

DAIRY SOILS AND FERTILISER MANUAL

Australian Nutrient Management Guidelines



April 2013



Dairy Soils and Fertiliser Manual

Australian Nutrient Management Guidelines

Compiled and edited by

The Dairy Soils and Fertiliser Manual

Development Team



Previous versions: ‘Fertilising Dairy Pastures’

Developed by the Soils and Fertilisers State-wide Activity Team of the Target 10 Program

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Developed by the Dairy Soils and Fertiliser Manual Team

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[Previous Version \(2005\)](#)



Fertilising Dairy Pastures

A manual for use in the Target 10
Soils and Fertilisers Program

Compiled and Edited by
The Target 10 Soils and Fertilisers
Statewide Activity Team

Second Edition

Dairy Australia

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The new *Dairy Soils and Fertiliser Manual: Australian Nutrient Management Guidelines* is an online resource intended for use by Australian dairy farmers, advisors, industry service providers and the dairy education sector. The *Dairy Soils and Fertiliser Manual* was adapted from the *Fertilising Dairy Pastures* manual which was last published by the Department of Primary Industries Victoria in 2005 for Victorian dairy farmers participating in the Target 10 Soils and Fertiliser program. The [Dairy Moving Forward](#), Nutrient Management Community of Interest acknowledge the enormous amount of work contributed over several years by many authors, and the generous contribution of the copyright of this material by the Department of Environment and Primary Industries Victoria.

Previous Versions – *Fertilising Dairy Pastures*

Fertilising Dairy Pastures was first developed in 1997 with input from a wide range of people involved in the dairy industry from all over Victoria. The original development team included Helen Chenoweth, Gregg Cook, Kate Dawson, Geoff Drysdale, Alex Goudy, Frank Mickan, Daryl Poole, Phil Shannon, David Tucker, David Pasztaleniec and Sylvia Vagg.

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Other contributors included: David Tucker - compiling and editing; Frank Mickan - final editing; John Gallienne - technical editing; Don Cook - information on the Northern Irrigation Region; and Liz Jacobsen - formatting and copy editing. Many individual farmers, farmer groups, and farmer-led steering committees across Victoria provided guidance and feedback.

Major contributors to the 2005 edition were: Alex Goudy, Frank Mickan, Helen Chenoweth, Mik Harford, Nadine Markham, Scott McDonald, Barrie Bradshaw, Jo Crosby, Rob O'Connor, Mark Imhoff, Frank McKenzie, Graeme Ward, Cameron Gourley, Richard Eckard, and Andrew Spiers.

Current version: *Dairy Soils and Fertiliser Manual*

There has been an enormous effort by over thirty individuals in reviewing and updating what is now known as the '*Dairy Soils and Fertiliser Manual*'. Many people have generously contributed their time, in addition to their existing workloads.

It is difficult to attribute the contribution of individual authors to specific chapters of the *Dairy Soils and Fertiliser Manual*, as there have been a number of contributing authors to each chapter since they were first written in 1997. The exceptions are the new chapters; 'Soil Biology' written by Declan McDonald (Department of Environment and Primary Industries Victoria), and 'Keeping Nutrients on Farm' written by Peter Day.

The following people have contributed significantly to the development of the *Dairy Soils and Fertiliser Manual*.

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Background

In 2010, the [Dairy Moving Forward Committee](#) identified a number of strategies to address the priority: *'Improve extension of nutrient management principles and practices; and to achieve a more rigorous, objective approach to nutrient management at a farm level'*. The strategies included:

- An agreed whole of industry consensus on nutrient management principles
- Increased industry confidence in nutrient management principles
- Investment in training, professional development and support for information sharing

The expert group also determined five key investment areas to deliver these strategies including:

- A national and regional network of simple test demonstrations/validation activities
- A nationally agreed framework for the delivery of regional nutrient management extension
- National agreement on a set of nutrient management principles together with a framework to integrate these principles into the decision making process
- Development and delivery of formal education on new nutrient management principles and practice
- A national and regional nutrient management RD&E innovators network

To deliver on a number of these strategies, Dairy Australia initiated the project "Dairy Guidelines: Managing soil acidity through improved nutrient use efficiency", better known as Fert\$mart. Industry consultation during the Fert\$mart project showed there was unanimous support for developing a trusted source of science for fertiliser management which was specific to Australian dairy farms.

Around the same time, the National Centre for Dairy Education Australia (NCDEA) also identified the need to update the *Fertilising Dairy Pastures* manual (DPIV 2005) as a national learning resource for soil and fertiliser management courses. The combined investment of resources has led to the development of the *'Dairy Soils and Fertiliser Manual: Australian Nutrient Management Guidelines'*.



Foreword

Australian dairy farmers are amongst the most efficient dairy producers in the world. To survive in this competitive industry, the production and utilisation of pasture as our main feed source will be the key to the future success of our dairy industry.

Many farmers are now finding that when they get soil and fertiliser management 'right', they can produce more feed at no extra cost, and with careful planning, fertiliser becomes a strategic tool to boost feed when it's most needed.

The aim of the on-line *Dairy Soils and Fertiliser Manual* is to provide farmers and advisors with a planning approach and the know-how to achieve this. The manual integrates the *Fert\$mart* planning approach which is underpinned by the internationally recognised 4Rs nutrient stewardship philosophy of using the *Right Source* of fertiliser, at the *Right Rate*, in the *Right Place* and at the *Right Time*.

The *Dairy Soils and Fertiliser Manual* was built upon the *Fertilising Dairy Pastures Manual* developed by the Victorian Department of Primary Industries for the successful Target 10 Soils and Fertiliser Program. The manual has now been updated and expanded to include all Australian dairy regions, the latest research, and current recommended practices for soil and fertiliser management.

The *Dairy Soils and Fertiliser Manual* will help farmers and advisors to make more informed cost-effective fertiliser management decisions. Pasture production depends on sound use of fertilisers, and it is important to understand soil conditions and what is limiting production if best results are to be achieved from fertiliser use. Regular soil testing is necessary to make informed decisions on fertiliser use, and the ability to interpret these results is the key to making the most cost-effective fertiliser choice. It is also important to understand the balance of nutrients in our farming systems.

The environmental impact of nutrients lost from our farming systems can be severe, and lost nutrients are also wasted money. An improved understanding of nutrient management will assist in the well-being of our waterways and in maintaining a healthy environment well into the future. A new chapter, 'Keeping Nutrients on Farm', has been introduced to help farmers and advisors with this increasingly important area.

Another area with increasing interest has been soil biology and soil health. Many dairy farmers are now recognising that productive soils are those with good soil structure, optimum fertility and are biologically active. The new chapter on soil biology removes some of 'mystery and myths' around managing soil organisms in a productive dairy system.

It is important to recognise that the *Dairy Soils and Fertiliser Manual* is also an investment in our future - Our future dairy farmers, and our future advisors. This has been, and will continue to be, a key resource for dairy education, particularly for the National Centre for Dairy Education Australia (NCDEA).

The Dairy Moving Forward Steering Committee is grateful to the organisations and individuals that have contributed towards this manual.

Noel Campbell
Chair, Dairy Moving Forward Steering Committee

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Chapter 1

Fert\$mart Planning

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1 Fert\$mart planning

The Fert\$mart Planning Cycle (Figure 1.1) was developed primarily as a guide for farm advisors to step through the planning process and to prepare a soil and fertiliser management plan for dairy farmers. It can also be used by dairy farmers who have a sound understanding of agronomy and soil fertility. The process consists of seven steps designed to be repeated annually to update and fine-tune fertiliser management, and it brings together information from all other chapters in this manual. The process aims to make fertiliser more profitable by managing soil condition and the targeted use of fertiliser.

