unfortunately this leads to increased loss of nutrients in drainage water and run-off (Figure 1.1). The amounts of nutrient lost in drainage and run-off can accelerate when the sum of nutrient inputs to the farm exceed the sum of nutrients in milk and meat plus those easily immobilised in the soil (i.e. the soils' ability to hold nutrients via phosphorus fixation and accumulation of semi-decomposed plant litter and dung as soil organic matter). Nutrient losses are higher from soils that have a low capacity to hold nutrients in the pasture root zone. These include coarse textured, sandy soils and soils with low phosphate retention (see description of soils in Section 2 and see notes on % P retention, anion sorption capacity, and cation exchange capacity, CEC in Section 3).

The role of soil tests - agronomic optimum or environmental risk

Read the following section in conjunction with:

http://www.fertiliser.org.nz/Site/resource_center/Booklets.aspx

- Assessing soil nutrients status
- Target soil test ranges
- Raising soil fertility status
- Maintaining soil fertility status

Soil and plant testing has been used to monitor soil and plant nutrient status. If soil (Table 1.1) and plant tests are below recommended agronomic optimum values then a capital input of fertiliser may be recommended to increase pasture yield, stocking rate and economic gross margin per hectare. If soil and plant test values are already in the recommended range for the optimum growth of pastures, only maintenance fertiliser application is recommended because soil fertility is not limiting pasture production.

For some nutrients (P, S and exchangeable cations) situations when the soils' ability to hold nutrients is exceeded can be indicated by soil test values (Table 1.1). For example, accelerated phosphate loss is indicated by an Olsen P test value significantly above the prescribed optimums for pasture growth. Olsen values on Pallic soils and Allophanic soils (soils formed on volcanic ash) above optimum are greater than 30 and 40 mg P/L soil, respectively. The difference in values reflects the greater phosphate retention characteristics of Allophanic soils (see Section 2 for information on soils and Section 3 for information on nutrient retention in soils). Soil test values above agronomic optimums (Table 1.1) indicate that costly nutrients purchased in fertiliser for pastures and forage crops are not being re-used (recycled) efficiently by farming practice.

Table 1.1 Target soil test ranges for near maximum production (source: Overseer*)*

Overseer soil name	**Sedimentary**	**Ash**	**Pumice**	**Peat**
NZ soil name	Pallic and Brown	Allophanic	Pumice	Organic
Soil Test				
Olsen P	20-30	20-30	35-45	35-45
Olsen P high *	30-40	30-40	45-55	45-55
Soil test K	5-8	7-10	7-10	5-7
Sulphate-S	10-12	10-12	10-12	10-12
Organic-S	15-20	15-20	15-20	15-20
Soil test Mg	pasture 8-10 animal 25-30	pasture 8-10 animal 25-30	pasture 8-10 animal 25-30	pasture 8-10 animal 25-30
pH	5.8-6.0	5.8-6.0	5.8-6.0	5.0-5.5 (0-75 mm)
				4.5-5.0 (75-100 mm)

* target ranges for high producing dairy farms (current milk solids production/ha is in the top 25 % for the supply area)

Unfortunately there is no useful soil test readout for N. Topsoil nitrate concentrations are always low because plant competition for nitrate uptake is high, and soils do not have the ability to hold nitrate (the form of N most commonly taken up by pasture plants) and it is easily lost as water drains through the soil. Soil nitrate levels decrease after each rain and drainage event and then increase slightly in warm moist soils as nitrate is released by decomposition of dung and soil organic matter (humus).

The role of Nutrient Budgeting in nutrient management

To manage soil fertility and any environmental risk that comes from nutrient surpluses it is necessary to know how much nutrient is entering and leaving the farm or paddock. Soil test values for a paddock or farm may indicate whether a low, optimum, or surplus supply of nutrients is available in the soil, but the soil test does not indicate how that situation arose. A nutrient surplus arises when the inputs of nutrients exceed both losses (Figure 1.2) and the soils' ability to immobilise nutrients. Processes causing nutrient loss, such as drainage, runoff, and immobilisation of nutrients in soil, involve complex interactions between soils, plants, animals and climate. Past research has provided an understanding of how these processes function, but, to estimate these losses requires complex calculations. These complex calculations can only be done using specially developed nutrient budgeting software that simulates nutrient cycles on the farm. Overseer has been designed to simulate the processes outlined in Figures 1.1 and 1.2. Overseer will provide estimates of nutrient inputs, transfers within the system and losses from paddocks, paddock blocks and the farm. It calculates the maintenance fertiliser requirement to replace those losses at paddock or farm level. It will estimate the losses of nitrate to ground water and phosphate in surface runoff that can have adverse environmental consequences.

With a good understanding of the farming system, and soil – plant – animal processes that lead to nutrient transfer, retention and loss, it is possible for a skilled user of Overseer to prepare an audit of a farm’s nutrient budget and develop a nutrient management plan that avoids excessive inputs of nutrients into dairy farm soils and recycles nutrients efficiently within the farm, thereby reducing off-farm impacts of nutrient loss.

1.2 The influence of the grazing cow on nutrient recycling in grazing systems

The pasture harvesting ability of stock is measured in standard stock units (ssu). A standard stock unit is a 50 kg ewe weaning one lamb, requiring 550 kg DM as pasture per year. A Friesian/Jersey cross cow (450 kg live weight) is approximately 6.8-7.0 ssu and requires approximately 3,700-3,900 kg DM per year.

The grazing cow rapidly recycles nutrients from ingested grass to the soil surface through excreta return. Unfortunately the return is to a small area of dung and urine patches and not to the whole grazed area. In one grazing, nutrients in a hectare of lush pasture are recycled as dung and urine on less than 0.02 ha (2 % of the grazed area). This leads to nutrient surplus in dung and urine patches, from which mobile nutrients like nitrate, sulphate and exchangeable cations may leach in drainage water. Immobile nutrients, like phosphate, are less affected by this process because after deposition on the soil in dung patches these nutrients are re-adsorbed to the soil particles.

Example – the inefficient recycling of nitrogen

A Friesian/Jersey cross cow (450 kg live weight) producing an average of 1.6 kg milk solids (MS) per day needs approximately 15.5 kg dry matter (DM) of good quality (11.3 MJME/kg DM) pasture per day to maintain body condition and milk production. The energy, carbohydrate and protein composition of good quality pasture is shown in Table 1.2.

Table 1.2 The protein, fibre, carbohydrate, fat and metabolisable (MJME) energy content of high and low quality pasture (adapted from Kuperus, 2002)

Component	**High quality, leafy spring pasture**	**Low quality, mature, stemmy late summer pasture**
	% DM	
Protein	26	12
Total fibre (NDF)[1]	40	56
Soluble Carbohydrates	18	13
Fat	6	4
	MJME/kg DM	
Metabolisable energy (MJME/kg DM)	12	8.9

[1] NDF (Neutral detergent Fibre) A method of measuring total fibre content (the digestible and indigestible parts). This indicates how bulky the feed is, and is important when allocating feed.

The leafy high quality pasture has the nutrient concentrations shown in Table 1.3.

Table 1.3 The chemical analysis of high quality dairy pasture (source: Overseer)

High Quality Pasture	
Element	**% of DM**
N	4.7
P	0.37
K	2.7
S	0.32
Mg	0.2
Ca	0.4
	ppm
Fe	58
Mn	28
Zn	17
Cu	7
B *	15
Mo *	0.15

The majority (60-90 %) of nutrients consumed in pasture and supplements by a cow (Figure 1.2 and Figure 1.3) are returned in excreta (Table 1.4), therefore, the greatest movement of nutrients is controlled by the pattern of feeding and deposition of dung and urine.

Table 1.4 The fate of minerals ingested by a lactating dairy cow (ingesting 15.5 kg DM/day) (adapted from During 1984).

Element	**Consumption**	**Percentage in**			
	kg /week	**Faeces**	**Urine**	**Milk**	**Retained**
N	**5.1**	**26**	**53**	**17**	**4**
P	**0.4**	**66**	**-**	**26**	**8**
K	**2.9**	**11**	**81**	**5**	**3**
Mg	**0.2**	**80**	**12**	**3**	**5**
Ca	**0.4**	**77**	**3**	**11**	**9**
Na	**0.4**	**30**	**56**	**8**	**6**

Between the two milkings that take ~4 hours, the cows may spend 20 hours per day in a paddock grazing pasture and resting. Therefore, time in the paddock represents 80 % of the day, which results in approximately 80 % of the excreta being deposited in the paddock.

The implications of the large return of N to the paddock as urine (Table 1.4) is best illustrated by considering early summer grazing events.

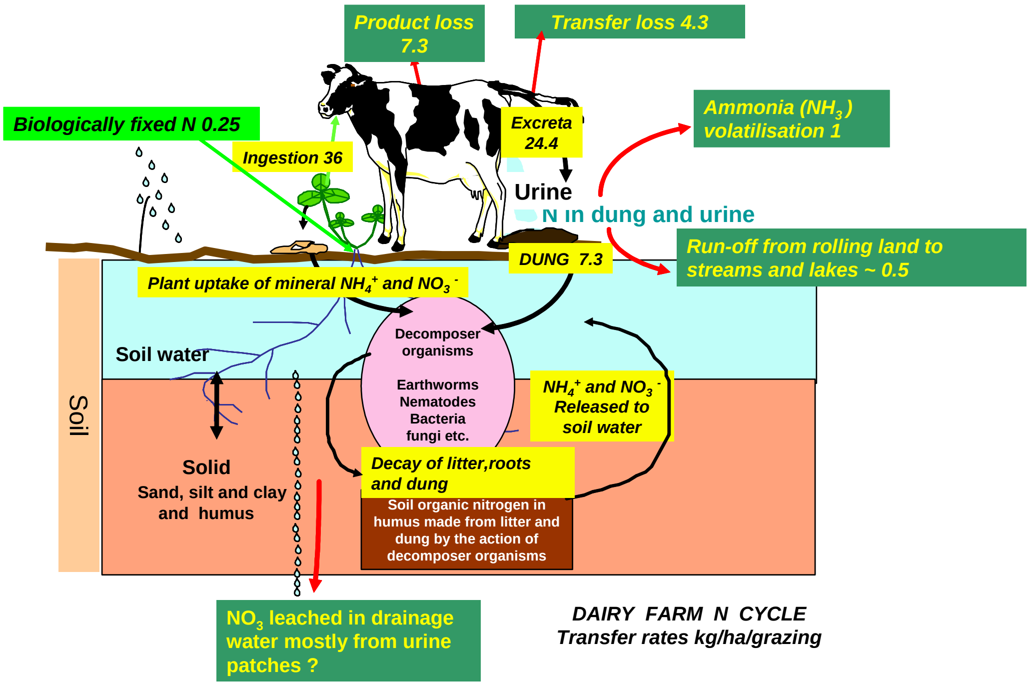


Figure 1.3. The transfers and losses of nitrogen from the soil-pasture system when 100 cows/ha eat 7.75 kg DM/cow/grazing.

Two grazings per day will be required for the cow to ingest the daily ration of 15.5 kg DM/cow/day. For one grazing, the Friesian/Jersey cross cows (450 kg live weight) will be stocked at 100 cows per hectare. Each cow will eat grass at a rate of 7.75 kg DM per grazing; 100 cows will eat 775 kg DM/ha/grazing containing 36 kg N/ha (Figure 1.3). They return 24.4 kg N as excreta, 7.3 kg N as dung and 17.1 kg N in urine.

On average each cow will urinate 11 times per day (or 5.5 times per grazing) and will produce 12.5 dung patches per day (Haynes and Williams 1993). Eighty percent of the urine and dung patches will be deposited in the paddock and 20 % in the time taken to go to the milking shed and yards (Transfer loss, Figure 1.3).

As 70 % of the excreta N (100 X 17.1/24.4) is returned in the urine patches, we will concentrate on the fate of the N in the urine patches. The average size of a urine patch is 0.28 m^2 and the total area covered by the urine patches deposited by the 100 cows in one grazing is 0.012 ha (80 % of 5.5 urinations @ 0.28 m^2 for 100 cows/10,000 m^2 = 0.012ha or 1.2% of the grazed area). The 17 kg urine N deposited on 0.012 ha/grazing is equivalent to an application rate of 1390 kg N/ha within the area affected by urine. Annually, the N rich pasture (5 % N) in urine patches can be expected to take up around 700 kg N/ha. This equates to the annual pasture growth taking up 8.4 kg N in the area (0.012 ha) covered by urine patches from one grazing. Therefore after a year's pasture growth, the area of pasture affected by urine (0.012 ha) still has an excess nitrogen load of 17.1 - 8.4 = 8.7 kg N, which has the potential to leach. If a hectare of pasture is grazed 10 times per year then urine patches will potentially generate an annual excess of 10 x 8.7 kg N/ha. This excess, 87 kg N/ha, has the potential to be leached with winter drainage as nitrate.

This problem of nitrogen loads in urine patches being excess to soil and pasture N requirements is a problem that is being addressed by current research. It is the central cause of winter nitrate leaching from dairy farms. So far no-one has found an economic solution to this problem – can you think of possible solutions?

1.3 Conclusion

There are many factors affecting nutrient cycling within the dairy production system. The interactions between the soil-plant-animal are complex. From soil tests fertiliser recommendations, both capital dressings and maintenance applications can be made. Nutrient budgeting software can assist in determining these recommendations and also highlight environmental issues concerning the farming system. The grazing animal has a strong influence on nutrient cycling within the system, particularly in nutrient transfer. This section has given a brief introduction to factors affecting nutrient cycling and the roles of nutrient management. The following sections will highlight the different soils and characteristics of soils used for dairying, the nutrient cycles within these soils, the fertilisers used on these farms, and information about soil water.

References

During C. 1984. Fertilisers and soils in New Zealand farming. 361 pp.

Haynes R. J.; Williams P. H. 1993. Nutrient cycling and soil fertility in the grazed pasture ecosystem. Advances in Agronomy 49, 119-199.

Kuperus W. 2002, Is Pasture Enough? South Island Dairy Event 2002. www.side.org.nz/index.cfm/Papers/2002/Trigger%20levels%20for%20utilising%20feed –

Test Your Knowledge – Section 1

Questions

1. Is the return of phosphorus in cow dung viewed as a nutrient input to a farm or a potential transfer event?
2. A dairy farmer on an Allophanic (Ash) soil in Taranaki has a paddock with an Olsen soil test of 22 mg P/L. Would you interpret this as :
    a. Posing an environmental risk
    b. Below the optimum target level for pasture growth on Allophanic soils.
    c. A paddock that may need a capital input of P fertiliser.
3. Describe two nutrient losses that do not leave the farm but make up a component of the P losses used to calculate a maintenance fertiliser requirement.
4. List 3 soil tests useful for indicating the plant supply of nutrients in soils.
5. Briefly explain why there is no useful N soil test.
6. Briefly describe how cows grazing pasture lead to inefficient N recycling that leads to nitrate leaching losses.

Answers at back of this book.

SECTION 2

2. Introduction to Soils Used for Dairy Farming in New Zealand

Key Learning Objectives

After studying this section you should be able to:

1. Name the major soil orders used for dairy farming in New Zealand.
2. Explain the landscapes and climates associated with the major soil orders used for dairy farming.
3. Describe some of the more important features of the profiles of these soils.
4. Explain the major limitations to dairy farming imposed by soil physical properties.
5. Discuss the management practices that may be employed to mitigate the impact of these limitations.
6. Discuss the general nature of some of the environmental risks associated with dairy farming.
7. Explain the primary physical limitations and strengths in each of the major soil orders for dairy farming.
8. Explain the primary chemical limitations and strengths in each of the major soil orders for dairy farming.
9. Provide recommendations on soil, fertiliser and grazing management strategies to minimise the above limitations.
10. Explain the optimum soil fertility indices for each of the soil orders.
11. Describe the target rates of fertilisers to raise P, K, and S to adequate levels.

2.1 Introduction to soils

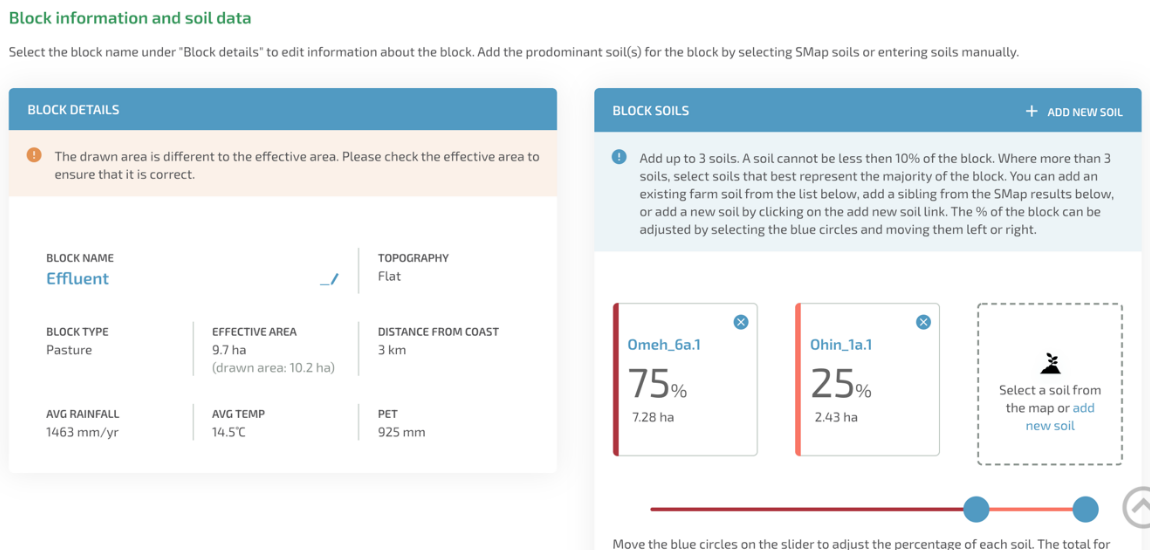
Dairy farming is dependent on reliable pasture growth to feed milking cows throughout the year. Sustainable dairy farming requires land of flat to rolling contours with reliable rainfall or water supply, and soils with good chemical, physical and biological properties. If the soils are poor with respect to any of these properties, proper management practices should be adopted to improve these properties. This section of the study guide presents the important chemical and physical properties of the major soil orders in New Zealand where dairy farming is practised. The soil limitations and strengths for sustainable dairying in these soils are highlighted and recommendations for minimising these limitations, if any, are presented.

A confusing array of soil names are used to describe soils, depending upon who is describing the soil. Agricultural advisers use the terms Sedimentary, Pumice, Volcanic (Ash), Peats and Clays and Recent alluvial soils. These terms refer to soil parent materials rather than the soil that has formed from the parent materials. In contrast, soil scientists used old nomenclature (NZ Genetic Classification) to describe the soil that had formed such as Yellow-Grey Earths, Yellow-Brown Earths, Yellow Brown loam soils etc., but recently have changed their descriptions to Pallic soils, Brown soils and Allophanic soils, respectively (NZ Soil Classification). All these terms are available in the Overseer drop down lists.

When enrolled on one of Massey University's Sustainable Nutrient Management or Farm Environment Planning courses, you will be given a student login for the education version of Overseer (called OverseerED).

https://edu.overseer.org.nz/#/

Once you have set up the farm management blocks, you will be able to click any one of these blocks to see the context in which the model requires soil information.



Block information and soil data

Select the block name under "Block details" to edit information about the block. Add the prodominant soil(s) for the block by selecting SMap soils or entering soils manually.

BLOCK DETAILS

The drawn area is different to the effective area. Please check the effective area to ensure that it is correct.

BLOCK NAME
Effluent

TOPOGRAPHY
Flat

BLOCK TYPE
Pasture

EFFECTIVE AREA
9.7 ha
(drawn area: 10.2 ha)

DISTANCE FROM COAST
3 km

AVG RAINFALL
1463 mm/yr

AVG TEMP
14.5℃

PET
925 mm

BLOCK SOILS

Add up to 3 soils. A soil cannot be less then 10% of the block. Where more than 3 soils, select soils that best represent the majority of the block. You can add an existing farm soil from the list below, add a sibling from the SMap results below, or add a new soil by clicking on the add new soil link. The % of the block can be adjusted by selecting the blue circles and moving them left or right.

Omeh_6a.1
75%
7.28 ha

Ohin_1a.1
25%
2.43 ha

Select a soil from the map or add new soil

Move the blue circles on the slider to adjust the percentage of each soil. The total for

The major orders of soils used for dairying are listed as follows.

Allophanic Soils. Commonly formed from volcanic ash deposits. Formerly known as Yellow Brown loam soils (Waikato, Taranaki); Red and Brown loams and Brown Granular clays and loams (Northland, Waikato), and poorly drained (Gley) soils formed from volcanic ash (Waikato).