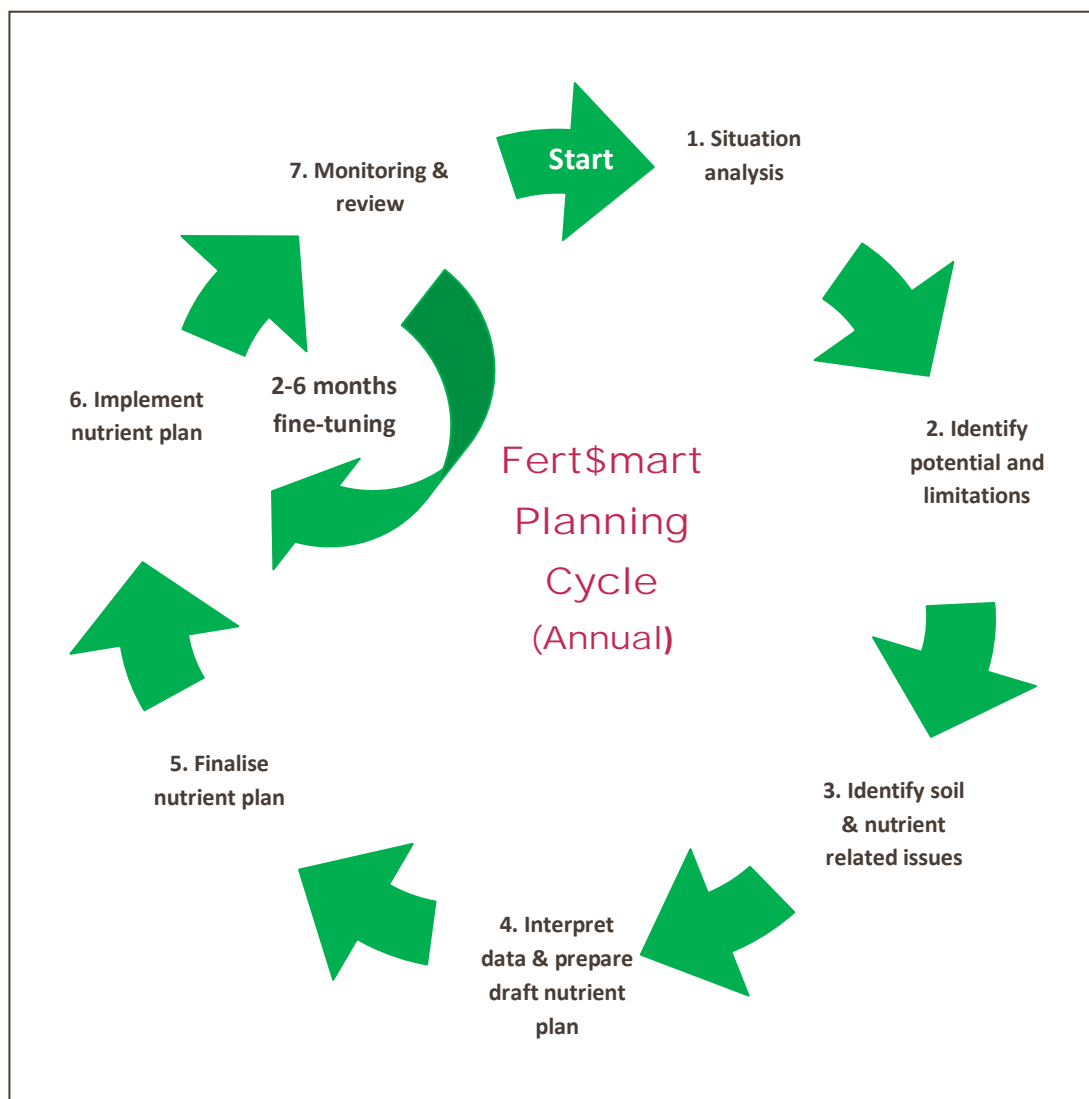


Figure 1.1 The Fert\$mart Planning Cycle

Fert\$mart planning recognises that crop and pasture production is often limited by factors other than soil fertility, and consequently the following steps have been developed to ensure fertiliser decisions are made in the context of the whole farm system.

- **Step 1: [Situation analysis](#)** - Focuses on understanding the farm business, the current farming system, resources (water, soils, nutrient sources, pastures and crop), infrastructure and management.



- **Step 2: [Identify potential and limitations](#)** - Checks that farm production goals are realistic, given there may be limitations other than nutrients. This step also identifies any gaps in knowledge and skills, and shortlists management options best suited to the farm and farm business.
- **Step 3: [Identify soil and nutrient related issues](#)** - Focuses purely on soil and nutrient related issues. Soil tests and field observations are used to narrow down which factors are limiting production and need to be managed.
- **Step 4: [Interpret data and prepare draft nutrient plan](#)** - The information from all previous steps is interpreted and used to prepare a draft soil and nutrient management plan.
- **Step 5: [Finalise nutrient plan](#)** – Practical aspects of the draft plan are checked and finalised.
- **Step 6: [Implement nutrient plan](#)** – Nutrient management plan is implemented.
- **Step 7: [Monitoring and review](#)** – Monitoring and review is on-going. Fine-tuning the plan may be required within 2-6 months depending on crop/pasture/milk production performance. In year 2 the planning cycle begins again, however soil testing may not be required. In year 3 soil tests are carried out across the farm to check soil fertility levels and trends.

1.1 Situation analysis

Fertiliser planning requires a good understanding of the farm and business. For best results, farmers work with their advisor to; discuss production information, inspect the paddocks, note the condition of soils and pastures, and carry out soil sampling. The following aspects of the farm business are all important to nutrient management and fertiliser decisions:

- Farm production goals
 - [Know the feeding system](#)
 - [Know farm production goals and feed requirements](#)
 - [Access information for the feed budget](#)
- Physical resources
 - [Map farm soil types](#)
 - [Map farm management zones](#)
 - [Collect soil samples](#)
 - [Assess soil condition](#)
 - [Assess pasture condition](#)
- [Financial resources](#)
 - Determine the fertiliser financial budget
- [Human resources](#)
 - Consider contractors, labour, equipment and skills
- [Animal health issues](#)
- [Infrastructure and management](#)

The following steps (1.1.1 to 1.1.13) explain the information needed for the situation analysis, and a well-informed fertiliser plan.



1.1.1 Know the feeding system

Knowledge of the feeding system is important to understanding farm nutrients. There are five feeding systems commonly used on Australia dairy farms ([Dairy Australia, 2012](#)):

1. *Pasture + other forages + low grain/concentrate feeding in bail* (i.e. Grazed pasture + other forages + up to 1.0 tonne grain/concentrates fed/cow/year in the bail).
2. *Pasture + other forages + moderate-high grain/concentrate feeding in bail* (i.e. Grazed pasture + other forages + more than 1.0 tonne grain/concentrates fed/cow/year in the bail).
3. *Pasture + partial mixed ration ± grain/concentrate feeding in bail* (i.e. Pasture grazed for most or all of year + partial mixed ration on feed pad ± grain/concentrates fed in bail).
4. *Hybrid system* (i.e. Pasture grazed for less than nine months per year + partial mixed ration on feed pad ± grain/concentrates fed in bail).
5. *Total Mixed Ration (TMR) system* (i.e. Zero grazing. Cows housed and fed total mixed ration).

In feeding system 1, dairy cows spend most of the time grazing pastures and therefore returning or recycling most nutrients to the paddocks. On the other hand, in feeding system 5, all nutrients are deposited on or near the feedpad/dairy and are then stored, distributed or sold. It is important to understand the feeding system and what happens to nutrients imported in feed when developing the nutrient budget.

[More on nutrient stores & transformations \(Chapter 10.2.2\)](#)

1.1.2 Know farm production goals and feed requirements

Production goals start with the volume and quality of milk required throughout the year. This determines the number of milkers, the herd size, and the feed requirements.

Feed is the largest cost for most dairy farmers. Growing and utilising more home-grown feed helps to keep farm costs down and improve profitability. Fertiliser plays an important role in achieving this. A [feed budget](#) can be used to work out the home-grown feed requirements and the dry matter (DM) production goals for the coming year.

If DM production goals are similar to the previous year, these figures can be used in the farm nutrient budget to work out what quantities of nutrients need to be brought onto the farm to maintain current production levels. Soil tests are also required to adjust the specific fertiliser requirements for each farm management zone (FMZ). A FMZ is a group of paddocks with similar soil types and management (See [Chapter 15.4.1](#)). Where nutrients are removed in product (e.g. silage, hay and crops) both a paddock/FMZ nutrient budget and soil tests are required to work out the fertiliser requirements. Crop types and estimated yields (kg DM/ha) are also required for the nutrient budget.

1.1.3 Access information for the nutrient budget

The nutrient budget is used in Step 4 (see [Section 1.4](#)) to work out farm fertiliser requirements. The first step in nutrient budgeting is to quantify the amount of nutrients coming on to, and leaving the farm, and this requires access to the farm records. The inputs required for the nutrient budget are described in [Chapter 15.6](#).

1.1.4 Map farm soil types

Knowing the soil types and where they are located across the farm is an important consideration for soil and fertiliser management. Regional soil maps are useful in identifying and describing soil types on a broad scale. Regional maps can be used in combination with the farmer's existing knowledge



of the farm soil types to produce a soil map at a paddock scale. The soil map is used to characterise the soil profile, properties, behaviour and suitability for crops and pastures. Soil information is used in steps 1.2 and 1.3.

[More on Regional Soil Types \(Chapter 6\)](#)

[More on Soil Properties \(Chapter 4\)](#)

1.1.5 Map farm management zones

Fertiliser use is more targeted and profitable when fertiliser recommendations are customised for each FMZ. The farm map, showing paddocks and soil types, is used in combination with previous soil tests and previous/current management to map the FMZs.

[More on FMZs \(Chapter 15.4.1\)](#)

1.1.6 Collect soil samples

If the farm soil tests are more than 2 to 3 years old, collect a new soil sample from each FMZ. At least 30 soil cores are required for each sample. Cores should be taken along monitor lines or transects that you can come back and resample in one or two years, or collected randomly across the area. In each case, however, care should be taken to avoid areas where nutrients may be concentrated such as dung and urine patches, areas near gateways, water troughs, and stock camps.

Take the samples to the standard depth (0 - 7.5cm in Tasmania, 0 - 10cm in all other states). Keep the samples cool (not on the back of the ute) and send them to a NATA accredited or ASPAC certified soil testing laboratory as soon as possible. Soil samples should be sent to the same soil testing laboratory each year to ensure consistency of soil testing methods.

[More details on soil sampling \(Chapter 8\)](#)

1.1.7 Assess soil condition

Fertiliser efficiency can be limited by soil constraints; however it can also be improved with better soil condition. A quick field assessment of soil condition in each FMZ can pick up issues not identified in the soil tests, and farmers should alert their advisor of known soil issues. Look for evidence of poor soil surface condition, slaking, dispersion, compaction, waterlogging, salinity and acidity. See the Fert\$mart [FMZ field sheet](#) for a basic checklist for soil condition assessment. Chapters 4 to 7 of this manual discuss soil condition

1.1.8 Assess pasture condition

Poor pasture performance and utilisation also reduces fertiliser efficiency. Pasture condition in each FMZ should be assessed and recorded. Observe current pasture species composition and consider their suitability (see [Chapter 15.5.1](#)). This can be carried out at the same time soil samples are taken in each FMZ:

1. Visually assess the species.
2. Consider recent performance/production of the paddock, grazing interval, silage/hay production.
3. Assess weed types and density.

Look for changes in species, growth and colour in urine and dung patches compared to the pasture around them. Look carefully at the old and fresh dung patches and record observations.



[More on assessing perennial ryegrass condition](#)

[More on visual symptoms of nutrient deficiencies \(Chapter 8.6\)](#)

1.1.9 Determine the fertiliser financial budget

The farm fertiliser budget will vary from year to year, depending on financial circumstances. A common strategy is to maintain soil fertility when finances are tight, and to apply additional nutrients to meet capital requirements (if required) in the better years (see [Chapter 15.3](#)). Farm fertiliser records are a useful starting point.

1.1.10 Consider contractors, labour, equipment and skills

Implementation of the fertiliser plan could be limited by contractors, farm labour, equipment and skills. For example; if contractors are used for fertiliser spreading, does this create any limitations on the fertiliser types, rates and blends used across the farm, and the timing of applications? Also consider distribution accuracy and the impact this has on fertiliser use efficiency. For more information on the accuracy of fertiliser spreaders refer to the [Fertilizer Australia](#) website, or to the Fertcare Accu-Spread link: http://www.fertilizer.org.au/default.asp?V_DOC_ID=1131

1.1.11 Consider animal health issues

Check for animal health issues linked to soil and plant nutrition or toxins. See the following links:

[Nitrate poisoning \(Chapter 12.6.1\)](#)

[Grass Tetany](#)

[Implications on transition cow management](#)

[Trace element deficiencies \(Chapter 3.5\)](#)

1.1.12 Consider infrastructure, equipment and management

Check the capability of existing handling and spreading equipment. Are there limitations to fertiliser use, e.g. the types, rates, placement and timing? Are there cost effective options to upgrade infrastructure/equipment to improve fertiliser efficiency, e.g. effluent distribution equipment or infrastructure?

Are there other aspects of farm management that can be improved? The following links will help to identify key areas for improvement:

[Soil management](#)

[Fertiliser management](#)

[Effluent management](#)

[Irrigation management](#)

[Feed conversion efficiency](#)

[Pasture Consumption and Feed Conversion Efficiency Calculator](#)

1.2 Identify potential and limitations

The purpose of this step is to consider the farm business and to determine if the production goals are realistic, and to identify opportunities where improved knowledge and skills will benefit soil and



fertiliser management. The aim is to shortlist the options that will help to achieve the production goals.

1.2.1 Determine if goals are realistic

Use production records and other information gathered in the situation analysis to check the farm production goals. Compare goals with what has been achieved on other local and regional farms (e.g. data from focus farms, case studies or demonstration sites). Also consider the capability of the farm and of the capacity of the business (i.e. knowledge, skills, equipment, labour resources, physical resources, financial resources and current management practices).

1.2.2 Identify gaps in knowledge, skills and practices

Compare current management with acceptable practices in the DairySAT checklists for [soils](#), [fertiliser](#), [effluent](#) and [irrigation](#) management. Are there any gaps in knowledge, skills, or farm practices that if addressed will result in better soil condition and/or fertiliser use? Check for research data that is relevant to the situation, and incorporate where appropriate.

1.2.3 Shortlist the options

Shortlist the options for improvement to knowledge, skills and practices, and revise production goals if necessary.

1.3 Identify soil and nutrient related issues

Before considering the plant nutrient requirements, it is important to identify if there are other soil and nutrient related issues. There could be limiting factors (other than nutrients) that need to be addressed to get the best value out of fertilisers. Some factors cannot be changed economically (e.g. highly sodic or saline soils) and land use and production goals in these areas need to be matched accordingly. Farm scale nutrient efficiencies are also considered in this step. Are there opportunities to use nutrients more strategically across the farm, e.g. better distribution of effluent?

1.3.1 Identify soil issues

Limiting factors can be identified using field observations described in [Sections 1.1.7](#) and [Section 1.1.8](#) in combination with the soil tests. Some factors can only be observed in the field (e.g. compaction, pugging, and waterlogging) while others may show signs in the field, but need to be confirmed with soil tests (e.g. salinity, sodicity and acidity). Chapters 4 to 7 of this manual discuss soil issues. Now work out cost effective management options where they exist. It may be necessary to prepare a program and budget to remedy these over a longer time period.

1.3.2 Identify irrigation water quality issues

Poor quality irrigation water can be harmful to crops, soil and irrigation equipment. This can result in lower production and poor fertiliser use efficiency. Check the water analysis for the five salinity and sodicity criteria.

[More on irrigation water quality](#)

1.3.3 Identify limiting crop/pasture condition issues

Production can also be limited by crop and pasture condition (e.g. species, plant population, diseases, pests and weeds). Crops and pastures in good condition and suited for the purpose will use soil nutrients more efficiently than unhealthy and weedy stands. See [Chapter 15.5.1](#) for more on species suitability.



1.3.4 Identify farm-scale nutrient issues and options

Prepare a farm nutrient budget (See [Nutrient Budgeting, Chapter 15.6](#)) to work out the quantities of nutrients coming onto, and leaving the farm. The nutrient budget will show whether there is a whole farm nutrient surplus or deficit. Phosphorus, potassium and sulphur are generally accounted for in the nutrient budget. In situations where a nutrient surplus exists there may be an opportunity to treat areas more strategically and reduce nutrient costs. This could apply to both fertiliser and effluent treated areas on the farm. When nutrients exported from the farm in produce exceed nutrients brought onto the farm, the deficit can be used to estimate the total nutrient requirements to maintain production.

It is also important to look for nutrient build up areas and cease further applications of nutrients already in abundance. [Nutrient maps](#) provide a good visual comparison of nutrient levels across the farm. Alternatively, nutrient levels in each paddock/FMZ can also be compared with the soil fertility guidelines using a graph or table (See [Chapter 15.10](#) and [Chapter 16.2.3](#)).