Brown Soils. Formerly known as Yellow-Brown Earths. These are terrace soils with reasonable drainage under moderate (Southland) to high rainfall (West Coast) or free-draining stony-plains soils under low rainfall (Canterbury/North Otago); or moderately to highly leached soils under moderate rainfall (Northland). These soils have been mainly formed from sedimentary rocks such as greywacke, sandstone and mudstone and is the most common soil order in NZ.

Pallic Soils. Formerly known as Yellow-Grey Earths**.** These are poorly drained terrace (Manawatu) or rolling (South Otago) soils under moderate rainfall. These soils have been mainly formed on wind-blown loess from eroded sedimentary rocks such as greywacke, sandstone and mudstone.

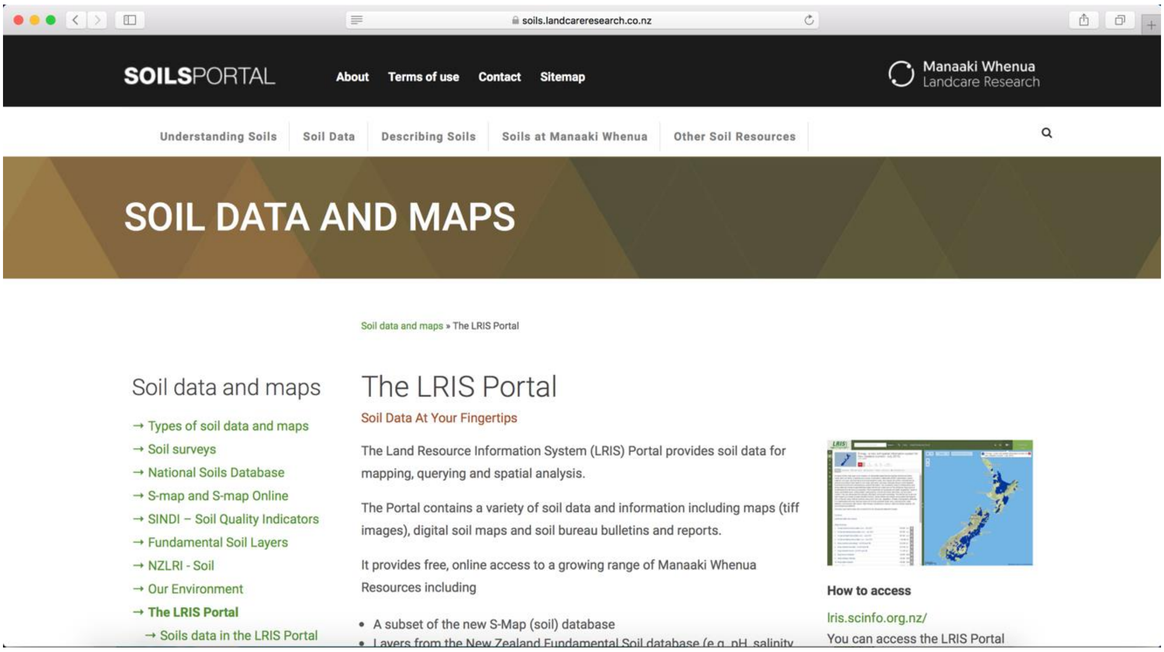
Recent Soils. These soils have been mainly formed on alluvial and fluvial material deposited by rivers and streams that have eroded sedimentary rocks such as greywacke, sandstone and mudstone.

Pumice Soils. Formerly known as Yellow Brown Pumice Soils and the Gley soils formed from pumice (Bay of Plenty, Central Plateau). These soils, although volcanic in origin, have different properties to the Allophanic soils above.

Peat or Organic Soils. Not included in this section. These soils have little or no mineral matter, and are made up of plant residues. They occur predominantly in the greater Waikato region.

New Zealand Soils Portal

This can be found at: https://soils.landcareresearch.co.nz/soil-data/the-lris-portal/



The LRIS Portal

Soil Data At Your Fingertips

The Land Resource Information System (LRIS) Portal provides soil data for mapping, querying and spatial analysis.

The Portal contains a variety of soil data and information including maps (tiff images), digital soil maps and soil bureau bulletins and reports.

It provides free, online access to a growing range of Manaaki Whenua Resources including

- A subset of the new S-Map (soil) database
- Layers from the New Zealand Fundamental Soil database (e.g. pH, salinity

How to access

lris.scinfo.org.nz/

You can access the LRIS Portal

Soil names and the distribution of soils

Within the NZ Soils Portal, go to: https://soils.landcareresearch.co.nz/describing-soils/nzsc/soil-order/

How to study this section

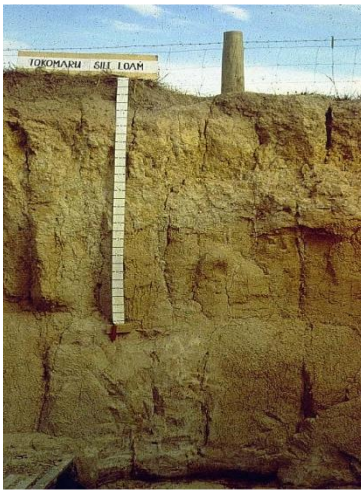
The information on soils in this section is given in tabular form. For each soil create your own table of key points. You may need to refer to Sections 4 and 5 to interpret the fertiliser and soil terms.

Soil Property	**Value**
Soil Name	
Rainfall regime	
Dominant parent material (see pages 2-2 to 2-3)	
Topography	
Key physical limitations	
Key soil fertility limitations	
Optimum Olsen P soil test	

Pallic Soils

Climate, landscape and soil profile

- Pallic Soils often form under sub-humid climates (500 to 1100 mm rainfall) where the winters are wet and the summers are dry.
- Pallic Soils are found predominately on flat and undulating landscapes.
- There is a marked contrast between the textures of the topsoil and the subsoil of Pallic Soils. The surface soil (0 to 18 cm) is silt loam in texture and it has a weak to moderate nut and block structure with friable consistence. At approximately 30 cm, the soil grades into a strongly mottled silty clay loam with coarse block structure and firm consistence. The very impermeable nature of the subsoil is one of the defining characteristics of Pallic Soils.



Limitations/advantages of soil physical properties

- Pallic Soils tend to have very poor natural drainage (perched water table).
- Where these soils are used for intensive grazing, treading damage is invariably a major problem.
- These soils are prone to compaction if they are routinely tilled for crop production.
- They tend to be dry in summer and bake hard. Available water holding capacity of these soils is moderate (e.g. 70 mm in the root zone).

Overcoming the limitations of soil physical properties

- Artificial drainage systems (typically mole-pipe networks) are required if Pallic Soils are to be used for intensive farming.
- In addition, farmers often practise different forms of ‘on-off’ grazing to minimise treading damage. On dairy farms, feedpads can be used to keep cows off wet paddocks. A number of farmers irrigate these soils to great effect.
- All of the field operations associated with tillage and harvesting of crops need to be carefully timed and kept to a minimum.

Environmental issues

- Rapid drainage through the cracks in the soil generated by the mole plough may transport nutrients to surface water bodies. The impermeable nature of the soil and the susceptibility to treading damage means that excess water, which is rich in P, can run off the surface of these soils. Managing land application of FDE to these soils is a challenge.

Soil Fertility in Pallic Soils

Soil Property	Low-medium	Optimum
Soil pH	5.7–5.9	5.8–6.0
Olsen P (mg P/L)	11–13	20–30
Sulphate-S	4–5	10–12
QT K	8	6–8
QT Mg	30–33	Pasture 8–10, Animal 25–30
% P retention (Anion Sorption capacity)	10 - 20	

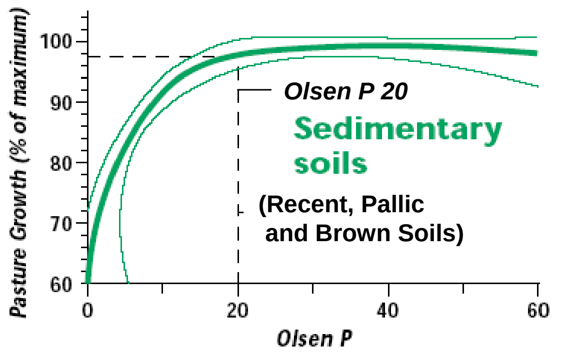
Soil Chemical Properties

Low P retention

Low available P and S

Adequate K and Mg

The relationship between relative pasture production and Olsen P for Pallic Soils (Sedimentary soils – Overseer).



On average, near maximum pasture production is achieved at Olsen P 20.

Amount of nutrient to add as fertiliser to raise soil test values by one unit.

Type of soil test	Range (kg element/ha)	Common fertiliser
P to raise Olsen 1 unit	4–7	SSP
K to raise Quick Test	100-250	KCl in SSP
S to overcome deficiency	30-40	SSP/S^0

Data reproduced with the permission of Landcare Research New Zealand Limited

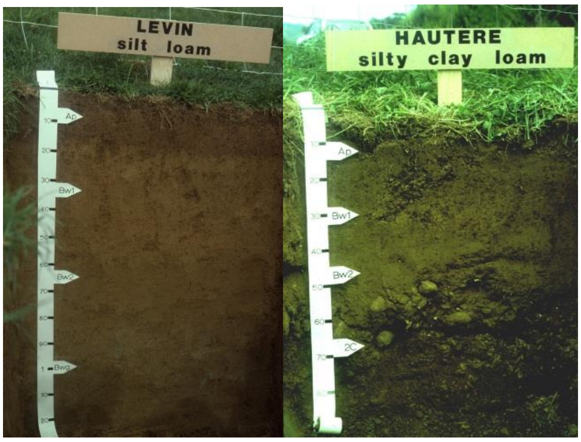
Figure 2.1
Pallic Soil distribution

Pallic Soils or Yellow-Grey Earths– poorly drained terrace (Manawatu) or rolling (South Otago) soils under moderate rainfall. Other soil groups of lesser area include Yellow Brown sands (Manawatu, Northland), Recent alluvial (all regions) and Gley podzol (pakihi) soils. These soils have been mainly formed on wind blown loess from sedimentary rocks such as greywacke, sandstone and mudstone.

Brown Soils

Climate, landscape and soil profile

- Brown Soils are generally found in humid areas i.e. more than 1000 mm rainfall.
- Brown Soils are found on a wider range of landscapes from flat river terraces to hill country.
- The profile of most Brown Soil is relatively uniform with depth. The soil texture is typically silt loam and the structure is strong nut with friable consistence. Some Brown Soils have greater clay contents in the subsoil.



Limitations/advantages of soil physical properties

- Generally, Brown Soils are free draining. However, those Brown Soils with larger clay contents may require artificial drainage systems (mole – pipe).
- The moderate structure of Brown Soils makes them suitable for cultivation.
- Organic matter content is generally low.
- These soils tend to be moist most seasons and have a relatively large available water holding capacity (e.g. 100 mm in the root zone).

Overcoming the limitations of soil physical properties

- Generally speaking soil physical properties are relatively easy to manage on Brown Soils as they are reasonably well structured, have free drainage and tend to form in moist environments.
- Some Brown Soils have a wetness limitation and will need artificial drainage and careful management.

Environmental issues

- The fertile nature of Brown Soils lends them to intensive use (e.g. high stocking rates). There is a large quantity of drainage from these soils. These features are likely to result in significant losses of nutrients in drainage water (e.g. upwards of 50 kg N ha-1 per year).

Soil Fertility in Brown Soils

Soil Property	Low-medium	Optimum
Soil pH	5.7–5.8	5.8–6.0
Olsen P (mg P/L)	12–14	20–30
Sulphate-S	4–6	10–12
QT K	6–8	6–8
QT Mg	17–31	Pasture 8–10, Animal 25–30
% P retention (Anion Sorption capacity)	30- 60	

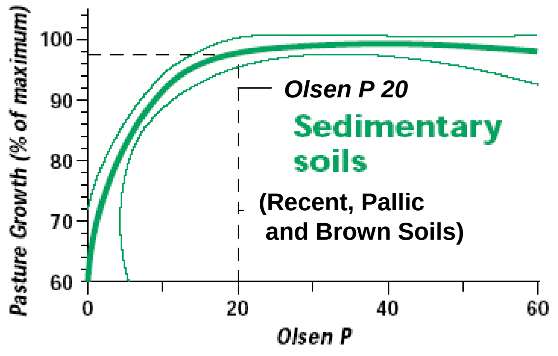
Soil Chemical Properties

Medium P retention

Low available P and S

Adequate K and Mg

The relationship between relative pasture production and Olsen P for Brown Soils (Sedimentary soils – Overseer).



On average, near maximum pasture production is achieved at Olsen P 20.

Amount of nutrient to add as fertiliser to raise soil test values by one unit.

Type of soil test	Range (kg element/ha)	Common fertiliser
P to raise Olsen 1 unit	4–7	SSP
K to raise Quick Test	100-250	KCl in SSP
S to overcome deficiency	30-40	SSP/S^0

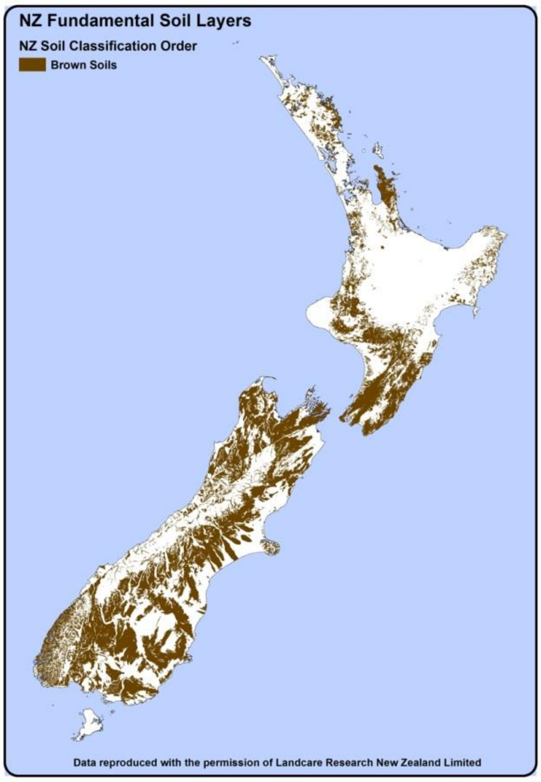


Figure 2.2
Brown Soil distribution

Brown Soils or Yellow-Brown Earths – terrace soils with reasonable drainage under moderate (Southland) to high rainfall (West Coast) or free draining stony plains soils under low rainfall (Canterbury/North Otago); moderately to highly leached soils under moderate rainfall (Northland). These soils have been mainly formed from sedimentary rocks such as greywacke, sandstone and mudstone.

Recent Soils (from alluvium)

Climate, landscape and soil profile

- Recent Soils are found on floodplains, low terraces and young fans.
- Recent Soils form under a wide range of climates from relatively dry through to moist.
- Recent Soils also vary greatly in texture. Some Recent Soils are coarse textured (e.g. sandy loam), very shallow and underlain by stones whilst others are quite fine textured (silty clay loam) and are impermeable (not unlike Pallic Soils in some ways).
- Recent Soils from alluvium are one of NZ’s most valuable soil resources.

Limitations/advantages of soil physical properties

- Coarse textured, Recent Soils often have excessive drainage, which is an advantage in wet winters but is a decided limitation in summer (they may store as little as 25 mm RAW [readily available water] in the root zone).
- Fine textured Recent Soils may have poor natural drainage.
- As a general rule, Recent Soils lend themselves to intensive use.

Overcoming the limitations of soil physical properties

- Irrigation has been used very successfully on coarse textured Recent Soils. Very large responses to irrigation have been measured on shallow Recent Soils.
- Recent Soils with fine textures often benefit from artificial drainage systems.

Environmental issues

- As Recent Soils are often subjected to intensive use, the input of nutrients into production systems is high. In shallow coarse textured Recent Soils, rapid nutrient movement can occur to groundwater.
- In fine textured Recent Soils with artificial drainage systems, nutrients may be conveyed to surface waters.

Soil Fertility in Recent Soils

Soil Property	**Low-medium**	**Optimum**
Soil pH	5.8–5.9	5.8–6.0
Olsen P (mg P/L)	15–17	20–30
Sulphate-S	4–7	10–12
QT K	5–9	6–8
QT Mg	23–34	Pasture 8–10, Animal 25–30
% P retention (Anion Sorption capacity)	10 - 20	

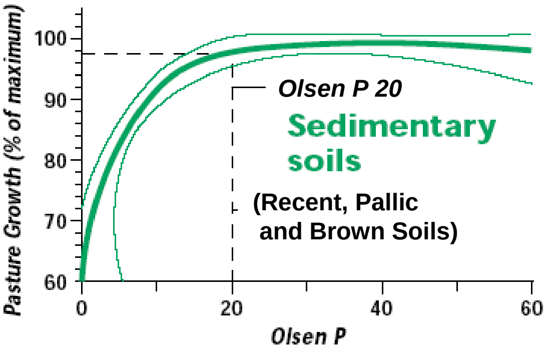
Soil Chemical Properties

Low P retention

Low available P and S

Adequate K and Mg

The relationship between relative pasture production and Olsen P for Recent Soils (Sedimentary soils – Overseer).



On average, near maximum pasture production is achieved at Olsen P 20.

Amount of nutrient to add as fertiliser to raise soil test values by one unit

Type of soil test	Range (kg element/ha)	Common fertiliser
P to raise Olsen 1 unit	4-7	SSP
K to raise Quick Test	100-250	KCl in SSP
S to overcome deficiency	30-40	SSP/S0

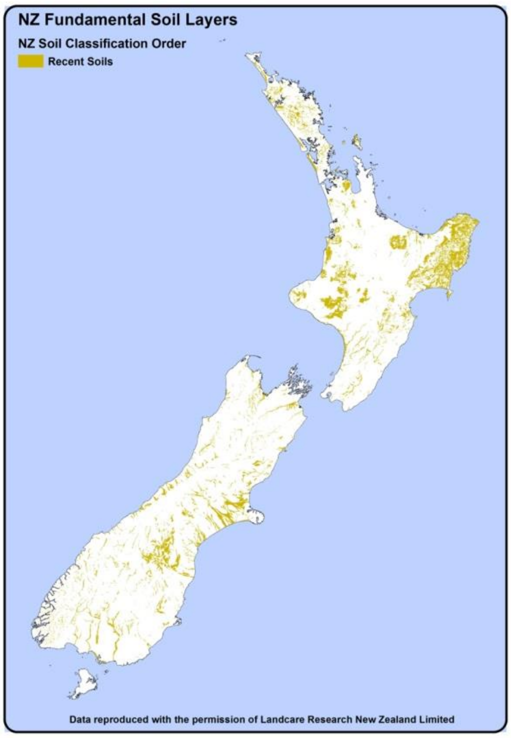


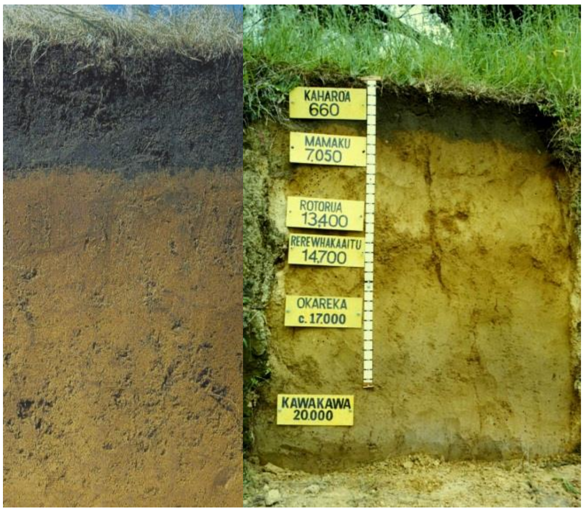
Figure 2.3
Recent Soil distribution

Recent Soils. These soils have been mainly formed on alluvial and fluvial material deposited by rivers and streams eroded from sedimentary rocks such as greywacke, sandstone and mudstone.

Allophanic Soils

Climate, landscape and soil profile

- These Allophanic Soils are associated, principally, with humid areas (1000-2000 mm of rainfall). The soil is moist for most of the year.
- These Allophanic Soils are found on a wide range of landscapes from flat, river and marine terraces to rolling hill country.
- The surface soils are often loam to sandy loam in texture. They are friable with strong fine nut and granule structures.
- The subsoils are of similar textures and have moderate to strong fine nut, granule or crumb structures.



Limitations/advantages of soil physical properties

- Allophane stabilises organic matter allowing it to accumulate in the topsoil.
- Allophane also promotes good soil structure.
- These soils are free draining.
- They also store large amounts of available water (80 – 100 mm in the root zone).

Management of physical properties

- Grazing and soil tillage can safely take place at a wide range of soil moisture contents. These soils are said to be ‘resilient’.

Environmental issues

- As for Brown Soils, the fertile nature of Allophanic Soils lends them to very intensive use. There is a large quantity of drainage from these soils. These features are likely to result in significant losses of nutrients in drainage water (e.g. upwards of 50 kg N ha-1 per year).