This information also helps to identify which FMZs will benefit most from the dairy effluent, provided it is practical to get the effluent onto that area of the farm. Estimate the quantity of effluent produced each year, and the nutrient composition to work out its value. Estimating the dollar value of effluent (equivalent fertiliser cost) helps to justify any additional costs required to use effluent more strategically around the farm. Explore cost effective options to improve effluent distribution - See [Chapter 13](#), 'Using Dairy Effluent'.

For more information on retaining and optimising nutrient use on dairy farms refer to [Chapter 10, Keeping Nutrients on Farm](#).

1.4 Interpret data and prepare draft nutrient plan

See [Chapter 16](#) for details on how to develop and document a fertiliser management plan using the 4Rs framework.

1.5 Finalise the nutrient plan

Check that the recommendations in the draft plan are feasible, practical and affordable as outlined below:

- Involve members of the farm business and the farm advisor in a face-to-face meeting. Discuss soil test results (graphically if available) by considering current levels in comparison with the optimal test value/range. Discuss/consider soil fertility trends, if previous soil test data is available.
- Check the management options are best suited to the farm and the farm budget.
- Discuss/consider the nutrient program costs and the economics, for instance a staged nutrient build-up plan.
- Check the 4Rs fertiliser plan is practical and compatible with farm infrastructure, machinery and management (i.e. fertiliser type, rate, place, time and frequency).
- Discuss/consider implementation of the plan, record keeping and monitoring crop/pasture performance in the next 2-6 months, and then beyond that time.
- Finalise the nutrient management plan.



1.6 Implement the nutrient plan

Implementation of the nutrient management plan requires the farmer to:

- Follow the 4Rs fertiliser program and other strategies in the nutrient management plan (where practical and affordable).
- Record the actual management decisions; sources, rates, placement and timing (including frequency) for each fertiliser application, and note the reasons for changes to the plan (e.g. weather conditions, product or contractor availability).
- Refer to DairySAT checklists for managing soils, fertiliser, effluent and irrigation.

1.7 Monitoring and review

1.7.1 Fine-tuning (2-6 months)

The farmer closely monitors pastures, crops and livestock performance, noting any issues and discussing these with their advisor. A visit from the advisor may be beneficial 2-6 months after starting the fertiliser program to assess pastures, crops and stock and to discuss/note current production and yields (milk, crop and pasture production/consumption). Further soil and/or tissue tests may be required to diagnose nutrient related issues if problems are observed in the crops and pastures.

1.7.2 Annual review (Year 2)

An annual review (may also be half yearly, or at the end of a crop cycle) provides opportunity to:

- Discuss/consider the fertiliser program and the records of fertilisers used in each FMZ.
- Visually assess crops, pasture and livestock, and consider the performance throughout the year/season. Has the performance met expectations? Have any problems been observed? If no problems have been observed, and production is meeting expectations, further soil/tissue testing may not be required in year 2.
- Redo the nutrient budget to check nutrient surpluses/deficits for the farm or FMZs.
- Work out maintenance fertiliser requirements for the farm and FMZs.
- Refer to previous soil tests and introduce capital fertiliser applications where required and if finances permit.
- Update the 4Rs fertiliser program for the coming year/season.

1.7.3 Future reviews (Year 3)

Every 3 years carry out soil testing in every FMZ then repeat the steps described in the Situation Analysis (Section 1.1) and update the 4Rs fertiliser program. An important part of the year 3 review is to check soil fertility trends in each FMZ against the guidelines. Soil fertility trends provide important feedback that can be used to fine-tune maintenance requirements, and help to keep soil fertility on track over the long term - See [Chapter 16](#).



1.8 Fert\$mart Planning Checklist

The following checklist provides a summary of the steps involved in Fert\$mart Planning along with the tools and knowhow that are available to undertake each step.

| 1. Situation Analysis | | Print checklist |
|--|--|--|
| Steps - Production Goals | Tools | Knowhow |
| 1.1 Understand the feeding system | ➤ Farm data collection sheet | ➤ Feeding systems |
| 1.2 Know farm production goals and feed requirements | | ➤ Feed budgets |
| 1.3 Access information for the nutrient budget | | ➤ Nutrient budgets (Chap 15) ➤ Nutrient stores & transformations (Chap 10) |
| Steps - Physical Resources | Tools | Knowhow |
| 1.4 Map farm soil types | ➤ Field data collection sheet ➤ Farm map ➤ Soil type map ➤ Soil sampling equipment ➤ Spade ➤ Camera | ➤ Farm Management Zones (Chapter 15) |
| ➤ Access previous soil tests | | ➤ Limits to plant growth (Chapter 2) |
| 1.5 Map FMZs | | ➤ Plant nutrient requirements (Chapter 3) |
| 1.6 Collect soil samples - FMZs | | ➤ Soil properties (Chapter 4) |
| 1.7 Assess soil condition - FMZs | | ➤ Soil biology (Chapter 5) |
| 1.8 Assess pasture condition -FMZs | | ➤ Soil types (Chapter 6) |
| | | ➤ Managing limiting soil factors (Chapter 7) |
| | | ➤ Assessing soil nutrients (Chapter 8) ➤ Keeping nutrients on farm (Chapter 10) ➤ Assessing perennial ryegrass condition |
| Steps - Financial Resources | Tools | Knowhow |
| 1.9 Determine fertiliser financial budget | ➤ Farm data collection sheet | ➤ Economics of N fertilisers |
| ➤ Access fertiliser records | | |
| Steps - Human Resources | Tools | Knowhow |
| 1.10 Consider contractors, labour & skills. | ➤ Farm data collection sheet | ➤ Fertcare Accu-Spread |
| Steps - Animal Health | Tools | Knowhow |
| 1.11 Consider animal health issues | ➤ Farm data collection sheet | ➤ Nitrate poisoning (Chapter 12) ➤ Grass Tetany ➤ Transition management |



1. Situation Analysis (cont'd)

| Steps - Infrastructure, equipment & management | Tools | Knowhow |
|--|---|--|
| 1.12 Consider infrastructure, equipment and management <ul style="list-style-type: none"> ➤ Review fertiliser/effluent handling and distribution. ➤ Consider options for cost effective upgrades. ➤ Consider management practices that can improve fertiliser use efficiency (incl. soil, fertiliser, irrigation, effluent, pasture utilisation). | <ul style="list-style-type: none"> ➤ Farm data collection sheet ➤ Pasture Consumption and Feed Conversion Efficiency Calculator | <ul style="list-style-type: none"> ➤ Soil management ➤ Fertiliser management ➤ Effluent management ➤ Irrigation management ➤ Feed conversion efficiency |

2. Identify potential and limitations

| Steps | Tools | Knowhow |
|---|--|---|
| 2.1 Determine if goals are realistic 2.2 Identify gaps in knowledge, skills and practices 2.3 Shortlist the options | <ul style="list-style-type: none"> ➤ DairySAT | <ul style="list-style-type: none"> ➤ Latest research |

3. Identify soil and nutrient related issues

| Steps | Tools | Knowhow |
|---|--|---|
| 3.1 Identify soil issues 3.2 Identify irrigation water quality issues 3.3 Limiting crop/pasture condition issues 3.4 Identify farm-scale nutrient issues/options | <ul style="list-style-type: none"> ➤ DairySAT | <ul style="list-style-type: none"> ➤ Soil properties (Chapter 4) ➤ Soil types (Chapter 6) ➤ Managing limiting soil factors (Chapter 7) ➤ Irrigation water quality ➤ Keeping nutrients on farm (Chapter 10) ➤ Nutrient budgets, nutrient maps (Chapter 15) ➤ Using dairy effluent (Chapter 13) ➤ Effluent Calculators (Chapter 13) |



4. Interpret data and prepare draft nutrient plan

| Steps | Tools | Knowhow |
|---|---|--|
| 4.1 Identify paddocks and FMZs on a farm map. For each FMZ consider the following: 4.2 Address soil constraints with cost effective management options. 4.3 Compare soil tests/trends with optimum ranges. 4.4 Address soil health: Determine management options. 4.5 Address weeds, pests and disease issues. 4.6 Effluent/manure use: Determine cost effective management options. 4.7 Prepare 4Rs fertiliser program. 4.8 Determine risk management strategies (human, stock, environment). 4.9 Document the nutrient management plan | <ul style="list-style-type: none"> ➤ DairySAT ➤ Soil and Fertiliser Management Plan (Example) ➤ ‘Soil and Fertiliser Management Plan’ template | <ul style="list-style-type: none"> ➤ Soil types (Chapter 6) ➤ Soil properties (Chapter 4) ➤ Managing limiting soil factors (Chapter 7) ➤ Interpreting soil and tissue tests (Chapter 9) ➤ Keeping nutrients on farm (Chapter 10) ➤ Soil fertility guidelines ➤ Introducing fertilisers (Chapter 11) ➤ Nitrogen and nitrogen fertilisers (Chapter 12) ➤ Using dairy effluent (Chapter 13) ➤ Calculating rates and costs (Chapter 14) ➤ Nutrient planning (Chapter 15) ➤ Developing a fertiliser plan (Chapter 16) |

5. Finalise nutrient plan

| Steps | Tools | Knowhow |
|--|------------------------------------|---------|
| Farmer/advisor discuss & check management options and finalise the draft nutrient plan: 5.1 Soil test results, soil fertility trends and maintenance requirements. 5.2 Check management options are best suited to the farm & farm budget. 5.3 Consider nutrient program costs/economics, e.g. staged nutrient build-up plan. 5.4 Check the 4Rs fertiliser plan suits farm infrastructure, machinery and management 5.5 Discuss implementation of the plan, record keeping and monitoring crop/pasture performance. 5.6 Finalise the nutrient management plan. | The draft nutrient management plan | |



6. Implement the nutrient plan

| Steps | Tools | Knowhow |
|--|---|--|
| 6.1 Farmer implements the 4Rs plan (where practical). 6.2 Farmer records the actual sources, rates, placement and timing (including frequency). 6.3 Farmer follows practices recommended in DairySAT (soils, fertiliser, effluent and irrigation). | <ul style="list-style-type: none"> ➤ Paddock record keeping tool DairySAT checklists: <ul style="list-style-type: none"> ➤ Soil management ➤ Fertiliser management ➤ Effluent management ➤ Irrigation management | <ul style="list-style-type: none"> ➤ Fertcare Accu-Spread |

7. Monitoring and review

| Steps | Tools | Knowhow |
|--|-------|---------|
| 7.1 Fine-tuning (2-6 months): <ul style="list-style-type: none"> ➤ Farmer monitors pastures, crops and livestock performance and discusses issues with advisor. ➤ Advisor visit and further soil/tissue testing as required to resolve issues. 7.2 Annual review (Year 2): <ul style="list-style-type: none"> ➤ Discuss/consider the fertiliser program ➤ Review production targets ➤ Soil/tissue testing if issues exist. ➤ Redo the nutrient budget. ➤ Work out fertiliser maintenance requirements. ➤ Introduce capital fertiliser applications if finances permit. ➤ Update the 4Rs fertiliser recommendations. 7.3 Future reviews (Year 3): <ul style="list-style-type: none"> ➤ Soil test every FMZ ➤ Repeat steps in Situation Analysis. ➤ Check soil fertility trends and update the fertiliser program. | | |



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Chapter 2

Limits to Plant Growth

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2 Limits to Plant Growth

2.1 Introduction

The growth of plants is the result of a sequence of complex steps starting with cell division and ending with the irreversible increase in size. Growth can be measured in many different ways but is generally measured either in terms of an increase in height or weight, although sometimes ground cover or density is the growth indicator. If measuring weight, pasture growth is more commonly expressed in terms of an increase in dry weight rather than fresh weight due to the variable moisture status.

For optimum pasture performance it is important to have an understanding of how the plant functions and responds to the various growth limiting factors.

Each factor, whether acting as an individual or interacting with another, can become the limiting factor to pasture or crop production. See “Law of the Limiting in Chapter 3.3.

Growth limiting factors could be classified according to internal or external factors including:

Internal

- Plant species or variety
- Plant growth hormones and regulators produced at different growth stages or maturity

External

- [Water](#)
- [Nutrients](#)
- [Light](#)
- [Temperature](#)
- [Soil constraints](#)
- [Plant Disease and Insects](#)
- [Weeds](#)

The external and internal factors do not act independent of each other, instead interacting in relationships that can be quite complex. The external factors will be discussed in this chapter.

2.2 Water

Water is an essential compound for so many plant functions; both at the cellular level and as a medium through which all biological substances move. Growing plants are not in equilibrium with their environment regarding water, as there is a continual gradient or upward movement of water from the soil solution to that lost from the above ground parts of plants.

The availability of soil moisture for root uptake and plant growth is such a basic requirement that practically all other plant functions will be impaired if soil moisture is lacking.

Soils hold and provide varying amounts of water to plants depending on many factors; for example texture and structure. The amount of water held in a soil varies with time and is called its water holding capacity (WHC) or soil moisture content. The soil's water holding capacity is usually expressed as the millimetres of water per metre of soil depth or sometimes as a % of a cubic metre of soil.



Evaporation from the pores (stomates) chiefly in leaves; called transpiration, creates a large water deficit within the leaf. This deficit is replenished by soil water pulled up from the root system by the cohesion of water molecules or “transpirational pull”. Under normal or optimal soil/plant conditions, as the soil water is absorbed by the root system from the larger soil pores it is replenished. This situation is ideal for plant growth and is referred to as “field capacity”. If the soil moisture is not replenished, the plants root system will continue to extract soil moisture from the smaller soil pores until the point where the remaining soil moisture is so tightly held that it is no longer available. At this point there is not sufficient water available to meet the plants needs so the plant wilts. Plants can exhibit what is called a “temporary wilt” which can occur as a result of the heat of the day. From a temporary wilt the plant will recover in the evening or early morning. However if the situation progresses, the plants normal turgor does not recover and the leaves wilt and change colour. This point is called the “permanent wilting point”. For more information on soil water, refer to Chapter 4.2.4.

Both the water content of the soil and rainfall vary throughout the year and are not easily manipulated on dryland farms. In order to conserve soil moisture, a healthy soil with good internal drainage and a friable surface, will allow greater acceptance and storage of water than a compacted or sealed soil. Crops or pastures that are irrigated can achieve more consistent growth and production, as long as the extra nutrient demands for the increased dry matter production are met.

2.3 Nutrients

We must properly feed the pasture before the pasture can feed the dairy cows that graze it. Of all the elements occurring in the soil, only some will be required for plant growth, while others are essential for the animal’s growth (e.g. cobalt).

Plants require varying quantities of nutrients at various stage of growth and if any essential nutrient is not plant available when it is required plant growth can become limited. There are optimum levels of nutrient availability that should be met in the soil and plant for maximum pasture production. Understanding and managing plant nutrients for dairy production is the key focus of this manual.

2.4 Light

Adequate light (sunlight) is important for plant or pasture growth. Light is responsible for photosynthesis in green plants, whereby the green plant pigment – chlorophyll, allows the energy from the sun to be utilised with carbon dioxide and water to create carbohydrates – See Figure 2.1.

The photosynthesis process is a basic energy storage process that all plants and animals depend upon. Only a small proportion of the suns light energy (0.1 %) that reaches the pasture is converted into plant growth, with about half this energy being used for respiration. Ultimately the amount of growth made by a plant will be determined by the net rate of photosynthesis; which is the gross photosynthesis minus the respiration.

Management of the pastures growth is important so as to prevent rank growth and maximise the amount of light reaching fresh young leaves. Young leaves are more efficient in converting sunlight to plant growth than older leaves especially when older leaves are being shaded.

Employing good grazing management will ensure maximum light is available to the plants at all times. It will also ensure that energy, in the form of sugars and carbohydrates that are stored in the plant’s root system, are not depleted by overgrazing. Optimal stocking rates and grazing periods ensures that the plant has sufficient time to recover in between grazing cycles and prevents the depletion of reserves held in the plants roots, especially nutrients like phosphorus.