Soil Fertility in Allophanic Soils

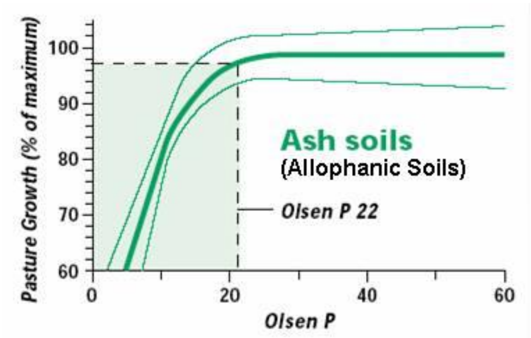
Soil Property	Low-medium	Optimum
Soil pH	5.7–5.8	5.8–6.0
Olsen P (mg P/L)	14–17	20–30
Sulphate-S	6–12	10–12
QT K	3–7	7–10
QT Mg	11–19	Pasture 8–10, Animal 25–30
% P retention (Anion Sorption capacity)	85-95	

Soil Chemical Properties

Very high P retention

Low available P, K and Mg

The relationship between relative pasture production and Olsen P for Allophanic Soils (Ash soils – Overseer).



On average, near maximum pasture production is achieved at Olsen P 22.

Amount of nutrient to add as fertiliser to raise soil test values by one unit

Type of soil test	Range (kg element/ha)	Common fertiliser
P to raise Olsen 1 unit	7-18	SSP
K to raise Quick Test	45-80	KCl in SSP
S to overcome deficiency	20-30	SSP/S0

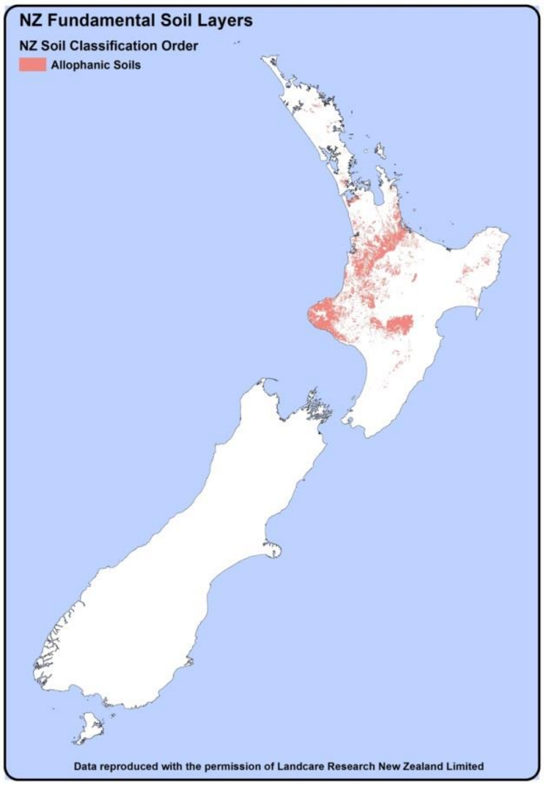
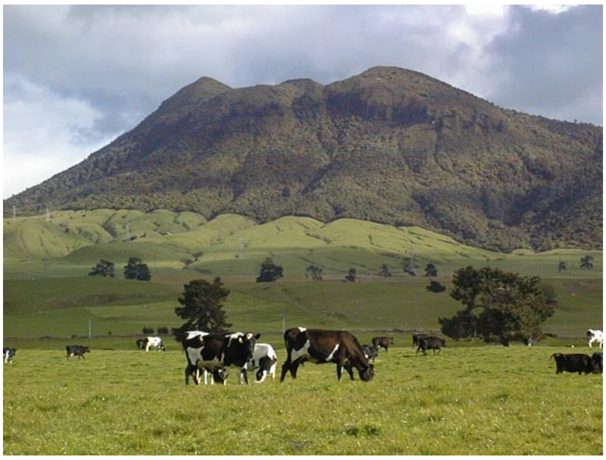


Figure 2.4
Allophanic Soil distribution

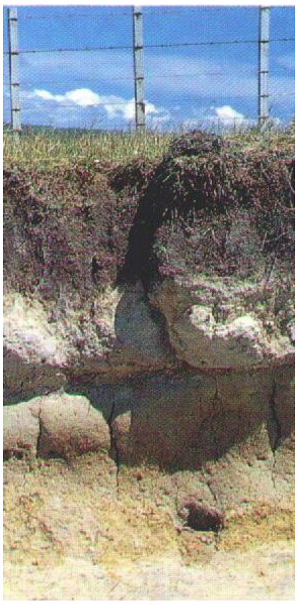
Allophanic Soils (Ash soils) such as Yellow Brown loam soils (Waikato, Taranaki), Red and Brown loams; Brown Granular clays and loams (Northland, Waikato), and the poorly drained (gley) soils formed from volcanic ash (Waikato).

Pumice Soils



Climate, landscape and soil profile

- Pumice Soils are formed in a range of climates (rainfalls of 1000 to 2000 mm; cool in the vicinity of Lake Taupo and warm in the Bay of Plenty).
- These soils are found on flat to rolling landscapes.
- Pumice Soils are formed in coarse, gravelly deposits. These soils have thin dark surface soil (0-15 cm) with moderate crumb and granule structure over yellowish brown soil with weak crumb structure (to a depth of 45 cm).



Limitations/advantages of soil physical properties

- Pumice Soils store only very small quantities of available water (as little as 20 to 30 mm in the root zone).
- These soils are excessively well drained and so are, generally speaking, relatively easy soils to manage in winter months.

Overcoming the limitations of soil physical properties

- Plant production on Pumice Soils will often benefit enormously from irrigation.

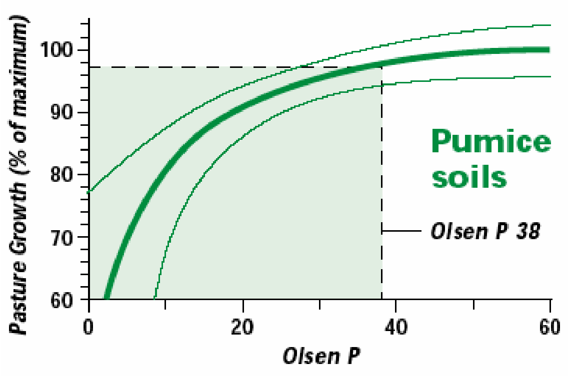
Environmental issues

- Pumice Soils are often in environmentally sensitive areas and the nutrients lost from these soils may impact upon some of our most pristine and valuable surface water bodies (the central North Island lakes being the most obvious example).

Soil Fertility in Pumice Soils

Soil Property	Low-medium	Optimum	Soil Chemical Properties
Soil pH	5.7	5.8–6.0	Medium P retention
Olsen P (mg P/L)	9	35–45	Low available P, S, K, Mg
Sulphate-S	3	10–12	
QT K	5	7–10	Generally cobalt deficiency in animals
QT Mg	11	Pasture 8–10, Animal 25–30	
% P retention (Anion Sorption capacity)		50 -60	

The relationship between relative pasture production and Olsen P for Pumice soils.



On average, near maximum pasture production is achieved at Olsen P 38.

Amount of nutrient to add as fertiliser to raise soil test values by one unit

Type of soil test	Range (kg element/ha)	Common fertiliser
P to raise Olsen 1 unit	4-15	SSP
K to raise Quick Test	35-60	KCl in SSP
S to overcome deficiency	40-50	SSP/S^0

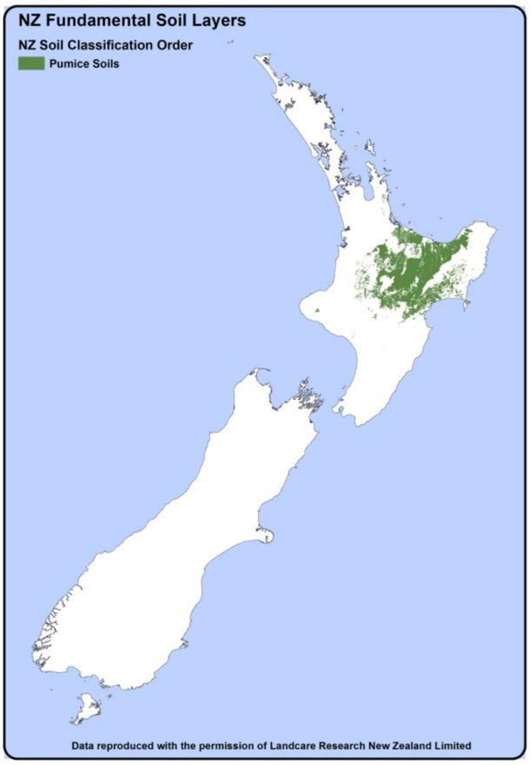


Figure 2.5
Pumice Soil distribution

Pumice Soils such as Yellow Brown Pumice Soils and Gley Soils formed from pumice (Bay of Plenty, Central Plateau). These soils, although volcanic in origin, have different properties to the Allophanic Soils above.

References

During C (1984) Fertilisers and soils in New Zealand farming. P. D. Hasselberg, Government Printer, Wellington, New Zealand.

Roberts AHC, Morton JD (1999) Fertiliser use on New Zealand dairy farms. New Zealand Fertiliser Manufacturers' Association, Auckland, New Zealand.

Wheeler DM, Roberts AHC (1997) Soil fertility status of sheep/beef and dairy farms in NZ: 1988–91. New Zealand Soil News 45: 90–97.

Test Your Knowledge – Section 2

Questions

1. Select a farm with which you are familiar. Describe the important features of the landscape, climate and soil of this farm.
2. Discuss how these features impact on production levels on this farm and on key management decisions.
3. Arrange the following soil groups in order of increasing phosphate retention: Allophanic Soil, Pallic Soil, Brown Soil, Recent Soil, Pumice Soil
4. A farm on a Pallic Soil has an Olsen P of 18 mg/L. For optimum pasture production in this soil type the Olsen P needs to be 25 mg/L. How much single superphosphate needs to be applied to reach this optimum production?

Answers at back of this book.

SECTION 3

3. Nutrient uptake by pasture from soils.

Key Learning Objectives

After studying this section you should be able to:

1. Describe the sources (soil or atmosphere) of four (4) major and two (2) minor essential elements required for pasture growth.
2. Write the chemical symbols for the ions of phosphate, nitrate, sulphate, potassium , calcium and magnesium that are taken up during pasture growth.
3. Briefly describe the role of three (3) major and two (2) minor elements in plant nutrition.
4. Briefly describe how exchangeable magnesium and potassium are held in soils.
5. Describe the reserve, slow soluble sources of potassium and nitrogen in soils.
6. Explain the term cation exchange capacity (CEC) and identify soil properties that lead to differences in CEC.
7. Briefly describe the process of phosphate sorption.
8. Identify soil groups that have differing phosphate retention capacities.
9. Describe the optimum pHs for pasture growth in mineral and peat soils.
10. Describe 2 elements that may become toxic to plants if soils become more acidic.
11. Explain why the addition of lime raises soil pH and increases biological activity in soils.
12. List two of New Zealand's most common liming materials and their calcium carbonate equivalents.

3.1 The pasture and its nutrition

In New Zealand we have an international reputation for producing milk from grazed pastures. In Section 1, we described how a Friesian/Jersey cross cow (450 kg liveweight) producing an average of 1.6 kg milk solids (MS) per day needs approximately 15.5 kg dry matter (DM) of good quality (11.3 MJME/ kg DM) pasture per day to maintain body condition and milk production. The energy, carbohydrate and protein composition of good quality pasture was shown in Table 1.2.

This good quality pasture requires 18 essential elements to grow.

The **non- mineral elements** carbon (chemical symbol, **C**), hydrogen (**H**) and oxygen (**O**) are derived from **carbon dioxide** (CO_2) gas in the atmosphere or water (**H_2O**). In leaves of pasture plants C, H and O are synthesised into carbohydrates (**CH_2O**) using energy from sunlight in the process called photosynthesis, which can be summarised as follows:

$$\text{Carbon dioxide + water} \quad \overset{\text{light energy}}{\Rightarrow} \quad \text{oxygen + carbohydrates}$$

or, using chemical formulae, we may write:

$$6CO_2 + 6H_2O \Rightarrow 6O_2 + 6\,(CH_2O)$$

The carbohydrates are used as the building blocks for pasture plants to manufacture proteins, lipids and other organic compounds, which combined contribute to 85-90 % of pasture dry matter (Table 1.2). Particularly important plant compounds, the proteins, are made when the essential element nitrogen (N) is chemically combined with organic compounds. For legumes such as clover and lotus, N can also be obtained by biological nitrogen fixation from the nitrogen gas (N_2) that makes up 80 % of the atmosphere.

Mineral elements from the soil

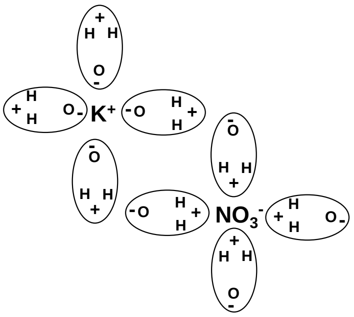
For pasture grasses and herbs (non- legumes), however, N must be derived from the soil. Nitrogen is just one of *16 mineral elements* essential for plant growth (see Table 3.2) that must be taken up from the soil by plant roots (that is, unless foliar fertilisers are used). For plant uptake to occur the essential element must be in a water soluble form in order to pass from the soil, through the root to the growing areas of the plant.

3.2 The Form of Nutrients Taken Up by Pasture Plants

For mineral elements to be soluble in the soil water, they must be present as extremely small particles called ions before they can pass across the membranes of the plant root cells and enter the plant. The mineral salts in the soil (and most fertilisers) are ionic compounds such as potassium nitrate (symbols KNO_3). These ionic compounds dissolve in water to form their component charged ions. The ions separate in water because the polar nature of the water molecules (positively charged hydrogens and negatively charged oxygen) act to 'pull' the ionic components apart. Each ion becomes surrounded with a cloud of oriented water molecules keeping them apart. The attraction between a polar water molecule and a nutrient ion is greater than the attraction of the two ions for each other.

$$KNO_3 \quad \overset{H_2O}{\Rightarrow\_} \quad K^+ \quad + \quad NO_3^-$$

salt in water solution of ions in water



Such K^+ and NO_3^- ions surrounded by water molecules are said to be hydrated ions. Positively charged ions of elements such as $\mathbf{K^+}$ are called ***cations*** and negatively charged ions of elements such as chloride ($\mathbf{Cl^-}$) are called ***anions***. Compounds such as ammonium ($\mathbf{NH_4^+}$), phosphate ($\mathbf{H_2PO_4^-}$) and nitrate ($\mathbf{NO_3^-}$) also form water soluble cations and anions. It is these hydrated ions which are taken up by plant roots. The forms of ions taken up are listed in Table 3.1.

Table 3.1 Essential Mineral Elements and Role in Plants

Element (Chemical Symbol)	**Role in Plants**	**Ion forms taken up by plants**
Macronutrients		
Nitrogen (N)	Constituent of all proteins, chlorophyll, and in coenzymes and nucleic acids	NH_4^+, NO_3^-
Phosphorus (P)	Important in energy transfer as part of adenosine triphosphate. Constituent of many proteins, coenzymes, nucleic acids and metabolic substrates.	$H_2PO_4^-$, HPO_4^{2-}
Potassium (K)	Involved in osmotic pressure control. Functions in regulatory mechanisms such as photosynthesis, carbohydrate translocation, protein synthesis etc.	K^+
Calcium (Ca)	Cell wall component. Plays role in the structure and permeability of membranes.	Ca^{2+}
Magnesium (Mg)	Constituent of chlorophyll and enzyme activator	Mg^{2+}
Sulphur (S)	Important constituent of plant proteins	SO_4^{2-}, SO_2 g
Sodium (Na)	Essential for some C4 plants (e.g. guinea grass) but not essential for the low concentrations found in common pasture grasses	Na^+
Micronutrients		
Boron (B)	Important for reproductive processes, sugar translocation and carbohydrate metabolism.	H_3BO_3, Boric acid
Iron (Fe)	Chlorophyll synthesis and in enzymes for electron transfer	Fe^{2+}
Manganese (Mn)	Controls several oxidation-reduction systems, formation of O_2 in photosynthesis	Mn^{2+}
Copper (Cu)	Catalyst for respiration, enzyme constituent.	Cu^{2+}
Zinc (Zn)	In enzyme systems that regulate various metabolic activities	Zn^{2+}
Molybdenum (Mo)	In nitrogenase needed for nitrogen fixation	MoO_4^{2-}
Cobalt (Co)	Essential for symbiotic nitrogen fixation by Rhizobium	Co^{2+}
Chlorine (Cl)	Activities system for production of O_2 in photosynthesis	Cl^-
Silicon (Si)	Si improves plant resistance to fungal attack and appears to have roles in heavy metal and drought tolerance	H_4SiO_4 ,Silicic acid

3.3 The Role of the Soil Water

Up to 50 % of topsoil volume in the field is pore space (Figure 3.1). Plant roots grow through this pore space. Generally the soil pore space is very irregular in shape, while plant roots and root hairs are cylindrical.

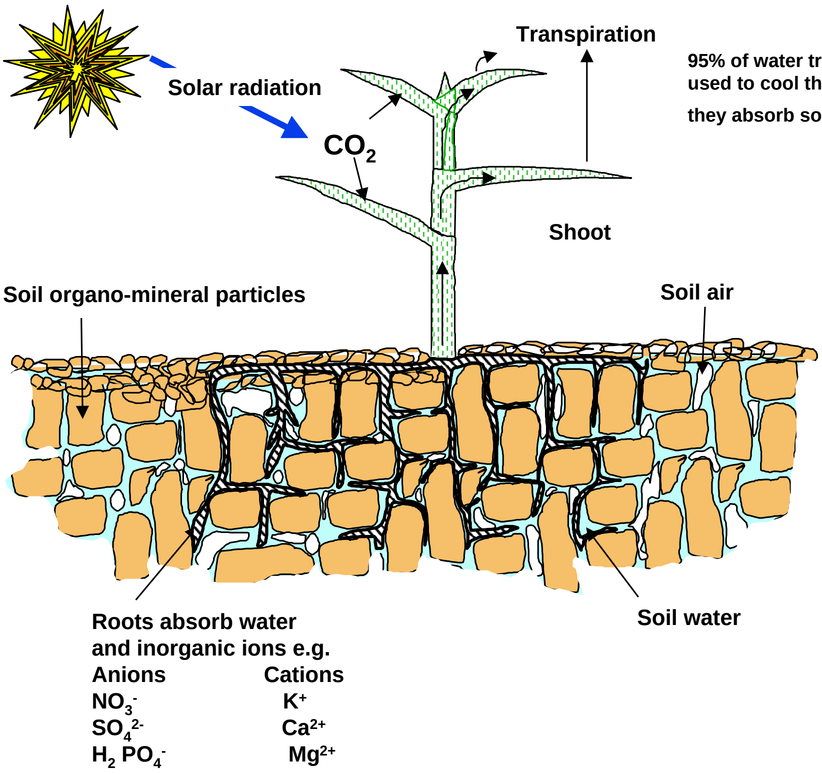


Figure 3.1 The uptake of nutrient ions and water from soil

Figure 3.2 provides a cartoon concept of how the different nutrient ions are held on the soil particles in relation to a root hair. This difference in shapes leads to poor contact between soil surfaces and root surfaces. Commonly less than 40 % of the root surface directly contacts a soil surface. Fortunately in a moist soil the small gaps between soil particles and between roots and soil particles are readily filled with water by the process called capillarity (the attraction of polar water molecules to the electrically charged soil surfaces). This thin soil water film connects the root surface, the **sink** for nutrient ions, with the soil mineral and soil organic matter surfaces that are the **sources** of nutrient ions (Figure 3.2). Thus as soil water is sucked up by plant roots to replace water evaporated from leaves (Figure 3.1) nutrients are transported from the soil to the leaf.