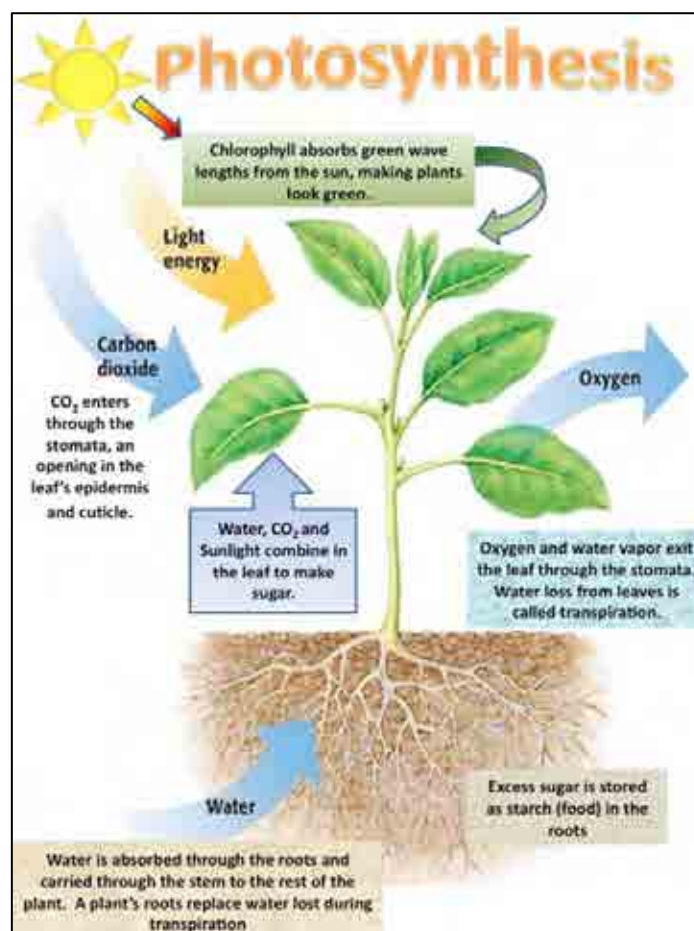


Figure 2.1 Inputs and outputs of the Photosynthesis process
(Source: <http://science6shms.pbworks.com/w/page/25870917/photosynthesis>)

2.5 Temperature

The amount of heat that *reaches* the soil is initially influenced by what is held in the atmosphere (clouds, particles, pollution). The amount of heat that is actually *retained* in the soil is further influenced by ground cover, soil texture and colour.

Soil is quite resilient to marked fluctuations in soil temperature, with this fluctuation decreasing with soil depth. The pasture growth itself will also have a buffering effect on the soil temperature due to its absorption and release of heat. Temperature affects the growth of all pasture plants in many ways; from the weathering of the parent material to the growth rate of soil microorganisms. Generally, how plants respond to temperature relates to the part of the world in which they evolved. Ryegrass has an optimum temperature for growth of around 18°C, while white clover does not reach a maximum growth rate until the temperature has reached 25°C - see Figure 2.2. Paspalum and other tropical C4 grasses, also favour high temperatures. Hence, pastures tend to be ryegrass dominant through the winter, but the level of white clover and tropical C4 grasses often increases greatly in spring and summer.

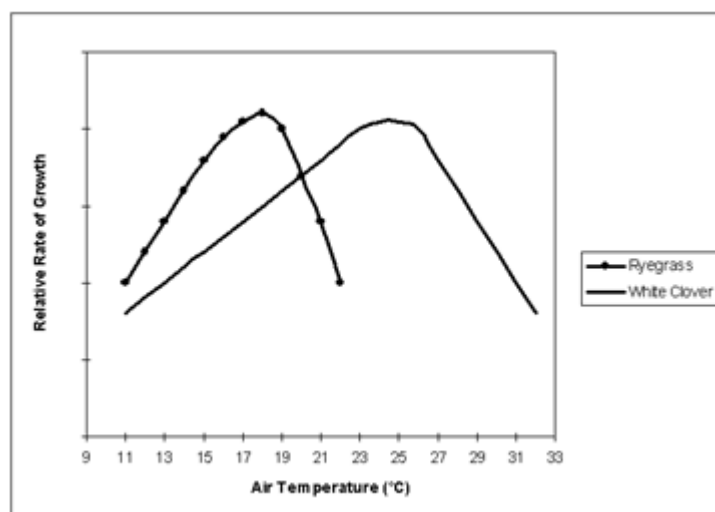


Figure 2.2 Growth rate of ryegrass and white clover in response to temperature

Plants require a certain amount of accumulated heat from the sun in order to photosynthesis and produce carbohydrates for growth. Each stage of a plants growth, e.g. from emergence to first mainstem leaf or emergence to full flower, requires a certain accumulated amount of heat units per day to complete that part of its growth. The heat units are accumulated until reaching the *threshold temperature* (or *base temperature*) that a plant species requires for normal maintenance. Below the threshold temperature, the plant is in stress or shock and no growth occurs. The number of heat units required at each stage are called “**day degrees**”. Weather conditions determine whether the day degrees accumulate over a short or longer period. Cool cloudy conditions mean less day degrees, thereby limiting pasture growth as seen from late autumn to early spring.

The formula for calculating day degrees is:

$$\text{Growing Day Degrees (GDD)} = \frac{(\text{Daily max. temp } ^\circ\text{C} - \text{daily min. temp } ^\circ\text{C}) - \text{Base Temperature } ^\circ\text{C}}{2}$$

The GDD number cannot be a negative; the number for that day would be carried forward as zero. The base temperatures for some common crops and pastures are shown in Table 2.1. Note that some temperate pasture species (e.g. White clover) grow very slowly at a base temperate of 4 - 5°C (Hutchinson *et al.*, 2000).

Table 2.1 The base temperatures of common crops and pastures.

| CROPS AND PASTURES | BASE TEMPERATURE (°C) |
|---|-----------------------|
| Corn, sorghum | 10°C |
| Temperate pasture species, ryegrass, oats, barley, rye, wheat | 5°C |

(Adapted from Fraisse *et al.*, 2012, and Hutchinson *et al.*, 2000)



2.6 Soil constraints

These can be any physical or chemical restriction to the normal root proliferation into the subsoil. Constraints can be naturally occurring; in the case of a dramatic change in layers or horizons, or as a result of pasture management in the case of pugging. Examples include a build up of chemical residues from herbicides; an increase in subsoil sodicity or salinity; an extreme soil pH - either acid or alkaline; a sudden physical change to soil structure due to compaction issues; nutrient imbalances - whether toxicities or deficiencies; or even just a lack of soil depth relative to the rooting depth of the pasture species.

Some soil constraints can be identified by soil testing, or a physical or visual examination. The constraint can often be minimised with the use of correct nutrition or the addition of soil ameliorants; be they organic (manures) or chemical (lime or gypsum). Managing soil constraints is covered in detail in Chapter 7.

2.7 Plant Disease and Insects

Pests and diseases can severely impact pastures and contribute to pasture rundown. Crops and pastures should be inspected regularly for pests as well as disease and deficiencies. A combination of biological, chemical and cultural control measures to control pests are considered the most effective and sustainable approach to addressing pest problems.

Insect pests and diseases affect pastures at all stages from germination of the seed (e.g. seedling blight or damping off disease caused by a fungus) through to the final leaf and stem (e.g. Rust on ryegrass, also caused by a fungus – see Figure 2.3).



Figure 2.3 Pustules of crown rust on ryegrass leaves.
(Source: http://www.niab.com/news_and_events/article/159)

Diseases can cause a significant loss of pasture production as well as effect forage quality. A diseased plant will also be more susceptible to other environmental stresses. Depending on what has caused the disease (fungus, virus, bacteria, nematodes or even another insect) will determine where it occurs on the plant. Generally plant diseases can be classified by the area affected such as those that affect the seedlings, leaf and stem, and root (see Figure 2.4) and crown.



Figure 2.4 Phytophthora root rot in Lucerne
(Source: http://www.daff.qld.gov.au/26_3593.htm)

The effects of insects on pastures will vary. Some can be of minor importance, especially in the case of some insect pests in lucerne. As a perennial crop, lucerne harbours all kinds of insects including those that are pests, predators or beneficials. For example, an insecticidal approach for the control of pests such as heliothis or lucerne leaf roller, could be unnecessary due to the natural control by other insects or virus. Insect control can be an option when insect numbers reach certain populations or *thresholds*. Thresholds are based on the potential economic damage, the costs to control and the likely yields to be gained from insect control. Monitoring insect populations during susceptible times of the year will prevent needless sprays, for example in the warmer months for aphids present in lucerne.

2.8 Weeds

Weeds can have many definitions, but generally in a farming context they are defined as “*any injurious or potentially disease causing plant that is relatively useless, whilst competing with established pastures or crops*”.

Weeds are usually species that are well adapted to survival with prolific seeding rates; the ability to remain dormant for extended periods of time; as well as excellent methods of seed dispersal - whether by wind, water or by stock movement.

It is often impossible or impractical to eradicate weeds from an area, so the best method of controlling weeds is relying on the management of them. There are many mechanical means by which weeds can be controlled. In the case of annual weeds for example, slashing in order to prevent seed set can be an effective means to control weeds, especially prior to flowering.

The losses to production due to weed infestation are incredibly difficult to estimate. Weeds can result in competition with pasture or cropping species for nutrients and soil moisture; the tainting of milk; stock poisoning; reduction of dry matter yields from lucerne paddocks; as well as reduced quality of the hay due to weed presence.

Grass weeds have prolific fibrous root structures and generally germinate under the more extreme conditions such as cooler soil temperatures. They require soil nutrients as do commercial plants, quickly draining the local soil of available nutrients and moisture, thereby leaving the soil depleted



for the following pasture or crop. Table 2.2 clearly demonstrates the effect that weed competition has on pasture establishment and production.

Table 2.2 The effect of fallow weed management on the population of annual summer grasses and the dry matter (DM) production of Bambatsi panic one month after sowing.

| FALLOW TREATMENT | Weed seeds in soil prior to sowing (seeds/m²) | Weed seedling N° 14 days after sowing (plants/m²) | Weed DM production 1 month after sowing (kg/ha) | Bambatsi DM production 1 month after sowing (kg/ha) |
|-----------------------------------|---|---|--|--|
| Control in spring before planting | 5500 | 900 | 2500 | 90 |
| One summer of weed control | 1650 | 200 | 2000 | 410 |
| Two summers of weed control | 15 | 15 | 250 | 1000 |

Source: <http://www.dpi.nsw.gov.au/archive/agriculture-today-stories/april-2008/weed-competition-kills-tropicals>

One of the best ways of reducing weed infestation in pastures is by maintaining a dense, healthy sward of desirable pasture species. Pasture species will generally have the greater nutritional value so optimum soil conditions should be met to encourage this production. Management strategies to favour desirable pasture species (see Section 2.9) alongside the integrated use of herbicides, offers the best approach to reduce the limitation imposed by weeds.

2.9 Management strategies to reduce limitations to plant growth

The amount of pasture growth is determined to a large extent by the prevailing climatic conditions of light, water and temperature. There are, however, a number of management strategies used to reduce the limitations and increase production, including:

- Irrigation: Provides soil water when it is limiting.
- Fertilisers: Provide essential nutrients limiting plant growth.
- Soil ameliorants: Products that change soil characteristics to be more favourable to plant growth, e.g. lime raises soil pH and can improve structure in some soils.
- Green manure planting: Increases soil organic matter, improves soil structure and the capacity of the soil to hold water, air and nutrients, and, if the green manure crop is a legume, it can build soil nitrogen.
- Grazing strategies: Used to manage the amount of light captured by the plant.
- Weed management: Reduces the population of unwanted plant species that are either competitors in a crop or pasture, or are poor producers in comparison to the more desirable plants.

It is important to remember that while there are a many factors that can be managed and manipulated, the key is to identify the most limiting factors and target these with cost-effective strategies to optimise production.

Where these factors cannot be managed cost effectively, e.g. extreme cold or saline soils, there is very little that can be done to lift production. The following chapters focus on managing the limitations of soils and nutrients to optimise production.



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Chapter 3

Plant Nutrient Requirements

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3 Plant Nutrient Requirements

3.1 Introduction

Plants require nutrients for normal growth. These must be in a form useable by the plants and in concentrations that allow optimum plant growth. Furthermore, the concentrations of the various soluble soil nutrients must be properly balanced.

Learning outcomes

At the completion of this chapter, you should:

- Know which nutrients are essential for plant growth.
- Know which nutrients are required in large quantities.
- Understand the principles of the nutrient cycles for the major nutrients.
- Know which nutrients are required in smaller quantities.

3.2 Why do we need fertilisers?

Many Australian soils are old and weathered. In fact, many are considered the oldest soils in the world; and the nutrients have been leached, which has resulted in soils of low fertility. For example, average Australian soil phosphorus levels are 40% lower than English soils and up to 50% lower than North American soils.

Improved pasture species allow a much higher stock-carrying capacity; but to maintain this productivity, they require a higher level of soil fertility than do native pasture species.

Fertiliser applications are required to overcome the soil's inherent nutrient deficiencies and to replace the nutrients that are lost or removed from the soil by pasture growth, fodder cropping or conservation, and animal products, such as milk or meat.

Nutrient redistribution around the farm and the inherent ability of soils to 'retain' applied nutrients; so they are less available for plant uptake, are other reasons for fertiliser applications.

In addition to the loss of nutrients in fodder, grain, and animal products, a significant amount of nutrients can be lost off the farm in runoff from irrigation and rainfall - see Chapters 10.5.2 and 12.3. There are many factors that need to be considered in working out a profitable fertiliser program for a dairy farm. For details on nutrient planning see Chapter 15.

3.3 The essential plant nutrients

Seventeen nutrients are known to be essential for plant growth. For a nutrient to be classified as essential it must be:

- Essential for the plant to complete its life-cycle.
- Unique, not able to be replaced by another.
- Required by a substantial number of plant species, not just a single species or two.
- Directly involved in plant metabolism, that is, it must be required for a specific physiological function.

The essential nutrients can be divided into two categories:

- Major nutrients (macronutrients).
- Minor nutrients (micronutrients), often referred to as trace elements.

These are listed in Table 3.1. (See also Table D.1 in Appendix D.)



Table 3.1 The essential nutrients required by plants

| MAJOR NUTRIENTS | MINOR NUTRIENTS (TRACE ELEMENTS) |
|-----------------|-------------------------------------|
| Carbon (C) | Molybdenum (Mo) |
| Hydrogen (H) | Copper (Cu) |
| Oxygen (O) | Boron (B) |
| Nitrogen (N) | Manganese (Mn) |
| Phosphorus (P) | Iron (Fe) |
| Potassium (K) | Chlorine (Cl) |
| Sulphur (S) | Nickel (Ni) |
| Calcium (Ca) | Zinc (Zn) |
| Magnesium (Mg) | |

Other minor elements, such as sodium, silicon, cobalt, strontium and barium, do not fit the criteria to be universally essential. These are called beneficial nutrients, as are the seventeen nutrients listed in Table 3.1, although the soluble compounds of some may increase plant growth. Other elements required for animal health, such as selenium, fluorine and iodine, have no known value to plants.

A deficiency in any one of the 17 essential nutrients will reduce growth and production, even though the others may be abundantly available. Optimum pasture production can only be obtained if all the requirements for plant growth are met. This fundamental principle is known as “**the law of the limiting**” or “**Liebig’s Law of the minimum**” and often represented by the barrel with uneven staves as in Figure 3.1.



Figure 3.1 Liebig’s Law of the Minimum.

(Source: <http://www.greencare-concept.nl/eng/pagina/141/prevention-through-nutrition.html>)

Liebig’s Law of the minimum says:
“The yield of a plant is limited by a deficiency of any one essential element, even though all others are present in adequate amounts.”



Even though Liebig's law is discussing essential nutrients, the same principle applies to all other facets of pasture management, for example soil moisture, soil structure, grazing management and ground cover. Pasture production will not reach full potential if any one management aspect is limiting even though plant nutrients are in adequate supply.

The first three major nutrients, carbon, hydrogen and oxygen, are non-mineral and generally considered to come from carbon dioxide in the atmosphere and from water. Combined, they make up 90% to 95% of the dry matter of all plants.

The remaining nutrients are found in the soil and are taken up through the root system of the plant. However, legumes (such as clovers, lucerne and medics) also have the ability to convert atmospheric nitrogen into a plant-available form - see [Section 3.4.1.3](#).

3.4 The major nutrients or macronutrients

The macronutrients (nitrogen, phosphorus, potassium, sulphur, calcium and magnesium) are required in relatively large quantities by plants; measured by either a percentage or mg/kg. Plant growth may be retarded because:

- These nutrients are lacking in the soil.
- They become available too slowly.
- They are not adequately balanced.

3.4.1 Nitrogen

Nitrogen (N) is needed for all growth processes, as it is the major component of amino acids, which are the building blocks of proteins, enzymes and the green pigment chlorophyll. Chlorophyll converts sunlight energy into plant energy in the form of sugars and carbohydrates.