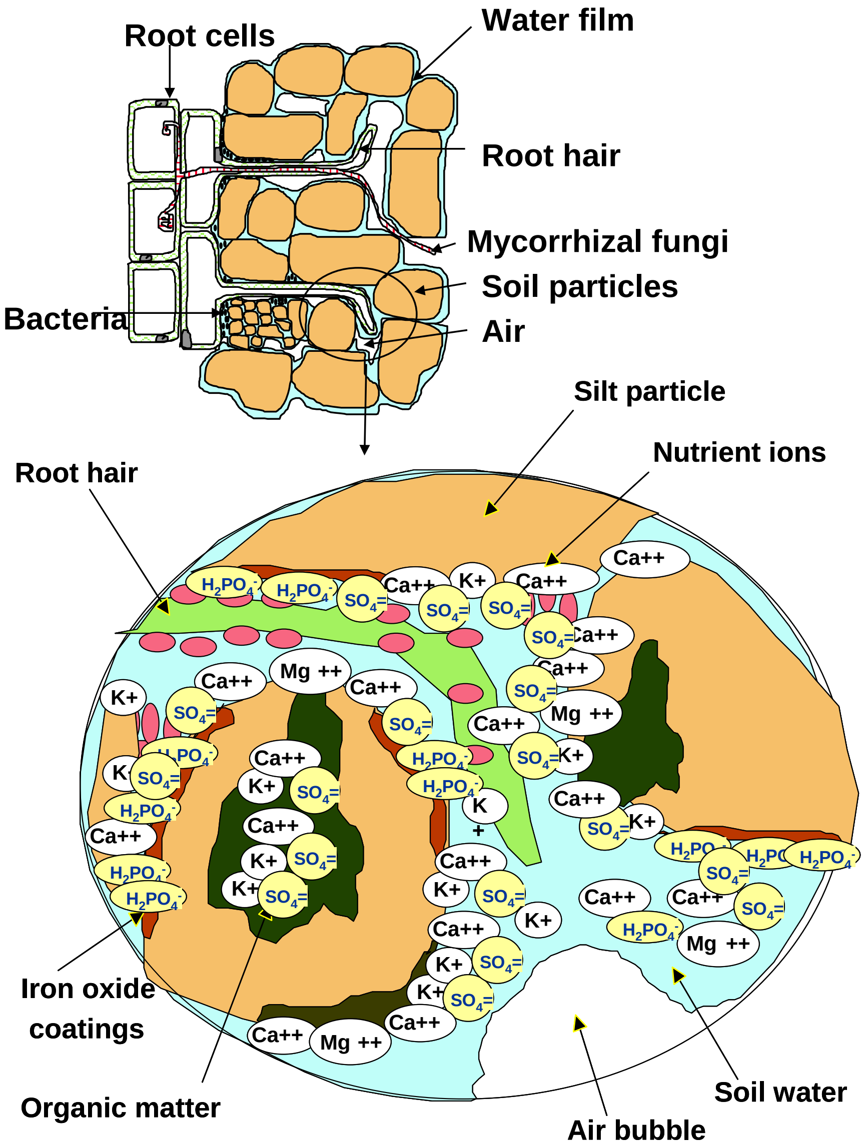


Figure 3.2 The microscopic arrangement of roots and water in soil

The cartoon (Figure 3.2) shows the phosphate ion ($H_2PO_4^-$) strongly attaches to the positive surface of iron oxide coatings on soil clay particles. The rest of the soil, clay minerals, sand and silt particles plus humus (organic matter) carries a net negative charge which attracts the positively charged cations such as K^+, Ca^{2+} and Mg^{2+}. For a plant root hair to take up these exchangeable ions the root hair must deplete the concentration of ions in the soil water and release a counter-ion that will balance the charge on the soil surface (Figure 3.2) e.g. K^+ uptake is balanced by hydrogen ion H^+ efflux from roots and when anions, e.g. nitrate NO_3^-, are taken up by plants, OH^- ions are released from roots.

3.4 Sources of Elements in Soils

Uptake from soil solution and replenishment from the solid phase

Nutrient supply to plants is a very dynamic process. The amount of nutrient held in the soil water will only supply plant growth for a few days.

Uptake of nutrients by roots and dilution or displacement of the soil solution by rainfall decreases nutrient concentrations in the soil solution. Nutrient concentrations are replenished from solid mineral and organic matter reserves in soil (See Figure 3.3). The reserves and important release processes are shown in Tables 3.2 and 3.4.

It is helpful to think of the soil nutrient supply in terms of its readiness for plant uptake.

There is a **readily available pool of nutrients** that includes nutrient ions dissolved in soil water and attached weakly to soil surfaces by electrostatic attraction (Figure 3.2). This readily available pool will supply nutrients for plant uptake over a period of several weeks. The relative size of this pool is indicated by the common soil tests such as the Olsen P test and the exchangeable cation test.

The readily available pool of nutrients is more slowly replenished (months to years) from the slow weathering of soil minerals or the slow decomposition (decay) of organic remains. These are termed the **slowly-available, less-soluble reserve** forms of nutrients in solid mineral and soil organic matter.

Table 3.2 Nutrient reserve forms in soils and the ions released.

Solid reserve forms	**Process retaining / *(or releasing)* nutrients**	**Main nutrients involved**
Primary and secondary minerals	Precipitation / *Dissolution (weathering)*	K^+, Na^+, Ca^{2+}, Mg^{2+}, and $H_2PO_4^-$ plus trace amounts of other ions
Clay and Humus colloid surfaces	Electrostatic forces; *ion exchange,* sorption / *desorption*	K^+, NH_4^+,Ca^{2+}, Mg^{2+}, Na^+ and Zn^{2+}, Mn^{2+}, Cu^{2+}, Fe^{2+} and soluble complexes of other ions
	Chemically bound on oxide surfaces	$H_2PO_4^-$, HPO_4^{2-}, MoO_4^{2-} and H_3BO_3
Incorporated in soil organic matter	Water insoluble organics. *Decay (mineralisation)*	NH_4^+, NO_3^-, SO_4^{2-}, $H_2PO_4^-$, HPO_4^{2-}

All of these processes involve the 'solution' of a solid phase form of a nutrient into the soil water film by biochemical (decay, decomposition, mineralisation) or chemical (dissolution) reactions. These reactions occur at the interface between the soil solid and water phases. The surface area of contact between the soil water and soil particles will partly govern the rate at which these reactions occur and therefore the rate at which the nutrient concentration in soil solution can be replenished. Therefore fine textured soils and soils containing fine colloids (colloids are the products of decomposing organic residues and clays) that have large surface areas per unit weight tend to have higher nutrient reserves than coarse textured soils (high sand content) or soils low in organo-mineral colloids.

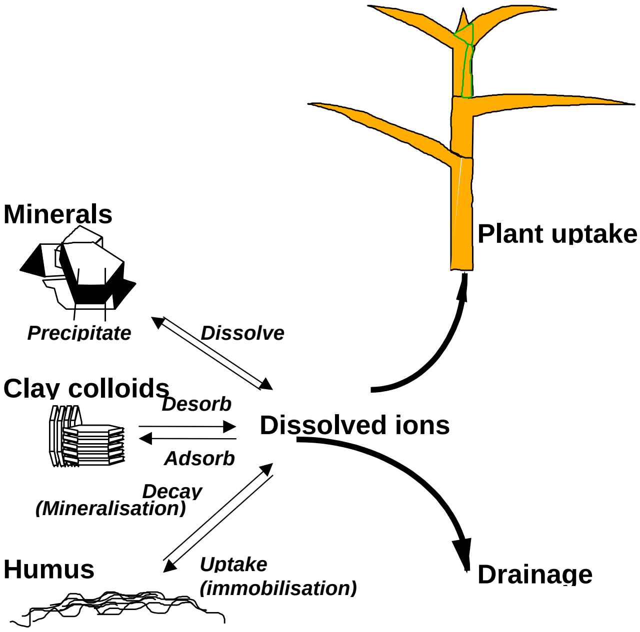


Figure 3.3 Reserve forms of nutrients and their release processes

Readily available, exchangeable forms of nutrients

A key factor in the retention of plant nutrients in soils is that the nutrients are all charged ions. Charged ions are attracted to oppositely charged ions or surfaces (Figure 3.2). The surfaces of the fine soil particles, clays and organic matter, carry mostly net negative charge. Thus nutrient cations (K^+, Na^+, Ca^{2+} and Mg^{2+}) are electrostatically attracted to the surfaces of fine organic matter and clay particles (Figure 3.2 and Figure 3.4).

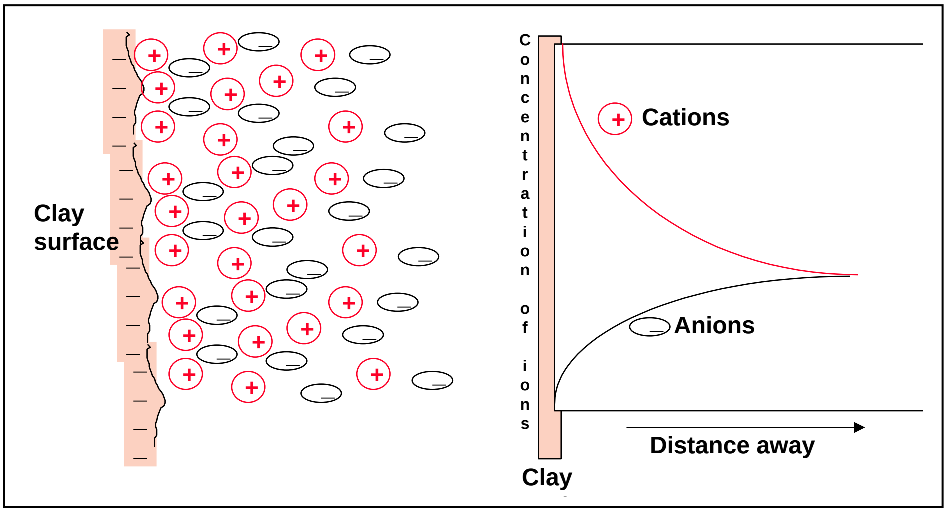


Figure 3.4 The arrangement of clouds of cations and anions at a negatively charged soil surface.

Cation concentrations at or near the soil surface are several thousand times higher than further away from the surface in the soil solution. This concentrated layer of positively charged cations will attract a diffuse layer of anions. These cations and anions held close to the soil particle surface are free to exchange positions with similarly charged ions further out in the soil solution.

Table 3.3 Forms of nutrient reserves in soils and their release processes

Solid reserve form	Release process	Solute form
Nitrogen		
organic matter	Microbial decay	Ammonium NH_4^+
interlayer NH_4^+ in mica and vermiculite clays	Weathering	NH_4^+
exchangeable NH_4^+	Cation exchange	NH_4^+(microbial oxidation to NO_3^-)
Sulphur		
organic matter	Microbial decay	S^{2-}, SO_4^{2-}
sulphides (e.g. FeS) and sulphur in anoxic soils	Microbial oxidation	SO_4^{2-}
gypsum (calcium sulphate)	Dissolution	SO_4^{2-}
Phosphorus		
organic matter	Microbial decay	$H_2PO_4^-$, HPO_4^{2-}
adsorbed and chemically bound to oxide clays and $CaCO_3$.	Ligand exchange and Dissolution	$H_2PO_4^-$, HPO_4^{2-}
Potassium, Calcium and Magnesium		
silicate minerals (e.g. feldspars micas and 2 to 1 clays)	Weathering and dissolution	K^+, Mg^{2+}
exchangeable cations	cation exchange	K^+, Mg^{2}+, Ca^{2+}
carbonates and sulphates	Weathering and dissolution	Mg^{2+}, Ca^{2+}
Iron, Manganese, Zinc and Copper		
precipitated as hydroxyoxides	Weathering and dissolution	Cations (Fe^{2+}, Mn^{2+}, Zn^{2+}, Cu^{2+}) or soluble chelates
bound on humus	Desorption	
exchangeable	Dissociation	
	Cation exchange	
Boron and Molybdenum		
adsorbed on Fe, Al, and Mn oxides and other clay minerals	Desorption	H_3BO_3 MoO_4^{2-}

Not all soil surfaces are negatively charged. Iron and aluminium oxides form at the edges of weathered clay minerals. In mildly acidic soils these oxides carry positive charges that attract and adsorb negatively charged anions (see Figure 3.2). Phosphate is strongly adsorbed, to a lesser extent sulphate, and nitrate is not adsorbed at all and is therefore easily leached from soils.

Exchangeable cations and cation exchange capacity

The greater a soil's content of organic matter and finely weathered clay, the more negatively charged sites it will have to attract cations (it is said to have a greater *cation exchange capacity*). Similarly it may have more oxide surfaces and have a large anion exchange capacity (Phosphate retention). This is shown conceptually in Figure 3.5.

If we examine the model of cation exchange (Figure 3.5), five of the nine negative charges on the soil colloid surface are balanced with basic nutrient cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+ called bases). The remaining 4 sites are balanced with the acidic cations (Al^{3+} and H^+). The total cation exchange capacity of this soil particle is 9. So 5/9ths of the exchange capacity is saturated with bases and 4/9ths with exchange acidity. The base saturation of the soil surface can be represented as the percentage of negative cation exchange sites filled with bases.

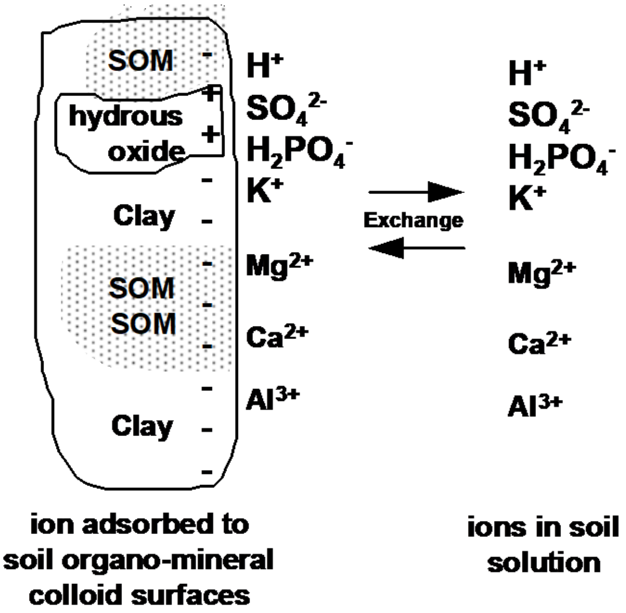


Figure 3.5 Visualising the cation and anion exchange processes.

Calculating percentage base saturation using Figure 3.5

$$\%\,\text{B.S.} = \frac{\text{sum of positive electrical charge on all exchangeable (adsorbed) basic cations}}{\text{negative charge due to cation exchange capacity}} \text{x} 100$$

$$\%\ \text{B.S.} = \frac{5\ \text{centimoles}\ \text{kg}^{-1}\text{soil}}{9\ \text{centimoles}\ \text{kg}^{-1}\text{soil}}\ \text{x}\ 100$$

= 56 %

N.B. Units of electrical charge on soils are expressed as centimoles (Mole/100) of charge per kg of dry soil (or milliequivalents per 100g soil). The latter measure is an old term but is still used by soil testing services to express soil cation exchange capacity and the quantities of exchangeable bases per unit weight of soil.

The range of cation exchange capacities commonly encountered in soils is presented in Table 3.4 with some practical consequences listed in Table 3.5. (The numbers refer to meq/100 g soil).

Table 3.4 The common range of cation exchange capacities found in NZ pasture soils

Common CEC range in topsoils (0-75 mm)		
0-5 meq/100g	**5-15 meq/100g**	**15-50 meq/100g**
Sandy soils very recent alluvium	Fine sandy loams and silts, recent soils Pallic soils	Silt loams to clays, Brown soils, Allophanic, peats
Low Organic Matter < 1 %	Organic Matter 3-5 %	Organic Matter > 5 %

Table 3.5 The practical consequences of differences in cation exchange capacities found in NZ pasture soils

Soils with CEC 1-10 range	**Soils with CEC 11-50 range**
High sand content + low organic matter content	High clay content/or high organic matter
Less lime required to correct acidity (but more frequent liming)	More lime required to correct soil acidity
Low capacity to hold nutrients. Nitrate and potassium leaching	Greater capacity to hold nutrient cations
Low water holding capacity	High water holding capacity

Organic soils with high clay contents have large cation exchange capacities (CEC) and can retain large amounts of nutrient cations. Sandy soils with low organic matter contents have low CEC and can only retain small quantities of nutrient cations. Thus, it is not wise to add all the required potassium (K) fertiliser to a sandy soil, before the seasonal rains. Much of the K may be washed out of the soil in the drainage water. Split dressings of K may be required.

Reserve, less-soluble forms of solid phase nutrients

Clay minerals

These reserve forms consist of mineral rock particles that remain unweathered in the soil and silt and clay sized minerals that have weathered from them. Various forms are mentioned in Table 3.3. Feldspars contain K in the aluminosilicate framework and it is slowly released on weathering. It is the 2:1 layer silicate clay minerals (Figure 3.6) derived from mica that are the most important K supplying minerals. Mica weathers to illite and will release K faster than feldspar. Strong weathering converts illite to vermiculite that will adsorb K. The soil fertiliser K requirements depend on the form of clay mineral present. Recent alluvial soils and weakly weathered soils commonly have the highest feldspar, mica and illite contents. Soils containing mica and illite may require no K fertiliser for most types of farming.

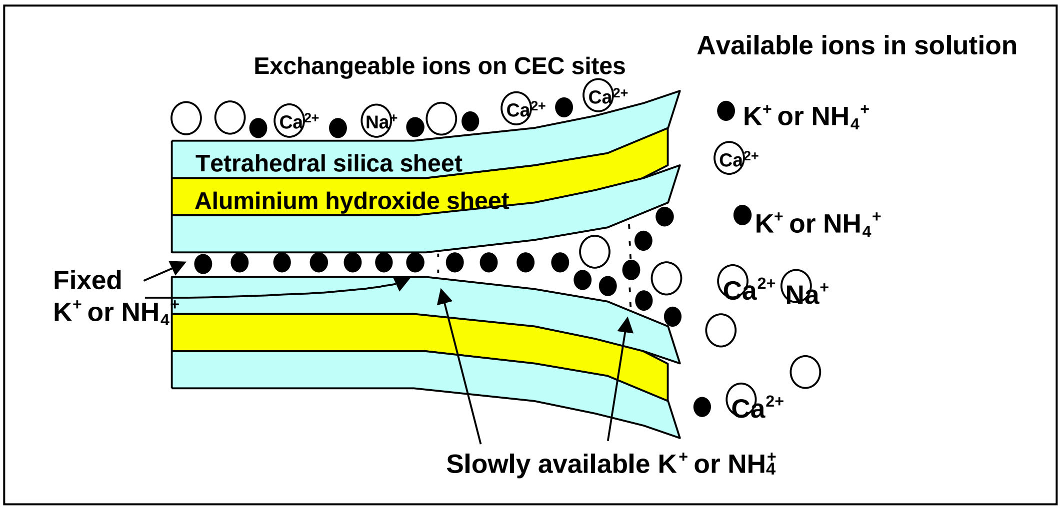


Figure 3.6 The structure of a 2:1 layer clay mineral. The left hand end illustrates the structure of less weathered illite, whereas the right hand end illustrates the structure of vermiculite.

Soil organic matter (SOM)

Soil organic matter consists of decomposing plant and animal remains and humus formed from their decomposition products. Topsoils (0-10 cm) receive most decomposing plant and animal remains and commonly contain between 1 % and 5 % organic matter. For this reason, topsoils have higher contents of organic matter than horizons lower in the soil profile (Figure 3.7). Nutrients associated with organic matter and the cation exchange sites on SOM are therefore retained and are more concentrated in the topsoil. This is fortunate because this is the main plant rooting depth.

SOM levels tend to be higher under permanent grassland and forest and lower in soils where plant residue return is lower or the soil is frequently disturbed (cropping soils). The level or organic matter in a soil represents the *balance* (dynamic equilibrium) between the rate of deposition of plant and animal remains and rates of decomposition by soil bacteria and fungi. Mechanisms which slow decomposition lead to soils high in organic matter (e.g. anaerobic conditions slow aerobic decomposition, which allows peats to form at 30-50 % organic matter, or, adsorption of SOM to soil clay minerals thus preventing enzyme attack).

SOM acts as a source and sink for plant nutrients; approximately 70-95 % nitrogen, 50-80 % sulphur, 20-60 % phosphorous are held in SOM. The ratio of C:N:S:P is usually 100:10:1:1.3.

Rates of Nutrient Release

Some of the release processes are rapid e.g. *cation exchange* from colloids or anion *desorption* from oxides on clays. They are less dependent upon temperature than biochemical processes that require the growth and activity of soil organisms.

Processes such as NH_4^+ and NO_3^- release, require bacteria and fungi to decompose organic residues. Microbial activity, and therefore *decomposition processes*, is temperature sensitive, hence plant growth can be N limited in cool seasons. (Strategic N fertiliser applications in cool seasons can be used to boost vegetable and pasture growth).

The *dissolution of minerals* can be a very slow process. Most soil minerals dissolve faster in acidic conditions. Many minerals that are salts of divalent cations dissolve faster in the presence of *chelating agents*. Plant roots and soil micro-organisms growing around roots are capable of producing *acids and chelating agents*.

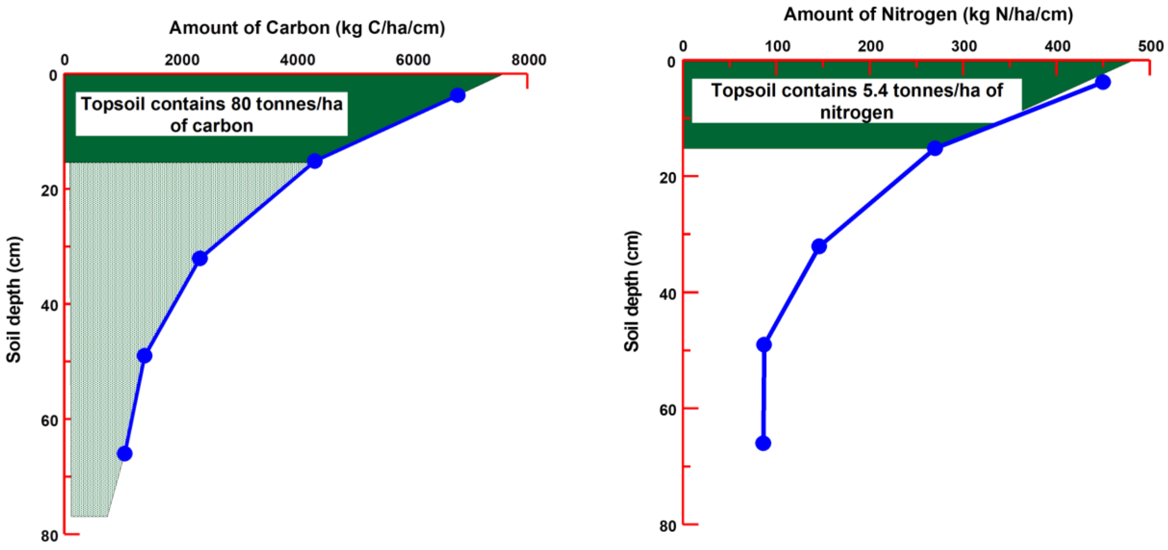


Figure 3.7 The distribution of soil organic matter (carbon) and nitrogen in a typical pastoral soil.

In the final analysis, the concentration of nutrient in soil solution and its rate of replenishment rely on the amount and chemical nature of the nutrient reserve as well as soil water content, temperature, aeration and energy sources, which control the activities of soil micro-organisms.

Immobilisation and Retention of Applied Nutrients in Soil

Most nutrient release processes from the soil solid phase are reversible chemical and biochemical reactions. If the concentration of the nutrient ions in soil water is increased by fertiliser, or dung and urine, then the net direction of the ion movement may reverse and the soluble nutrient may be immobilised in the solid phase. For example, water soluble fertiliser addition to soil will increase the amount of nutrient in soil solution. Significant amounts of the nutrient may become ‘immobilised’ in a reserve form. Relationships between solid and dissolved forms of nutrients are diagrammatically represented in Figure 3.3.

3.6 Factors Influencing Nutrient Retention and Plant Availability.

In Section 3.5, we described the main forms of nutrient reserves in soils. In this section we highlight some of the factors controlling the rate of nutrient release and uptake by plants in soils. A soil is a dynamic mixture of minerals, organic residues and living micro- and macro-organisms. Soil properties that influence soil fertility status are not static.

The important factors which influence soil during soil development and through current farming practices, are shown in Figure 3.8. In this brief discussion we will concentrate on two aspects, phosphate retention (or fixation) and soil acidity.

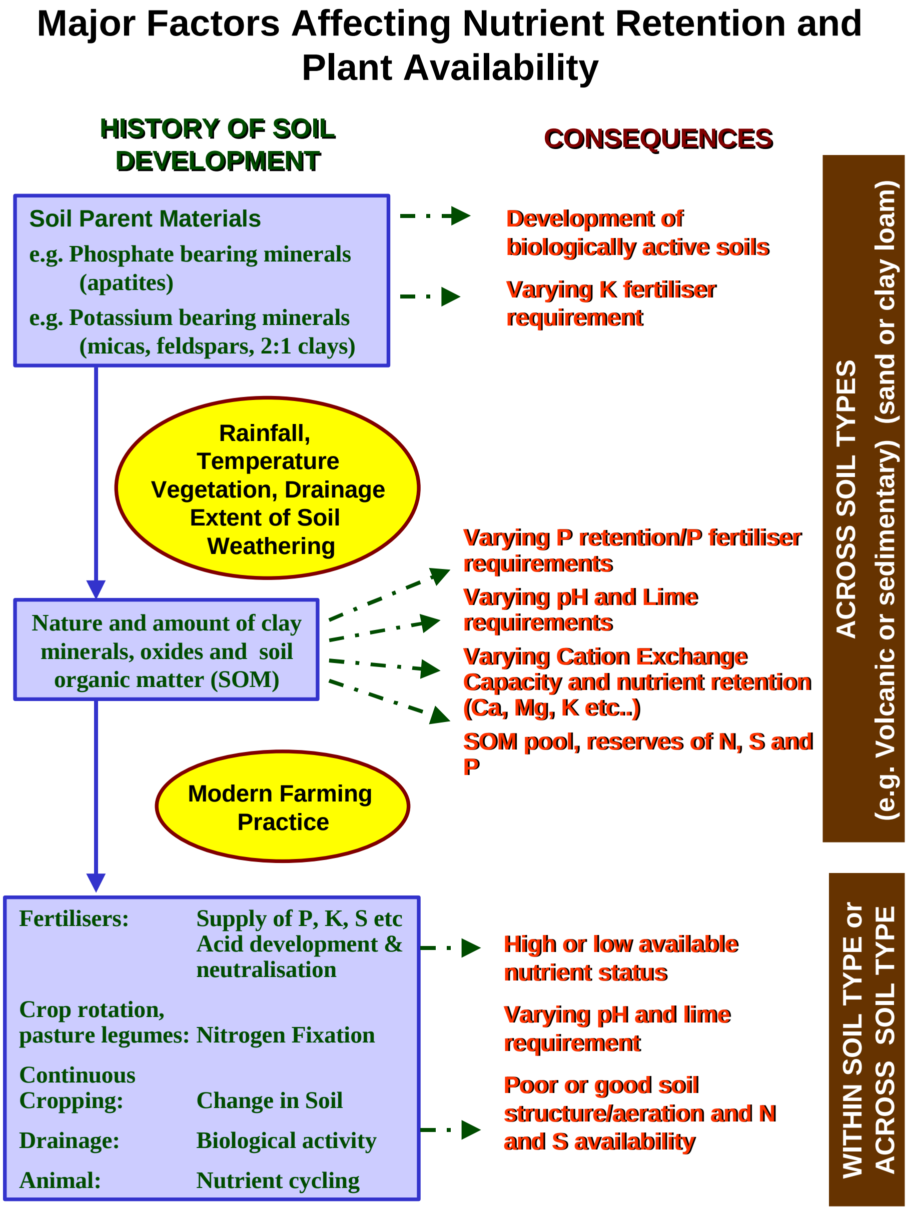


Figure 3.8 The interaction of soil parent material, climate, time and modern farming practices on differences in soil fertility and nutrient supply to pastures.

Phosphate Retention

A concept to explain P fixation

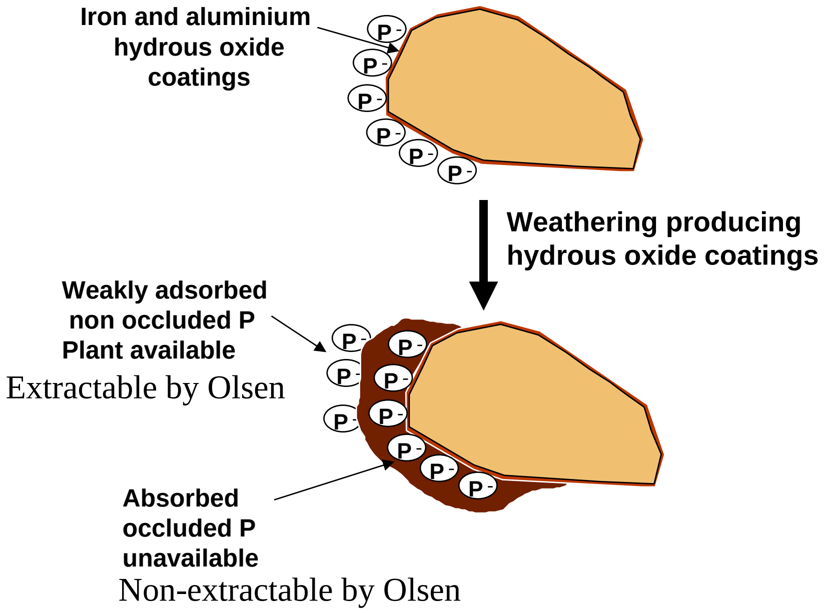


Figure 3.9 A concept to visualize ongoing P retention by oxide coatings forming on a soil particle

Over thousands of years the rocks that make up soil parent material, physically and chemically weather to fine particles. Phosphate minerals like apatite (a phosphate rock) chemically weather to release soluble phosphate that can be taken up by plants.

Minerals containing iron and aluminium weather to form iron and aluminium oxides. As time passes apatite minerals vanish from moderately weathered topsoils and the content of iron and aluminium oxides increases. These oxides are responsible for strongly adsorbing phosphate (Figure 3.2 and 3.9) that was naturally present in the soil, or latterly, has been added in the form of fertiliser. In most soils, this phosphate adsorbing power of the oxides is what keeps the soil solution phosphate concentration low and the plant supply continually limited. For this reason, plant growth responds to phosphate fertiliser on most soils, particularly at the initial stages of agricultural development.

In hot-wet climates which favour weathering of soil minerals, large amounts of oxides are formed. These soils are particularly responsive to phosphate fertiliser. Even the small range of climate change over the length of New Zealand causes soil differences. We find soils in Northland generally have higher P retention than soils formed on similar parents rocks in the South Island.

Phosphate adsorption and finally fixation in a form unavailable to plants can proceed in the following way. Phosphate is first adsorbed onto Iron (Fe) and Aluminium (Al) oxides (Figure 3.9) and then may be covered by further weathering oxides, reducing its availability to plant roots (see Figure 3.2). Phosphate retention markedly influences the mobility of phosphate ions in soils, plant uptake of phosphate and the soils initial fertiliser phosphate requirements.

Phosphate retention varies because of the amount of Iron (Fe) and Aluminium (Al) oxides that have been produced by weathering of soil parent materials. Volcanic loams contain large amounts of Fe and Al oxides and even young weakly weathered soils have high P retention. Soils formed on sedimentary rocks and alluvial material from sedimentary rocks weather to produce lower amounts of Fe and Al oxides. Only the older strongly weathered sedimentary soils have medium to high P retentions. Soils with high P retention require more phosphate but in New Zealand's climate they usually have bound and accumulated more SOM and sulphate, and with added P become very fertile soils. (e.g. Allophanic Soils used for dairying in Taranaki and Waikato.)

A P retention soil test (also termed the anion sorption capacity, ASC) can be performed to provide advice on the relative ability of soils to adsorb P.

The influence of soil acidity on plant nutrition

Many agricultural and garden plants will not grow well in acid soils. Therefore it is important to understand what soil acidity is, how soil acidity is formed and how to reduce the negative effects of soil acids on plant growth. The reasons for the effects soil acidity has on plant root growth and nutrient availability to the plant are summarised in Figure 3.10.

Severe problems are caused when soils are so acid that either most Ca has been lost in drainage from the soil, or, the acidic conditions have increased the solubility of previously insoluble aluminium and manganese. The most important biological processes (see overheads that accompany the lecture) that become inhibited are plant root growth (calcium is required for the elongation of new roots, and high concentrations of Al^{3+} ions instead of Ca^{2+} in the soil water stop root growth), infection of clover root nodules by nitrogen fixing bacteria and the activities of bacteria responsible for the turnover and decomposition of plant and animal remains.

In excessively acid soils, one or more of the following effects may be observed.

1. Some plants simply do not grow well at low pH (i.e. they are not adapted).
2. The activities of many of the following soil organisms are reduced:
   Nitrogen-fixing bacteria
   Bacteria that convert ammonium to nitrate
   Organisms that break down organic matter.
3. Elements such as aluminium and manganese become so soluble they are toxic to plant growth.
4. Phosphorus and molybdenum may become insoluble and unavailable.
5. A low pH may indicate low levels of calcium and magnesium present.
6. Various agricultural chemicals, especially certain herbicides and nematicides, are less effective.

You should note that there is no such thing as a "correct pH" because different plants have different pH at which they grow best.

It is stated in point 4 above, that at low pH, phosphorus and molybdenum may become insoluble and unavailable. The implication is that if the pH is increased (by liming) then phosphorus and molybdenum will become more available. It should be noted however, that liming will only increase the amount of plant-available molybdenum on soils which have a reserve of molybdenum. There are some soils in New Zealand (e.g. some highly weathered "gumland" soils of Northland and deep acid peats in the Waikato) that have no reserve molybdenum and hence liming has no effect on the amount of plant-available molybdenum. In such cases molybdenum must be applied as a fertiliser.

Similarly, an increase in the availability of phosphorus can only be expected on soils which have accumulated a reserve (in this case organic phosphorus or inorganic "fixed" phosphorus) of this element. This effect is known to occur to some extent on soils in the Manawatu and Wairarapa regions, but its extent on other soils is not known.

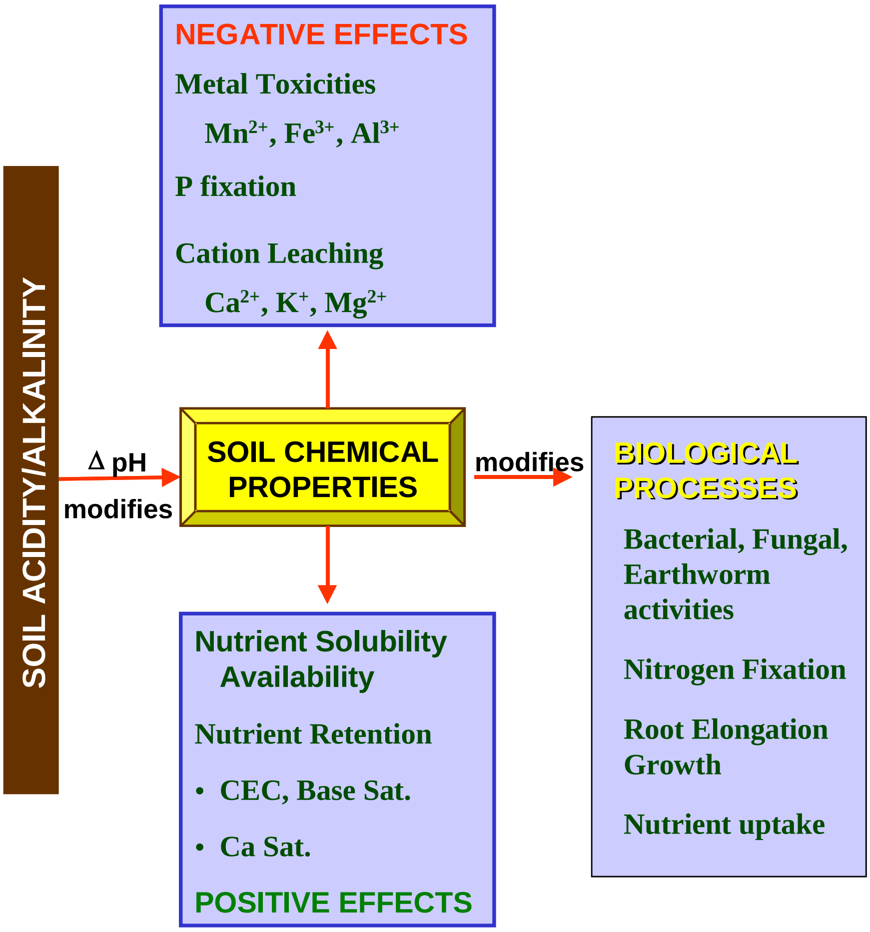


Figure 3.10 The negative and positive effects on soil chemical and biological properties and plant growth caused by changes in soil acidity (pH changes=Δ pH). In general a decrease in soil pH below pH 5 in mineral soils leads to negative effects.

The development of soil acidity in pasture soils is a natural process but is accelerated as inputs and losses of nitrogen increase. It is the process that naturally releases elements from the parent minerals. Most acid is produced by micro-organisms and plants from the transformations of carbon and the nutrient nitrogen. In climates where drainage occurs, most soils will become acidic with time.

Increasing the amounts of carbon and nitrogen used by growing plants, as is done in agricultural production systems, usually leads to accelerated soil acidification. This acid accumulates as exchange acidity (Al^{3+} and H^{+}) on the cation exchange sites on the soil particles (see previous section).

Exchange Acidity

Hydrogen ions will also exchange with nutrient cations held on the negatively charged surfaces of the clay mineral and organic colloid surfaces (see earlier Figure on cation exchange).

As more acidity is produced, more nutrient cations are displaced into soil solution where they are susceptible to leaching. Very acidic soils therefore have their cation exchange sites mostly full with acidic cations H^{+} and Al^{3+}. Such soils are said to have a low ***Base saturation or % BS*** (see Figure 3.5).

Table 3.6 The loose relationship between soil pH in water and base saturation.

Soil pH	% Base saturation (% B.S.)
7	~ 100
6	70
5	30
4	20

At high pH, B.S. (Table 3.6) is high and vice versa.

Optimum soil pH (0-7.5 cm soil depth) for pasture production is 5.8 to 6.1 for mineral soils and 5.0 for organic soils (peat). These pHs represent conditions where little Al^{3+} is on exchange sites and therefore non-toxic to plants.

Measurement of Soil Acidity

To maintain the healthy growth of plants and soil organisms, from time to time lime must be added to neutralise the exchange acidity. To know how much lime is required we must have a method of measuring how acid a soil is. This method is called the pH test. Soils behave like weak acids and in the simplest terms, acidic soils are soils which can donate hydrogen ions to the soil water molecules, forming hydronium ions in the soil water Figure 3.11.

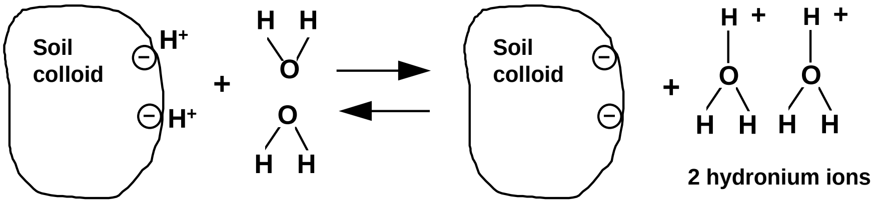


Figure 3.11 A clay or organic matter surface (soil colloid) releasing H^+ ions to form acidic water molecules called hydronium ions.

The more acidic a soil is, the higher the concentration of hydronium ions in the soil water. In the most acidic New Zealand soils the concentration of hydronium ions is at least 10,000 times greater than in the least acidic (or most basic) soils. Because of this enormous range in concentration a logarithmic scale is used to describe acidity. This scale is termed the pH scale.

$$pH = -\log[H^+]$$

Where $[H^+]$ is the concentration of hydronium ions in the soil water.

The key point to grasp is that when acidity is expressed in terms of pH, a scale is obtained on which pH=7 is considered the midpoint. If the pH is less than 7 the solution is said to be acidic. If the pH is greater than 7 the solution is said to be basic. pH 7 is therefore the "neutral point".

The diagram below gives an indication of the degree of acidity, or pH, of a number of common liquids. We observe from this table that virtually all New Zealand soils have pH values between 4 and 8 (Figure 3.12). In fact, the vast majority have pH values between 5.0 and 6.5, i.e. they are slightly acid.

When we talk of "Soil pH" we are referring to the pH we obtain when a sample of soil is stirred with a relatively large volume of water. In New Zealand the test is carried out by mixing 10g of soil with 25mL of distilled water and then measuring the pH - usually with a special electrode and meter.

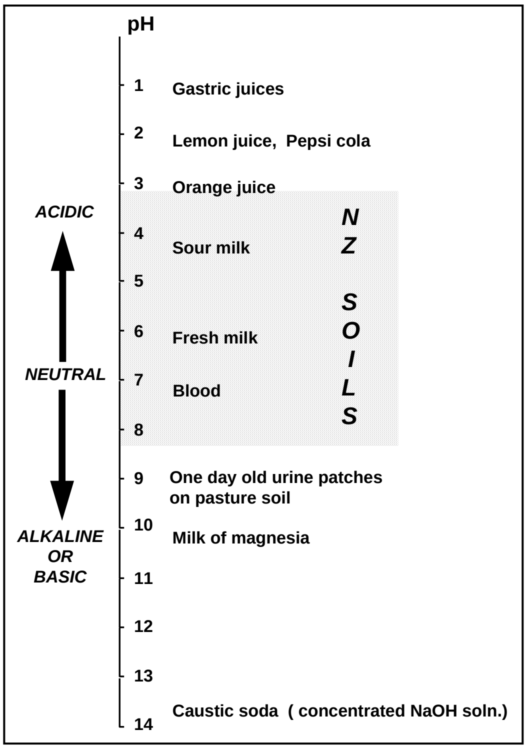
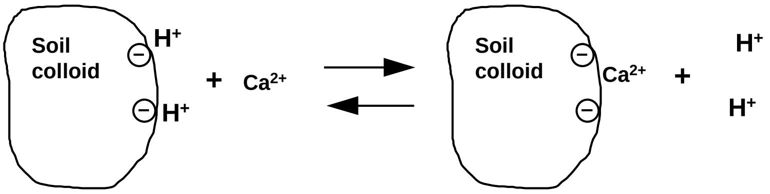


Figure 3.12 The pH scale in relation to common aqueous solutions and the pH range for NZ soils.

Neutralising Soil Acidity

Soil acidity is normally overcome by the addition of lime. The complete reaction for lime ($CaCO_3$) neutralising soil acidity involves two stages.

a) displacement of H^+ ions from the clay colloids by Ca^{2+} ions:



and

b) neutralisation of the H^+ ions by carbonate from the lime to produce water H_2O and CO_2 gas.

$$CO_3^{2-} + 2H^+ \Leftrightarrow H_2O + CO_2$$

Since the CO_2 gas can escape from the reaction site, this series of reactions tends to be driven to the right.

It should be clear from the complete set of reactions above that lime neutralises both H^+ ions in solution and H^+ ions on the soil colloids. This means that to become neutral a soil will use up more $CaCO_3$ than can be calculated from the estimated amount of H^+ ions in the soil solution (i.e. the pH measurement).

This added effect which causes the soil pH measurement to resist change when liming materials are added is called **pH buffering**. The capacity of a soil to buffer its pH (i.e. resist change in soil acidity) depends on how much acidity is held on the soil surface. That is to say it depends on its CEC (see Cation Exchange Capacity notes), which in turn depends on its clay and organic matter content.

A soil will be more buffered if it has fine texture (e.g. a clay loam) and/or high organic matter content, and will consequently require more lime to raise the pH by a certain amount. As a general guide, approximately 3 tonnes/ha of lime ($CaCO_3$) will raise the pH from 5.5 to 6.0 on clays and silt loams derived from sedimentary parent materials and with organic carbon contents of between 4 to 8 %, or, organic matter contents of 8 to 16 %.

Liming Materials

The most common liming material is calcium carbonate. Other materials are listed below and their liming power compared to calcium carbonate is given as the "neutralising value".

Table 3.7 Common Liming materials

Liming Material	Neutralising Value (Calcium carbonate equivalent)
Calcium Carbonate $CaCO_3$	100
Dolomitic Lime $CaMg(CO)_3$	95-108
Calcitic Lime $CaCO_3$	85-100
Baked Sea Shells	80-90
Burnt Lime (Quicklime) CaO	150-175
Hydrated Lime $Ca(OH)_2$	120-135
Basic Slag (also contains P)	50-70
Calcined magnesite (MgO)	200 -240

Recommended Reading

Soil Science, 2nd edition. by R G McLaren and K C Cameron pages. 173-176

Test Your Knowledge – Section 3

Questions

1. What are the two ionic forms of nitrogen taken up by plants? Write down the chemical symbols for them. Which one of them is adsorbed more to the soil clay minerals? Why?

2. Which clay minerals will provide a reserve supply of potassium?

3. Which soil test would you use to indicate the readily-available pool of K in soils?

4. A soil sample was chemically analysed in a laboratory and found to contain the following quantities of exchangeable cations:

Ca^{2+}	10 meq/100 g soil
Mg^{2+}	2 meq/100 g soil
K^+	0.8 meq/100 g soil
Na^+	0.2 meq/100 g soil
Acidic cations (H^+ and Al^{3+})	4 meq/100 g soil

   a. What is the CEC of the soil?

   b. What is the % BS of the soil?

5. A Pallic Soil and an Allophanic Soil have the same amount of total P but the Olsen P test value is lower for Allophanic Soil. Why?

6. Briefly describe the soil components that contribute to a soil having a high % phosphate retention test.

7. Under what soil conditions will a lime application increase the pasture herbage Mo concentration?

8. A clay soil and a sandy soil both had a soil pH of 5. An application of 3 tonne lime/ha increased the sandy soil pH to 5.8 and the clay soil to 5.3. Explain this difference using the terms *buffering* and *pH*.

9. Briefly describe how lime application may influence soil organic matter decomposition. Would you expect an application of lime that increased soil pH from 5 to 6 to have any influence on N and P availability to plants?

10. Arrange the following ions in the order of increasing rate of leaching from soils: nitrate, phosphate, sulphate. Give reasons for your answer.

11. Give reasons why soil organic matter content is important in nutrient availability to plants.

12. What are the optimum pHs for pasture growth in mineral and peat soils? List two negative effects of over liming.

Answers at back of this book.

SECTION 4

4. Introduction to Fertiliser Materials

Key Learning Objectives

After studying this section you should be able to:

1. List the common nitrogen, phosphorus, potassium and sulphur fertilisers used on pasture in New Zealand.
2. Describe the solubility of the above fertilisers.
3. Describe fertilisers that should not be mixed.
4. Calculate the nutrient contents of a fertiliser from the grade label.
5. Calculate the amount of fertiliser required per hectare if the nutrient requirement of a farm or crop is known.

4.1 Basic Introduction to Fertiliser Materials

Fertiliser Grade –the percentage of nutrient elements per unit dry weight

The New Zealand Convention

In New Zealand there is a standard terminology used to refer to the grade of fertiliser (nutrient content of fertilisers). The grade numbers on the label such as 12-10-10 are percentages of element by weight. They are always shown in the order N, P, K, and if needed, S and Mg. So 12-10-10 is a product that contains 12 % N, 10 %P and 10 % K by weight.

For example, 1 tonne (1000 kg) of a product with a grade of 12-10-10 will contain 120 kg of N, 100 kg of P and 100 kg of K. The nutrient content of any fertiliser, liquid or solid, containing more than one element should be checked by referring to the N, P, K, S figures (e.g. 30 % potassic superphosphate has an N P K S rating of 0-6-15- 8, meaning it contains 0 % N, 6 % P, 15 % K and 8 % S).

The Fertiliser and its grade can be registered with The New Zealand Fertiliser Quality Council. A fertiliser that is manufactured to consistent grade specification will receive Fertmark accreditation. Fertmark is an independently assessed fertiliser quality assurance programme hosted by New Zealand Federated Farmers Union.

The USA Convention

In some countries (e.g. USA) however the fertiliser P and K contents are expressed in terms of their oxide content (P_2O_5 and K_2O) instead of the elemental composition. These differences can lead to confusion as the P_2O_5 content is more than twice the elemental P content. Therefore care should be taken in interpreting literature on fertiliser grades from these countries.

Conversion factors to calculate elemental % from oxide % are:

$$\% \, P = \% \, P_2O_5 \times 0.43$$

$$\% \, K = \% \, K_2O \times 0.83$$

4.2 Common Nitrogen Fertilisers

Fertiliser	**Composition (% N-P-K-S)**	**Appearance**	
Ammonium Sulphate $((NH_4)_2SO_4)$	21-0-0-24	White salt, pale greyish green coarse particles	
Manufactured fertiliser, 100 % water soluble; acidifies soil.			
Urea $((NH_2)_2CO)$	46-0-0-0	White salt, white granules	
Manufactured fertiliser, 100 % water soluble; produces alkalinity in soil soon after application but acidifies soil on long-term; hygroscopic; should not be mixed with KCl and superphosphate.			
DAP (Di-Ammonium Phosphate) $((NH_4)_2HPO_4)$	18-20-0-0	Dark greyish green granules or white granules	
DAP (Di-Ammonium Phosphate) $((NH_4)_2HPO_4)$	18-20-0-0	Dark greyish green granules or white granules	
Manufactured fertiliser, 100 % water soluble; produces alkalinity in soil soon after application but acidifies soil on long-term; has contaminants - cadmium and fluorine.			

4.3 Common Phosphorus Fertilisers

Fertiliser	Composition (% N-P-K-S)	Appearance	
RPR (Reactive Phosphate Rock) (Ca_{10} $[PO_4]_5$ (CO_3) $(F,OH)_3$)	0-13-0-0	Light brown sandy powder	
Mined fertiliser, <1 % water soluble but soluble in moist acid (annual rainfalls > 800 mm, soil pH< 5.7) soil over long-term (1 - 4 years); has liming action; has contaminants - cadmium and fluorine.			
SSP (Single Superphosphate) ($Ca_5[H_2PO_4]_2(SO_4)(F)$)	0-9-0-12	Small to large white granules and powder	
Manufactured fertiliser, 50 % P and 100 % S soluble in water; fertiliser is slightly acidic but does not acidify soil; has contaminants - cadmium and fluorine.			
TSP (Triple Superphosphate) ($Ca_3[H_2PO_4]_2$ (F) plus trace (SO_4))	0-21-0-1	Small greyish green granules	
Manufactured fertiliser, 100 % water soluble; fertiliser is slightly acidic but does not acidify soil; has contaminants - cadmium and fluorine.			

4.4 Common Potassium Fertilisers

<table>
<tr><th>Fertiliser</th><th>Composition
(% N-P-K-S)</th><th colspan="2">Appearance</th></tr>
<tr><td>Potassium Chloride
(KCl)</td><td>0-0-50-0</td><td>Red or sometimes white crystals</td><td></td></tr>
<tr><td colspan="4">Mined fertiliser, 100 % water soluble.</td></tr>
<tr><td>Potassium Sulphate
(K_2SO_4)</td><td>0-0-42-18</td><td>White crystals</td><td></td></tr>
<tr><td colspan="4">Manufactured or recovered from natural brines, 100 % water soluble.</td></tr>
</table>

4.5 Common Sulphur Fertilisers

<table>
<tr><th>Fertiliser</th><th>Composition
(% N-P-K-S)</th><th colspan="2">Appearance</th></tr>
<tr><td>Elemental Sulphur
(S^0)</td><td>0-0-0-100</td><td>Yellow crystals or fine powder</td><td></td></tr>
<tr><td colspan="4">Mined fertiliser or recovered from oil refineries, insoluble in water; converts to soluble sulphate by soil micro-organisms; acidifies soil.</td></tr>
<tr><td>Maxi Sulphur / Superphosphate 50 S
($Ca_5[H_2PO_4]_2(SO_4)(F)$)
Plus S^0</td><td>0-5-0-50</td><td>Powdery white granules flecked with yellow crystals</td><td></td></tr>
<tr><td colspan="4">Manufactured fertiliser, behaves like elemental sulphur and superphosphate; acidifies soil due to elemental S oxidation by soil microorganisms; has contaminants - cadmium and fluorine; has both slow and fast release sulphur to plants.</td></tr>
</table>

Calculating fertiliser application rates

Phosphorus and sulphur example

A consultant, using Overseer software, has estimated that the maintenance P and S requirement of a dairy farm on Pallic soils is 27 kg P/ha and 30 kg S/ha. Knowing his fertiliser materials he chooses single superphosphate (0-9-0-12) to supply both P and S. Because P is the more costly element his rate calculation begins in converting the rate per hectare of P to a weight per hectare of single superphosphate that should be applied by spreader.

P required = 27 kg P/ha

Single Superphosphate (SSP) at (0-9-0-12) contains 9 kg P/100 kg of SSP.

Therefore:
Rate of SSP required per hectare (kg) = 27 kg P required per ha x (100 kg SSP/ 9 kg P)
= 27 x (100 / 9)
= 300 kg SSP/ha

The 300 kg SSP/ha at (0-9-0-12) contains 12 % by weight S.

Therefore:
Rate of S supplied per hectare (kg) = 300 kg P SSP per ha x (12 kg S/100 kg SSP)
= 300 x (12/100)
= 36 kg S/ha

Therefore by using superphosphate at 300 kg SSP/ha the consultant can meet the P maintenance requirement accurately but supplies 6 kg S/ha (required 30 kg S supplied 36 kgS) more than that required.

It is often the case with fertiliser materials that the multi-nutrient requirements of crops or pasture per hectare cannot exactly be met using common fertilisers.

More information on how to calculate the plant-available nutrient content of the fertiliser is presented in higher level courses.

Nitrogen example

For each nutrient there are many sources of fertilisers available in the market to choose from. The choice depends on the fertiliser most suitable for the soil, climate, topography, farm condition, other nutrients present in the fertiliser and the cost of fertiliser per unit weight of the nutrient. The following example illustrates the difference in the cost of two nitrogen fertilisers, urea and ammonium sulphate for supplying a unit weight of nitrogen.

1 tonne (1000 kg) of urea costs $490.

The grade of urea is 46-0-0-0; i.e. 46 % N or 46 kg N/100kg Urea.

Therefore 1 tonne (1000 kg) of urea contains 460 kg N, which costs $490.

Therefore for urea 1kg N costs $490/460 kg N = $1.07/ kg N.

1 tonne of ammonium sulphate (AMSULPH) costs $380.

The grade of ammonium sulphate is 21-0-0-24. i.e. 21 % N or 21 kg N/100 kg AMSULPH.

Therefore 1 tonne (1000 kg) of AMSULPH contains 210 kg N, which costs $380.

Therefore for ammonium sulphate 1 kg N costs $380/210 = $1.81/ kg N

Therefore urea is cheaper in supplying N. But it should be noted that ammonium sulphate also contains another nutrient, sulphur which was not considered in this cost comparison.

Fertiliser mixtures

The supply of multiple nutrients can be achieved through use of compound fertilisers, or through the use of blends or mixtures. Compound and blended fertilisers are proprietary products that take account of problems of compatibility of fertilisers. Mixing fertilisers may result in poor handling characteristics, inaccurate spreading, and reduced agronomic performance. Before preparing any mixtures, users should ensure that the products to be mixed are physically and chemically compatible.

Physical compatibility

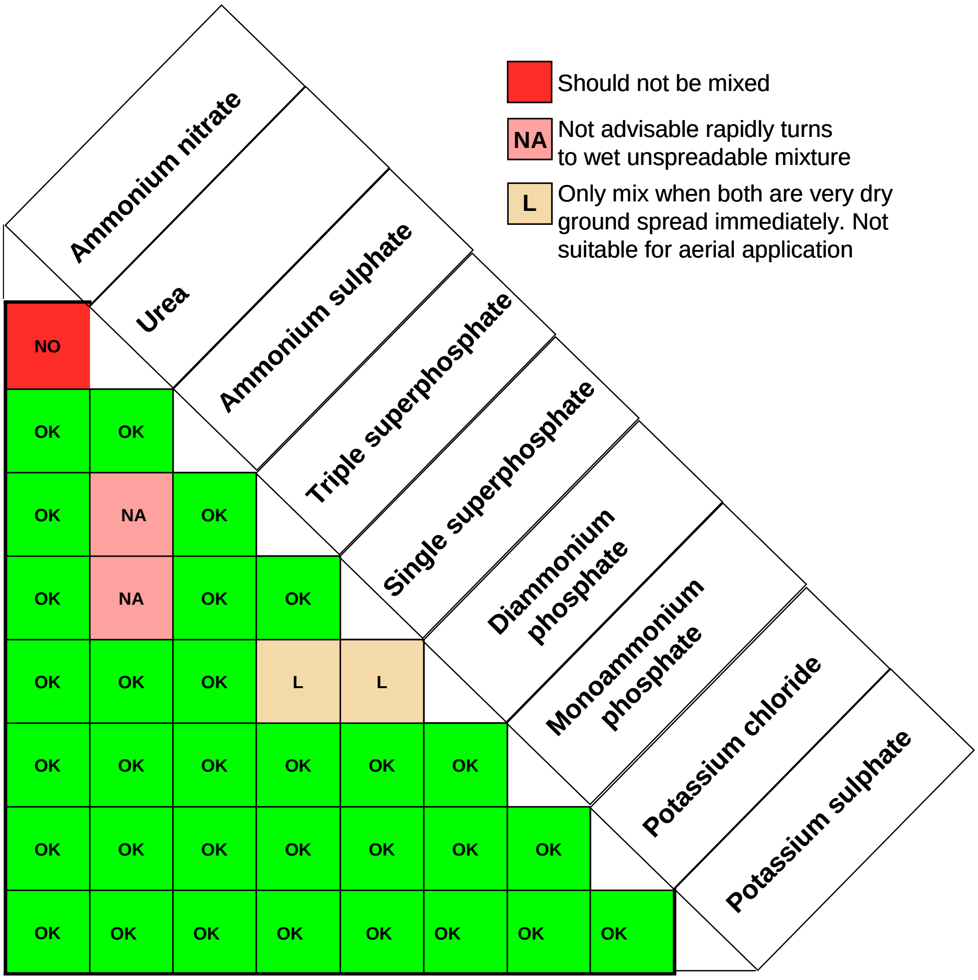
When two fertilisers with different particle size ranges are mixed, segregation of the two fertilisers in the mixture will occur. The wider the range in particle sizes, the greater will be the segregation. For, best results, there should be no more than 10 % divergence in particle size between component fertilisers in a mixture.

Chemical compatibility

Generally, fertilisers are chemically compatible in that no explosive or toxic mixtures are produced, but chemical reactions can occur which will cause handling problems. Some fertilisers, when mixed, absorb moisture and may react with other fertilisers in the mixtures resulting in caking and formation of large lumps. When large lumps are formed they cannot be spread and more importantly they create a life threatening hazard to aerial topdressing pilots who are unable to jettison a load.

The compatibility of fertilisers for mixing in blends is shown in Figure 4.1.

Trace elements salts are usually mixed with superphosphate fertiliser, e.g. molybdenum, cobalt and copper.



🟥 Should not be mixed

NA Not advisable rapidly turns to wet unspreadable mixture

L Only mix when both are very dry ground spread immediately. Not suitable for aerial application

	Ammonium nitrate	Urea	Ammonium sulphate	Triple superphosphate	Single superphosphate	Diammonium phosphate	Monoammonium phosphate	Potassium chloride
Urea	NO							
Ammonium sulphate	OK	OK						
Triple superphosphate	OK	NA	OK					
Single superphosphate	OK	NA	OK	OK				
Diammonium phosphate	OK	OK	OK	L	L			
Monoammonium phosphate	OK	OK	OK	OK	OK	OK		
Potassium chloride	OK	OK	OK	OK	OK	OK	OK	
Potassium sulphate	OK	OK	OK	OK	OK	OK	OK	OK

Figure 4.1 Chemical compatibility of mixing fertiliser materials.

References

During C (1984) Fertilisers and soils in New Zealand farming. P. D. Hasselberg, Government Printer, Wellington, New Zealand.

McLaren RC, Cameron KC (1996) Soil Science, Sustainable production and environmental protection. Oxford University Press New Zealand, Auckland

Test Your Knowledge – Section 4

Questions

1. A farmer has asked you to provide him with a mixture of fertiliser materials to supply 67 kg N, 45 kg P, 45 kg K, 30 kg S per ha as a pre-plant broadcast fertiliser to be incorporated into the seed bed of a 10 ha fodder turnip crop.
   a. List fertiliser materials that can be used to make a safe, spreadable mixture that will supply N, P, K, S to be released rapidly to the seed bed soils.
   b. List some materials that could be used but would have to be spread separately.
   c. Calculate the amounts (in kgs) of DAP, AMSULP and KCl that would be required to meet the needs of the preplant fertiliser required for the 10ha.
2. Consider the solubilities of all phosphate carrying fertilisers (include DAP). Explain why plants are able to utilise the phosphorus in DAP and SSP quicker than that in RPR. Under what soil conditions can RPR be an effective P fertiliser?
3. What soil conditions will enhance the release of plant available sulphate from elemental sulphur fertiliser?
4. If Triple superphosphate costs $470/tonne and single superphosphate costs $188/tonne. Which fertiliser is cheaper to use if the farm is deficient in both phosphorus and sulphur?

Answers at back of this book.

SECTION 5

5. Introduction to Soil Physical Properties

Key Learning Objectives

After studying this section, you should be able to:

1. Explain what is meant by the term 'soil texture' and describe the fundamental place of soil texture in the understanding of soil properties and processes.
2. Explain what is meant by the term 'soil structure' and describe the effects that soil structure has on other soil properties and plant growth.
3. Describe how management practices modify structure.
4. Explain what is meant by the term 'soil consistence'.
5. Describe basic concepts of water storage and movement in soils.
6. Describe the terms commonly used to describe soil water.
7. Explain the fundamentals of the hydrological cycle and the soil water balance and their importance.

5.1 Soil Texture

What is soil texture?

Soil texture is the particle size distribution of the solid inorganic or mineral part of the soil i.e. the proportion of sand, silt and clay in a soil. Texture normally refers to the particles less than 2 mm in diameter.

Mineral components (clay, silt and sand) are given the following size divisions in New Zealand (Milne et al. 1991):

Clay - < 0.002 mm in diameter

Silt - 0.002 to 0.06 mm in diameter

Sand - 0.06 to 2.00 mm diameter.

Particles that are larger than 2 mm in diameter, and organic matter are usually omitted from textural names unless they are present in sufficient quantity to affect soil behaviour. In this case, they will be incorporated in the textural class name. For example, a soil with a large quantity of gravel might be named a gravelly sandy loam. Soils with large quantities of organic matter are called peats or humic soils.

As you can see from the above size categories, clay is much smaller than either silt or sand particles. In terms of relative size, a clay particle is like a bus ticket on a football field. This size difference is an important point – one that helps explain a great deal of the differences in soil behaviour, and one that will be constantly referred to throughout the course.

Soils are given a textural name (e.g. Tokomaru silt loam) according to the relative amounts of sand, silt and clay present. That is, the textural name tells us which component most influences a soil's characteristics and behaviour. For example, if a soil is most influenced by the sand fraction then it is likely to be called a sandy soil (e.g. Himatangi sand). If no particular fraction dominates then the soil is called a loam. However, clays, silts and sands and intergrades between these - sandy loams, clay loams and silt loams - are more common in New Zealand. Sandy soils are sometimes referred to as coarse textured soils while clay soils are designated as fine textured soils. In the vernacular, these soils may be referred to as light and heavy soils, respectfully. While widely understood, these latter terms are misleading if they are taken to convey something about the relative mass or density of these soils. Rather, in this context, the terms light and heavy to the relative ease of cultivation (more about this later).

What soil properties does texture affect?

Texture will obviously determine or influence the way a soil behaves: there will be numerous examples of this throughout the course. Below are some key examples of soil properties that are directly related to soil texture (many of these examples will be discussed in more detail later on).

(a) Water movement –
Water tends to move much more quickly through coarse textured soils than it does through fine textured soils.

(b) Aeration –
Fine textured soils are often poorly drained and have poor aeration.

(c) Water retention –
Plants growing in sandy soils are often at risk due to dry or drought conditions.

(d) Nutrient availability –
Sandy soils often have relatively small reserves of some key plant nutrients.

(e) Ease of tillage –
Clay soils are often difficult to cultivate (heavy) both in terms of the number of field operations required to prepare a seedbed, and the need to carefully time this field work.

(f) Susceptibility to compaction –
Intermediate and fine textured soils are prone to soil compaction.

(g) Erosion –

Soil particles that do not cohere well are at risk to erosion by wind and water.

Soils of intermediate texture e.g. soils containing 15 – 30 % clay, 15 – 30 % silt and 40 – 55 % sand (loams, sandy clay loams and sandy loams) will usually present relatively few problems for cultivation, drainage or availability of water and nutrients.

5.2 Soil Structure

What is soil structure?

Soil texture indicates the predominant particle size, but says little about how the particles are arranged relative to each other, or how strongly they are held together. These facets are described by soil structure.

One definition of soil structure is:

"the arrangement and organisation of soil particles into aggregates (or peds) ***and*** *the stability of such arrangements to stress."*

Some common soil structure units are illustrated n Figure 1.

What is soil consistence?

Soil consistence is often discussed alongside structure. Consistence is the resistance to deformation or rupture, and is dependent on the water content of the soil i.e. the wetter the soil, the less strength it has, and the more easily it is deformed. Above a certain water content, called the plastic limit, instead of being friable and crumbling when a force is applied, the soil deforms plastically i.e. acts like plasticine. Clearly, it is important that farmers confine cultivation to periods when the soil is less then (i.e. drier) than the plastic limit. Generally, the more humus a soil contains then the greater its water content at the plastic limit. Again, there is a protocol for determining soil consistence by hand (not discussed here).

Figure 5.1 Some soil structural units. Top left; small, nutty aggregates. This is the type of aggregates that is found in well-structured soils. Top right; massive structure. There is essentially no structure. This lack of structure is observed in soils that have been structurally damaged by, for example, pugging. Bottom left; large, columnar aggregate. This is the type of structure found in the subsoil of Pallic soils. These large aggregates expand and fit very tightly together when the soil is wet and are impermeable to water. Bottom right; platy structure. This is the structure found in very clayey soils. It will impede water and root movement.

What soil properties does structure affect?

The structure of a soil has a profound influence on numerous characteristics, including the following.

- The rate of water entry and movement through the soil profile, including drainage.

- Water storage or retention.

- Aeration – by improving drainage, good structure facilitates oxygen movement.

- Root penetration (improved structure makes it easier for root growth, and so increases the volume of soil that the roots can explore for water and nutrients).

- The susceptibility to, and extent of, wind and water erosion.

- Susceptibility to the formation of crusts at the soil surface (caused by: raindrops, machines, animals).

If structure affects the above properties then it may also affect the productive potential of the soil, the profitability of the production system and ultimately the sustainability of the land use. Interestingly, when it is said that a land use is “unsustainable”, this often means that soil structure is being degraded to the point where it precludes the current land use.

What are the best management practices for soil structure?

Management is very important when it comes to maintaining or improving soil structure. The management of structure is an interesting and involved topic –all we have the space to do here is identify the main objectives of some ‘best’ management practices including:

- Cultivate at the correct water content.

- Don’t over cultivate and physically destroy soil structure.

- Use minimum tillage / direct drilling where appropriate.

- Retain crop residues to return organic matter and add nutrients.

- Minimise the time that the soil surface is bare.

- Grow perennial pastures regularly in the crop rotation. Pasture left to grow for three to four years is beneficial for soil structure because it obviously, spells the soil from cultivation, adds organic matter, increases the level of nitrogen (due to the presence of clover), and assists structure formation by the activity of a fibrous root system and an associated build up of soil organisms.

- Add lime if required to increase pH and enhance soil organism activity.

- Avoid heavy traffic and stock when the soil is wet.

- Install artificial drainage systems in poorly drained soils.

5.3 Soil Water

How does water move through soil?

The adhesive and cohesive behaviour of water molecules mean that flowing water is quite viscous or sticky. If you could see it, water movement in the smaller macropores would look a bit like honey moving very slowly though a narrow tube. In the soil micro-pores the movement of water is so slow that it is negligible. While they can store water, they are effectively non-conductive. For example, a single smallish macro-pore 0.1 mm in diameter (about the smallest pore you can see with the naked eye) will conduct as much water as 10 000 largish micro-pores 0.01 mm in diameter, given the same driving force.

Thus it is the number of macropores, and their diameter and continuity that determine how well a soil can conduct water (and not the total porosity). A soil may have a relatively low porosity but if it contains large pores, it will convey water very quickly when saturated.

What terms are commonly used to discuss soil water?

Saturation

A soil is said to be saturated when all the pores are full of water i.e. all the air has been displaced – this is common in winter and spring immediately after heavy rainfall. The volumetric water content then equals the porosity.

Field capacity (FC)

Field capacity is defined, somewhat imprecisely, as the water content of the soil after excess water has drained away. This drainage has usually occurred two or three days after heavy rain or irrigation in free-draining soils. At field capacity the macropores have drained and are air-filled, but the smaller micropores are still water-filled. Further drainage is so slow as to be negligible, due to the micropores being effectively non-conductive, as discussed above. Field capacity represents the upper limit of plant-available water.

Stress point (SP)

The drier a soil is relative to field capacity, the greater the force that plants must exert to extract water. If the soil dries to a point where the roots cannot extract water at the rate demanded by the leaves, then the stomata will close and the plant will be under ‘stress’. Growth rate (or other aspects of plant performance) may be reduced by this water shortage.

Permanent wilting point (PWP)

PWP is the water content in the soil when the plants have extracted all the water that they are capable of taking from the soil.

Available water storage capacity (RA and TA)

While the distinction is not clear-cut, it is useful to consider two plant-available water storage capacities, the readily available (RA) and the total available (TA). The readily available water storage capacity (W_{RA}) is the equivalent depth of water held in the root zone between field capacity and stress point. In uniform soil:

$$W_{\mathrm{RA}} = (\theta_{\mathrm{FC}} - \theta_{\mathrm{SP}})z$$

where θ_{FC} and θ_{SP} are the volumetric water contents (the volume of water in a unit volume of soil) at field capacity and stress point respectively, and z is the effective rooting depth. W_{RA} depends on both the soil properties and the rooting depth. A typical W_{RA} value for pasture would be around 60 mm. But for shallow-rooted turf on sand W_{RA} might be only 10 mm, while it could be over 500 mm for an established pine forest on a pumice soil.

The total available water storage capacity (W_{TA}) is the equivalent depth of water held in the root zone between field capacity and permanent wilting point. In uniform soil:

$$W_{\mathrm{TA}} = (\theta_{\mathrm{FC}} - \theta_{\mathrm{PWP}})z$$

where θ_{PWP} is the volumetric water content at permanent wilting point. Often W_{TA} is about twice or three times WRA.

Infiltration rate, hydraulic conductivity and drainage rate

These three terms describe the speed that water enters the profile (infiltration), moves through the soil (hydraulic conductivity) and exits the soil (drainage). Because water-filled macropores can transmit water much more quickly than smaller pores, the hydraulic conductivity varies with the soil moisture content. When the soil is saturated, the rate that water moves through it is determined by the saturated hydraulic conductivity. The value of the saturated hydraulic conductivity depends on the number, size and continuity of macropores. The saturated hydraulic conductivity is often used to quantify the extent of drainage and aeration problems and in the design of artificial drainage systems.

As stated previously, soil structure affects the rate water moves through and drains from soil. Figure 5.2, an illustration of the relationship between some common aggregate forms and permeability recapitulates some of these points.

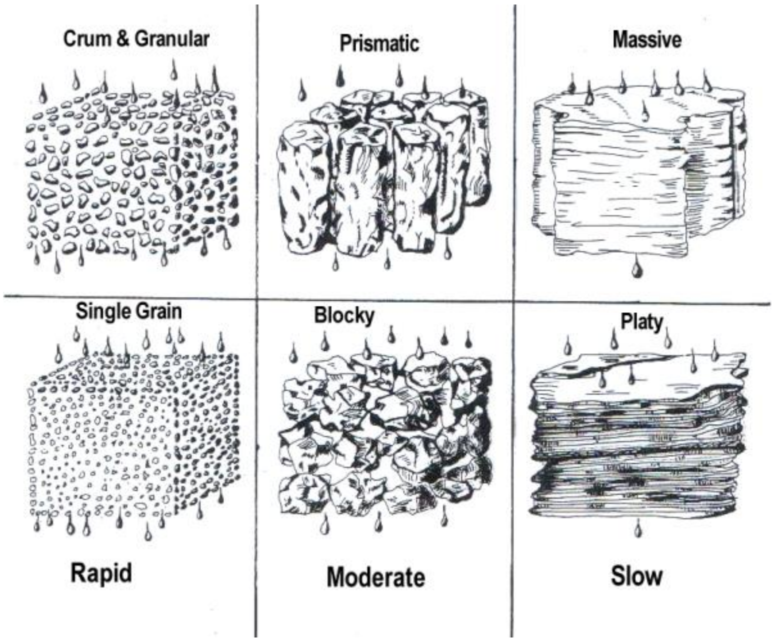


Figure 5.2 Effect of structure on infiltration and hydraulic conductivity (after Bowler, 1980).

The hydrological cycle

The soil plays a key role in determining the fate of water in the environment. Its ability to soak up rain, and to store plant-available water (as discussed above), keeps plants alive and growing between rainfall events. Thus the soil is given a pivotal place in most schematic diagrams of the hydrological cycle – see Figure 5.3 for an example. When the rate of rainfall exceeds the soil's infiltration rate, surface runoff will occur. When the soil gets wetter than field capacity, deep drainage will occur.

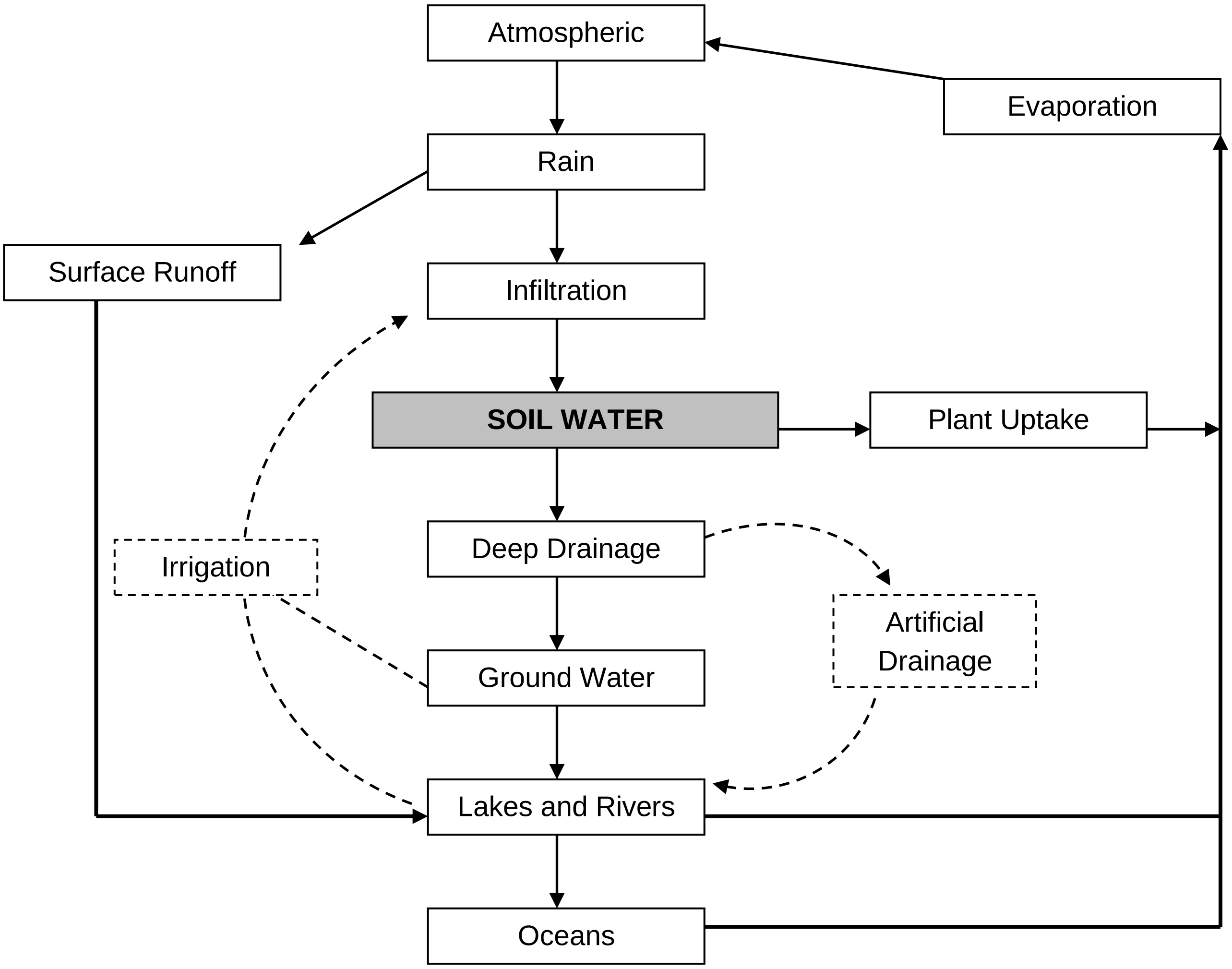


Figure 5.3 A simplified diagram of the hydrological cycle.

Rainfall

Rainfall or precipitation is the key soil water input. Relative to many countries, in New Zealand rainfall is plentiful and reliable, but as you will be aware, it is still highly variable in space and time. What causes this variation?

Air masses moving onto New Zealand from the ocean are moist. The warmer air is, the more water vapour it can carry. Thus cool air can carry less water vapour than warm air; the amount about halves when the air temperature drops 10°C. Thus cooling air leads to condensation, cloud (i.e. water drop) formation, and often rain.

But what causes air to cool? As air rises it cools. Air pressure decreases with altitude, so rising air expands and cools (like air coming out of a bike tyre) by about 1°C per 100 m rise.

But what causes rising air, leading to condensation, cloud and rain? One mechanism is mountains in the pathway of moving air. For example, prevailing westerly winds and the

Southern Alps combine to make the West Coast a much wetter place than Central Otago. This is illustrated in Figure 5.4, which shows the average monthly rainfall at Palmerston North, Alexandra and Hokitika.

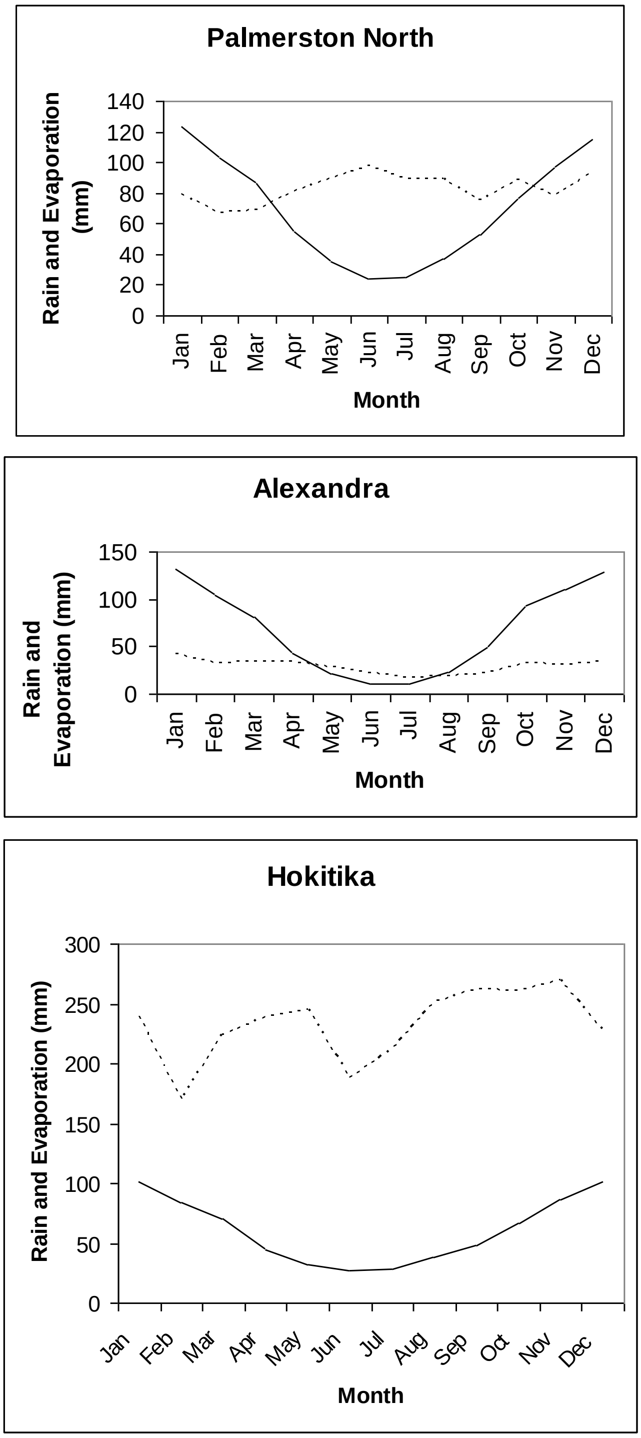


Figure 5.4 Average reference crop evaporation (solid lines) and monthly rainfall (broken lines) at Palmerston North, Alexandra and Hokitika.

As you will be aware from the TV or newspaper weather reports, the day-to-day presence or absence of rainfall is related to the atmospheric circulation. The spinning of the earth and the hot equator and cold polar regions cause winds and high and low pressure cells to develop. The air spirals in towards a low-pressure location and is forced upwards as it nears the centre, as it has nowhere else to go. Thus, low-pressure cells, or depressions, tend to be associated with rising air, causing cooling, condensation, cloud and rain. Conversely, air tends to subside to replace the air spirally out from high-pressure cells or anticyclones. These regions are usually associated with fine weather. Also at the fronts separating warmer and colder air, wind forces either the warmer air up over the cooler air, or wedges the cooler air under the warm air. Either way, there is rising air associated with a front, and often rain as well.

Evaporation

Often the largest pathway for water moving out of the soil is plant uptake and evaporation (sometimes called evapotranspiration). A large energy input is needed for evaporation. Unless the soil is drier than stress point, for vegetation-covered soil it is the available energy supply that determines the evaporation rate. This energy supply is determined largely by weather variables such as the amount of sunshine and the air temperature. As the evaporation varies somewhat with vegetation type, it is useful to define the reference crop evaporation as the evaporation from a large area of short green actively growing vegetation that is not short of water. Pasture in New Zealand fits this definition a lot of the time.

The reference crop evaporation rate, which we denote E_O, can be estimated solely from weather data. Average monthly E_O values for Palmerston North, Alexandra and Hokitika are shown in Figure 5.4. Notice that the E_O values at the three sites are reasonably similar, with values of around 120 mm or 4 mm/day for January, 20 mm or 1 mm/day for July and 75 mm or 2.5 mm/day for October. While an average summer value in New Zealand is 4 mm/day, 6 mm of evaporation may occur on a sunny summer’s day, but only 2 mm on a cloudy day.

Of course if the root zone is drier than stress point, the actual evaporation rate will be lower than E_O.

The soil water balance equation

It is possible to quantitatively track the major daily inputs and outputs of water to and from the soil using the soil water balance equation. This is, or should be, common practice where irrigation is used. The procedure is analogous to that used to balance a chequebook. The basic equation is:

$$W_n = W_{n-1} + P + I - E - R - D - S$$

where:

W_n is the water stored in the root zone at the end of day n,
W_{n-1} is the water stored at the end of the preceding day,
P is the daily rainfall,
I is any irrigation applied,
E is the evaporation,
R is any water moving below the root zone to recharge the groundwater,
D is any flow out of artificial drains, and
S is any surface runoff of rain or irrigation.

The unit for all these variables is mm (i.e. equivalent depth). There are obvious limits to W, as the root zone can only temporarily be wetter than field capacity, and cannot get drier than permanent wilting point. Also R, D, and S, can usually be taken as zero for permeable soils that are drier than field capacity. Then above equation reduces to:

$$W_n = W_{n-1} + P + I - E$$

and the water required for irrigation can be estimated by matching inputs with losses so:

$$I = E - P$$

Construction of a soil water balance is not the only or necessarily the best way to schedule irrigation. Its utility lies in the fact that its computation requires only two readily available parameters, P and E, and an assumed value for W_{RA}. An irrigator can, and should, measure daily rainfall. E is often assumed equal to E_O, values for which are given in some newspapers. Failing that, long-term average E_O values for the month and location of interest, such as those in Figure 5.4 can be used, or if pan evaporation data are available, E_O can be estimated as 80 % of the pan values.

References and Recommended Readings:

McLaren, R. G. and Cameron K. C. (1996). Soil Science – Sustainable production and environmental protection (2nd ed). Oxford University Press.

Bowler, D.G. (1980). The Drainage of Wet Soils. Hodder and Stoughton. p.29.

White, R.E. (1987). Introduction to the principles and practise of soil science. Blackwell: Oxford. p.56.

Test Your Knowledge – Section 5

Questions

1. What are some steps that might be taken to improve damaged soil structure in a paddock on a dairy farm?

2. What are some management options that might be employed to prevent treading damage on dairy farms?

3. What are the available water holding capacities of the pasture soils that you commonly encounter?

4. What would be typical evaporation rates on a July and February day in the region that you live in?

5. If a soil was able to store 60 mm of readily available water then how long would this water last if the evaporation rate was 5 mm/day?

6. What volume of water (m^3) would drain (per hectare) if 30 mm of rain fell on a soil that was at field capacity? Remember there are 10,000 m^2 per ha and 1 mm of rain is a depth of 0.001 m.

Answers at back of this book.

Test Your Knowledge--

- Answers--

Test Your Knowledge – Section 1 Answers

1. The return of phosphorus in cow dung is an internal transfer but as the cow can deposit some dung in raceways, gateways and yards it can also constitute a transfer loss from the grazing area. Transfer losses need replacing with maintenance nutrient inputs.

2. a. Incorrect; not an environmental risk.
   b. Below the optimum target level for pasture growth on Allophanic soils.
   c. A paddock that may need a capital input of P fertiliser.

3. Immobilisation of nutrients in soil and transfer losses of nutrients make up a component of the P losses used to calculate a maintenance fertiliser requirement.

4. The Olsen P, Soil test K, and Sulphate-S soil tests are useful for indicating the plant supply of nutrients in soils.

5. There is no useful N soil test because topsoil nitrate concentrations are always low. Also, because, plant competition for nitrate uptake is high and soils do not have the ability to hold nitrate (the form of N most commonly taken up by pasture plants) and it is easily lost as water drains through the soil.

6. Cows recycle nitrogen from ingested grass rapidly but it falls as excreta on only 2-3 % of the grazing area. Therefore 2-3 % of the grazing area has high N load from excreta, which exceeds the amount of N that can be taken up by pasture growth before the next drainage season. Surplus N not taken up by the pasture will be leached as nitrate because soils do not have the capacity to hold nitrate.

Test Your Knowledge – Section 2 Answers

1. **Location**

   The Watkins farm (60 ha) is located 6 km North of Palmerston North, Manawatu.

   Landscape, Parent materials and soil types

   A flat to undulating landscape (< 10^0 slope), where the parent material of soils has been Recent alluvium from the Manawatu River. Only during infrequent large floods is fresh alluvium deposited. The dominant soil group on the farm is Recent Soils, the soil types are Manawatu fine sandy loam, a well-drained soil and Manawatu silt loam, a well to moderately drained soil.

   Climate

   The long-term average rainfall is 900 mm yr^{-1}, which can be evenly spread over all months. Any month, however, can receive as little as 7-25 mm and as much as 140-225 mm. There is normally a rainfall deficit in summer and autumn, and a large surplus in winter.

   Soil Fertility

   These soils have low % P retention (anion sorption capacity), and can have low organic matter content but have adequate supplies of potassium. Sulphur becomes limiting with intensive farming.

2. All soils are cultivatable in the flat to undulating landscape (< 10^0 slope) and require no additional drainage systems. Irrigation may be required for intensive crop or grass production in summer months.

   These low % P retention soils require low to moderate rates of P and S fertiliser to raise soil fertility in comparison with high P retaining Allophanic soils. Potassium fertilisers are unlikely to be required for many decades.

3. In order of increasing % P retention the soils would be Recent soils < = Pallic Soils < Brown Soils < = Pumice Soils < Allophanic Soils.

4. The Olsen P test is required to be raised to 25 from 18, an increase of 7 units (mg P/L soil).

   To raise the test one unit in the 0-75 mm soil depth takes 4 -7 kg P/ha applied as soluble P fertiliser.

   Therefore to increase the Olsen P test by 7 units, 28 – 49 kg P/ha are required.

   Super phosphate (0-9-0-12) contains 90 kg P/tonne.

   Therefore between 0.311 and 0.544 tonnes/ha (311 kg – 544 kg/ha) of superphosphate are required per hectare to raise the Olsen P test from 18 to 25 mg P/L soil.

Test Your Knowledge – Section 3 Answers

1. NH_4^+ and NO_3^-. NH_4^+ is adsorbed more to the clay minerals because most clay minerals carry negative charges on their surfaces at normal soil pHs and therefore they adsorb the oppositely charged cations. Therefore more of the cationic NH_4^+ is adsorbed than the NO_3^- anions.

2. A reserve supply of potassium is present in partly weathered mica clay (illites) and feldspars, but is not supplied by more strongly weathered clays such as vermiculite.

3. Exchangeable cation test.

4. CEC = 10 + 2 + 0.8 + 0.2 + 4 = 17 meq/100 g soil

   % BS = (10 + 2 + 0.8 + 0.2)/17 = 76 %

5. Allophanic soils have much higher P fixation (90-100 % P retention) than Pallic Soils (10-20 % P retention). Therefore, despite the same total P content in the two soils the plant available P pool as measured by the Olsen test is lower in the Allophanic Soil.

6. Iron and aluminium oxide surfaces on fine particles of soil, and particularly the clay allophane, found in volcanic soils (Allophanic soils).

7. Mo availability to pasture will increase if the soil has a high Mo reserve adsorbed on soil surfaces that was prevented from release to plants through low soil pH.

8. The Sandy soil would have a greater pH increase after liming because this soil has a lower pH buffering capacity.

9. At pH 5 there is lower biological activity to break down the soil organic matter. Liming increases the activity of the decomposer organisms (earthworms and microorganisms). It is expected that raising the pH will cause more decomposition that will release N and P stored in soil organic matter. In addition, in some soils P availability is low at pH 5 because there is higher P fixation at lower pH. Raising the pH reduces P fixation.

10. Order of increasing rate of leaching: phosphate < sulphate < nitrate. This is the reverse order of the strength of adsorption to soils.

11. Organic matter has many nutrient elements in its structure (e.g. N, P, S) and when it is decomposed it releases these nutrients. Also, organic matter has surface negative charges and therefore it contributes to CEC. The higher the CEC and base saturation, the higher the plant available cationic nutrients and less leaching losses.

12. Optimum pH for pasture in a mineral soil is 5.8-6.1; in peat soil 5.0. Too much lime (over liming) may cause deficiency of many trace element metallic nutrients (copper, zinc, cobalt due to precipitation) and phosphorus (due to calcium phosphate precipitation).

Test Your Knowledge – Section 4 Answers

1. a. DAP, ammonium sulphate and KCl.

   Another combination of fertilisers is MAP, Single superphosphate, KCl and ammonium nitrate.

   b. Urea, KCl, single superphosphate and DAP.

   c. 10 ha seed bed requires 670 kg N, 450 kg P, 450 kg K and 300 kg S.

   Possible fertilisers that would supply these nutrients are: KCl, ammonium sulphate and DAP.

   450 kg K can be supplied by 100/50 x 450 kg KCl (KCl has 50 % K) = 900 kg KCl

   300 kg S can be supplied by 100/24 x 300 kg Ammonium sulphate (Amm Sul has 24 % S) = 1250 kg Ammonium sulphate

   450 kg P can be supplied by 100/20 x 450 kg DAP (DAP has 20 % P) = 2250 kg DAP

   <u>Amount of N coming from ammonium sulphate (21 % N) and DAP (18 % N)</u>

   N from 1250 kg Ammonium sulphate = 1250 x 21/100 kg N = 263 kg

   N from 2250 kg DAP = 2250 x 18/100 kg N = 405 kg N

   Total N coming from ammonium sulphate and DAP = 668 kg which is approximately the amount of N required for the seed bed.

   Therefore the amounts of fertilisers required for 10 ha seed bed are 900 kg KCl, 1250 kg ammonium sulphate and 2250 kg DAP

2. Phosphate solubility in DAP and SSP is ≥ 50 %. Phosphate solubility in RPR is < 1 %. Therefore plants are able to utilise P from DAP and SSP quicker than that in RPR.
   RPR is an effective P fertiliser in acidic (pH < 6) and moist soils (good rainfall spread throughout the growing period).

3. Elemental S needs to be oxidised to plant available sulphate form in soil for plant to utilise S. This oxidation is carried out by elemental S oxidising bacteria in soil. Increase in temperature and moisture increases the activity of these bacteria and therefore the rate of this oxidation. However extremely high temperature and moisture (less aeration) in soil will reduce the activity of these bacteria and therefore the rate of oxidation.

4. 1 tonne of TSP has 21/100 x 1000 kg P= 210 kg P (TSP has 21 % P).Therefore the cost of P in TSP is $470/210/kg P= $2.23/kg P.

   Similarly the cost of P in SSP = $188/90/kg P = $2.09/kg P

   Therefore the cost of unit weight of P in both fertilisers is approximately the same. Even though TSP has slight advantage in transport and application cost because of less weight per unit P in this fertiliser, unlike SSP it does not have sufficient S to correct the S deficiency in the farm. Therefore to correct both P and S deficiency a sulphur fertiliser has to be applied with TSP and this increases the total fertiliser cost. Therefore SSP is cheaper to use in this farm.

Test Your Knowledge – Section 5 Answers

1. Regrass and avoid grazing when soil is above field capacity. Drain soil to minimise time soil is above field capacity. Graze with young, lighter stock.

2. Avoid grazing when soil is above field capacity. Remove stock to loafing pad when heavy rain is expected. Do not strip graze in wet weather. Avoid congregating stock around gateways when unnecessary.

3. Between 60 and 10 mm depending upon soil texture varying from silt loam to sand, respectively.

4. Answer depends on location but for central New Zealand evaporation rates of < 1mm/day in July to > 3 mm/day in February.

5. 12 days (i.e. 60/5)

6. Volume of water = 0.03 m depth x 10,000 m^2 = 300 m^3

Multi-choice Self-Assessment

Select the correct letter, or letters in questions 1-30.
There may be more than one correct answer per question.

Q.1. A maintenance application of superphosphate fertiliser replaces the following nutrient losses?

- **A** Losses due to product leaving the farm, drainage and runoff and excreta transfer only.
- **B** Losses due to product leaving the farm, excreta transfer, immobilisation in soil and drainage and runoff.
- **C** Losses due to phosphate retention only.
- **D** Losses due to product leaving the farm, excreta transfer, immobilisation in soil, drainage and runoff and volatilisation.

Q.2. A capital application of fertiliser is required to?

- **A** Replace nutrient losses due to product leaving the farm, nutrient transfer, immobilisation in soil and drainage and runoff.
- **B** Raise the soil fertility to a status higher than the status currently indicated by soil, plant or animal testing.
- **C** Meet the loss of nutrients removed in product.
- **D** Raise soil pH.

Q.3. Soil testing is a useful procedure to indicate the soil fertility status with respect to the plant availability of the following elements:

- **A** P, K and N
- **B** P, K , S and Mg
- **C** S, P, Ca and Mo
- **D** P, K, S, and Zn

Q.4. Cows eating 16 kg/DM of ryegrass/clover pasture per day will ingest:

- **A** between 0.5 and 0.8 kg of N and 30 to 60 g of P.
- **B** between 0.5 and 0.8 g of N and 3 to 6 g of P.
- **C** between 0.5 and 0.8 T of N.
- **D** between 0.5 and 0.8 kg of N 3 to 6 g of P

Q.5. The predominant pathway transporting N from dairy pastures to waterways is:

- **A** Volatilisation of ammonia from urine patches.
- **B** Leaching of nitrate from current and past urine patches.
- **C** Runoff of nitrogen from grazed areas.
- **D** Drainage or seepage from non-urine affected areas.

Q.6. Cows eating 16 kg/DM of ryegrass/clover pasture will excrete:

- **A** between 6 to 7 % of the ingested N in urine.
- **B** between 60 to 80 % of the ingested N as dung plus urine.
- **C** between 60 to 70 % of ingested P as urine.
- **D** between 60 to 70 % of ingested P as dung.

Q.7. The predominant input pathway for N into New Zealand farms

- **A** Nitrogen fertiliser use.
- **B** Rainfall.
- **C** Biological N fixation.
- **D** Purchased stock / supplementary feeds.

Q.8. A standard stock unit is:

- **A** Is a truck and trailer unit
- **B** 1 ewe weaning 1 lamb requiring 550 kg grass dry matter to eat.
- **C** 1/7th of what a Friesian/jersey cow may eat per year
- **D** A unit very important in nutrient budgeting.

Q.9. The most likely stocking rate on a NZ dairy farm and dry matter(DM) grown /ha is:

- **A** 0.3 cows/ha and 3 tonnes DM /ha/y.
- **B** 3 cows/ha and 12 tonnes DM /ha/y.
- **C** 9 cows/ha and 3 tonnes DM /ha/y.
- **D** 12 cows/ha and 3 kg DM /ha/y.

Q.10. Similar chemical and physical properties are found in:

A Brown Soils and Yellow Brown Earths.

B Yellow Brown loams and Pumice soils.

C Yellow Brown loams and Allophanic soils.

D Recent alluvial Soils and Allophanic soils.

Q.11. Pallic soils have:

A Lower % P retention values than Pumice soils.

B Higher % P retention values than Pumice soils.

C Lower % P retention values than Allophanic soils.

D % P retention values < 30 %.

Q.12. Allophanic soils are widespread in :

A Taranaki and Waikato regions.

B The east coast of North Island.

C Canterbury.

D Manawatu.

Q.13. Soils with 80 -100 mm available water holding capacity in the pasture root zone are:

A Sandy coarse textured soils.

B Brown Soils and Allophanic Soils with silt loam texture.

C Pumice soils.

D Pallic soils.

Q.14. The essential elements nitrogen, phosphate and potassium are taken up by plants from soils:

A In elemental form

B As anions dissolved in soil water

C As anions and cations dissolved in soil water

D As charged ions dissolved in the soil water

Q.15. Select the correctly labelled ions

A	Ammonium and potassium cations and nitrate anion	NH_4^+, NO_3^- and K^+
B	Phosphate cations	$H_2PO_4^-$, HPO_4^{2-}
C	Potassium anion	K^+
D	Calcium and sulphate ions	Ca^{2+}, SO_4^{2-}

Q.16. Select the correct statements about the main role of essential elements

A Nitrogen is required for plants to build protein and chlorophyll

B Magnesium is involved in cell wall building

C Phosphorus is required in osmotic pressure control

D Potassium is required in osmotic pressure control

Q.17. Select the correct match(s) of the following ions to the soil constituent responsible for holding a readily available plant supply:

A	NO_3^-	Fe and Al oxides on soil particle surfaces
B	$H_2PO_4^-$, HPO_4^{2-}	Fe and Al oxides on soil particle surfaces
C	K^+,Ca^{2+}	Organic matter and clay surfaces
D	$H_2PO_4^-$, HPO_4^{2-}	Organic matter and clay surfaces

Q.18. Select the correct match of the following ions to the soil test measurements that will best describe their plant available status in soils:

A	NH_4^+, NO_3^- and K^+	Cation exchange capacity
B	$H_2PO_4^-$, HPO_4^{2-}	Olsen P test and % P retention
C	K^+,Ca^{2+}	Cation exchange capacity plus exchangeable potassium and calcium
D	$H_2PO_4^-$, HPO_4^{2-}	Cation exchange capacity plus exchangeable phosphate.

Q.19. Select the correct match of cation exchange capacity with the appropriate soil description:

A	0- 5 meq/100g	Allophanic soils with silt loam texture.
B	15- 50 meq/100g	Allophanic soils and Brown soils with silt loam texture.
C	0- 5 meq/100g	Sandy soils and very recent alluvium.
D	0- 5 meq/100g	Pallic soils with silt loam texture.

Q.20. The optimum pH for pasture growth in mineral soils is :

A pH 4-5

B pH 4.5 -4.8

C pH 5.8 - 6

D pH 6-8.

Q.21. Liming a highly acidic soil (pH < 5) is expected to:

A Decrease molybdenum availability to plants.

B Reduce aluminium toxicity to plants.

C Increase the clay content in soil.

D Decrease the rate of organic matter decomposition.

Q.22. Which of the following is **in**correct?:

A Single superphosphate contains both sulphur and phosphorus.

B DAP contains phosphorus, nitrogen and sulphur.

C Long-term use of ammonium sulphate fertiliser will acidify soil.

D Reactive phosphate rock (RPR) solubility is lower than that of Single superphosphate.

Q.23. Urea should not be mixed with single superphosphate because the mixture:

A Is explosive.

B Turns wet and forms lumps on storage.

C Toxic to plants and soil microorganisms.

D Releases nitrogen to atmosphere.

Q.24. A label 0-9-0-12 in a fertiliser bag indicates that the fertiliser :

- **A** Contains 9 kg nitrogen and 12 kg sulphur per 100 kg fertiliser
- **B** Contains 9 kg phosphorus and 12 kg sulphur per 100 kg fertiliser
- **C** Contains 9 kg phosphorus and 12 kg sulphur per tonne fertiliser
- **D** is DAP.

Q.25. The most common form of Nitrogen fertiliser used in NZ is:

- **A** Superphosphate
- **B** Diammonium phosphate
- **C** Urea
- **D** Ammonium sulphate

Q.26. A paddocks Olsen P value is ‘optimum’ for pasture growth in the range:

- **A** 1-5 (mg P/L soil)
- **B** 5 – 10 (mg P/L soil)
- **C** 20 -40 (mg P/L soil)
- **D** 80 -90 (mg P/L soil)

Q.27. If you applied 100 kg /ha of urea, you would add:

- **A** Nitrogen, carbon, hydrogen, and oxygen to the soil
- **B** 100 kg N/ha
- **C** 23 kg N/ha
- **D** 46 kg N/ha

Q.28. A soil ideal for pasture growth will have

- **A** A fine nutty structure in the topsoil.
- **B** A blocky structure in the topsoil.
- **C** Large columnar aggregates in the topsoil.
- **D** A perched water table.

Q.29. Potential Evaporation in central New Zealand is commonly

- **A** Between 0 and 10 mm per day in July
- **B** Between 0 and 1 mm per day in July
- **C** Between 0 and 7 mm per day in February
- **D** Between 0 and 7 mm per day in July

Q.30. In a region of New Zealand with 150 mm rainfall in July

- **A** Drainage in July will occur every July
- **B** Drainage will be greater than 50 mm every July
- **C** Drainage will be greater than 500 mm every July
- **D** Drainage will be less than 50 mm every July

Multichoice Self-Assessment
Answer score sheet

Question	***Correct Answers***	***Marks***	***Score***
1	B	1	
2	B	1	
3	B	1	
4	A	1	
5	B	1	
6	B and D	2	
7	C	1	
8	B, C and D	3	
9	B	1	
10	A and C	2	
11	A, C and D	3	
12	A	1	
13	B	1	
14	C and D	2	
15	A and D	2	
16	A and D	2	
17	A and C	2	
18	B and C	2	
19	B and C	2	
20	C	1	
21	B	1	
22	B	1	
23	B	1	
24	B	1	
25	C	1	
26	C	1	
27	A and D	2	
28	A	1	
29	B and C	2	
30	A and B	2	
	Total	**45**	