3.4.1.1 Nitrogen deficiency symptoms

Nitrogen deficiency symptoms include:

- Stunted growth.
- Yellowing or light-green colour in pastures (very occasionally orange and red pigments may dominate).
- Low protein content of grasses and crops.
- A lack of nodules or very small whitish nodules on clovers and other legumes.

Nitrogen is mobile in plants, so deficiencies show up in the oldest plant tissue first – see Chapter 8.6.2.1. Nitrogen deficiency in legumes and grasses has similar symptoms to a sulphur deficiency. However, sulphur is immobile in *most* plant species, so sulphur deficiencies typically show up in the youngest plant tissues first. An exception is in subterranean clover where sulphur is more mobile, so the deficiency shows up in young and old plant tissue.

3.4.1.2 The nitrogen cycle

Nitrogen is present in the soil in many different forms (Figure 3.2), including as a gas (N_2); as various oxides of nitrogen, such as nitrate (NO_3) and nitrite (NO_2); and as ammonia (NH_3), amines (formed from ammonia), or ammonium (NH_4). Organic matter is a major storage area for nitrogen. In fact, in most soils, more than 95% of the nitrogen is present in the organic matter.

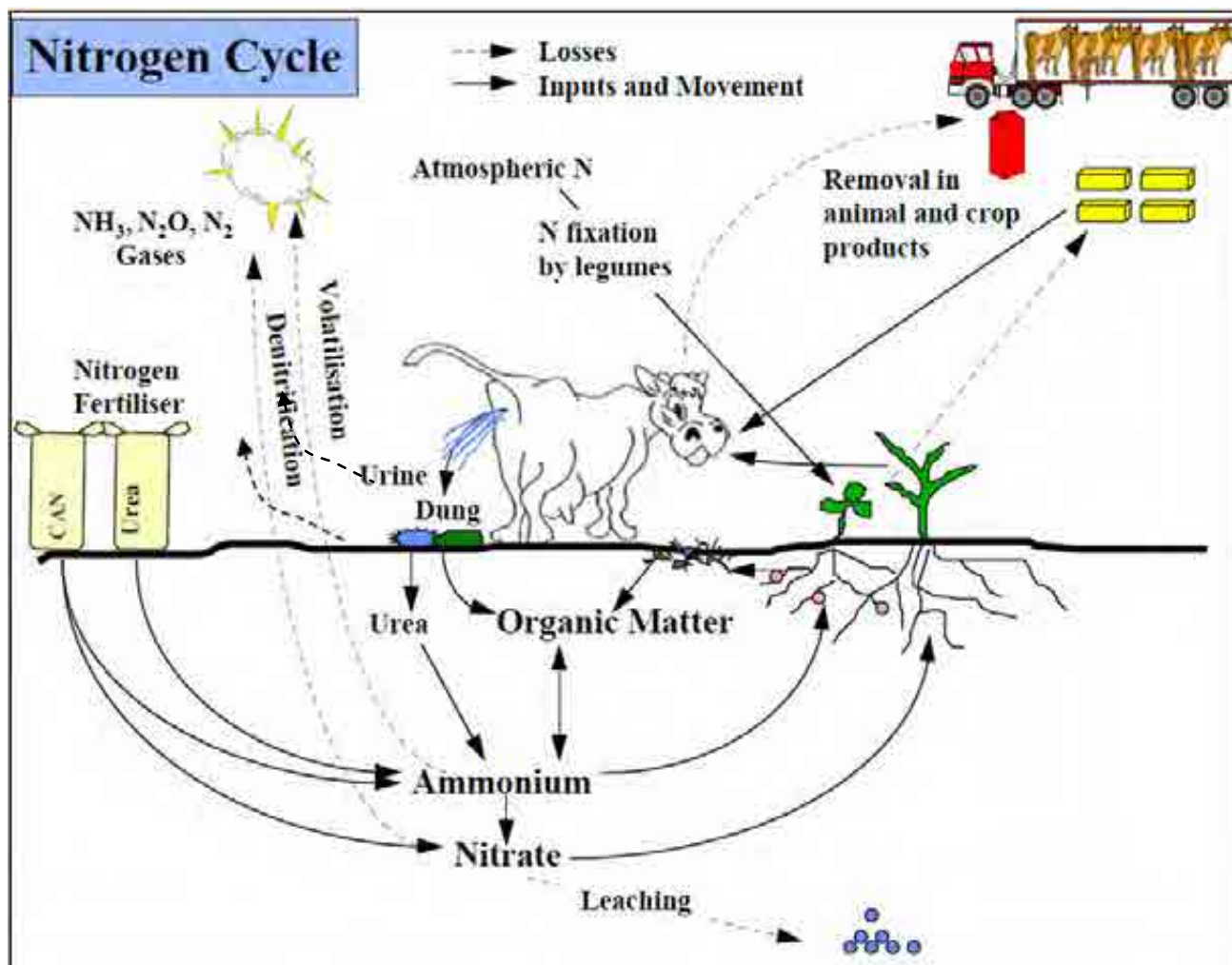


Figure 3.2 The nitrogen cycle of a dairy pasture

Plants can only use two of the many forms of nitrogen, namely, nitrate (NO_3) and ammonium (NH_4). Therefore, other forms of nitrogen need to be converted to either nitrate or ammonium before the plant can use them.

The conversion process is carried out by various soil micro-organisms, such as fungi and bacteria, and by chemical reactions in the soil - See Chapter 5.

Major losses of nitrogen occur through leaching, denitrification (breakdown of nitrogen compounds to less available forms), volatilisation (conversion of nitrogen to gaseous forms, which are lost to the atmosphere), and the removal of animal products and fodder (See Chapter 12.3)

Nitrogen is returned to the soil with varying levels of efficiency via animal manure and urine, bought-in feeds, nitrogenous fertilisers, and legumes (See the [nitrogen cycle animation](#)).

3.4.1.3 Where do legumes fit in?

The atmosphere is about 80% N, but plants such as legumes are able to use nitrogen from the air. They are able to do this by the development of small growths on their root system called nodules. These nodules contain bacteria called rhizobia, which can 'fix', or convert, nitrogen from the air into a plant-available form. This fixed nitrogen then becomes part of the pasture nitrogen cycle (see Figure 3.2). The nitrogen becomes available to grasses when the nodules or legume plants (roots, stems and leaves) die or are eaten by an animal then returned as dung or urine. The legume root



nodules have a life span of up to 6 weeks, and new ones are constantly developing. The nodules are a pinkish colour when actively fixing nitrogen; however, they may be white (N deficient), green (when nodules become older) or brown (decomposing) if growing in suboptimal conditions.



Figure 3.3 Nodules sliced in half, showing the pinkish colour (leghaemoglobin) indicative of healthy nodules in the centre, with old decomposing nodules on the left and ineffective white nodules on the right.

Source: <http://www.dpi.nsw.gov.au/agriculture/pastures/pastures-and-rangelands/establishment/inoculating-legume-seed>

In a ryegrass/clover pasture, 50 to 250 kg N/ha/year can be fixed by the clover, depending on such factors as the clover content of the pasture, soil fertility, and moisture availability. This is equivalent to applying urea (which is 46% nitrogen) at a rate of 109 to 543 kg of urea/ha/year. At a price of \$500/tonne spread for urea, this is equivalent to about \$55 to \$270/ha/year. However, the amount of N fixed by clover in Australian dairy pastures is typically 50 kg N/ha/year or less due to the low legume content - see Chapter 12.2.1.

The rhizobia bacteria supply nitrogen compounds to the legume, and the legume supplies carbohydrates (energy) to the nitrogen-fixing rhizobia bacteria. If the soil environment is not ideal (for example, high acidity, lack of other nutrients, dry soils or salinity), these bacteria are adversely affected, which results in reduced nitrogen fixation and thus reduced pasture growth.

The various legume species often require 'inoculation' of the seed (mixing the seed with rhizobia bacteria) at sowing. Specific strains of the rhizobia bacteria are required for each of the major legume groups. For example, sub clovers require inoculant strain C, and white clover requires inoculant strain B.

It is essential to inoculate legume seeds when sowing into virgin, recently flooded, or newly cleared land because the soil will not have enough of the required rhizobia naturally present. Although it may not always be necessary to inoculate when resowing an old pasture, it is advisable.

Lime coating of the legume seed ensures that the soil environment surrounding the seed is more favourable (less acidic) for the rhizobia bacteria and young legume roots. In addition, several proprietary forms of coating (e.g. Prillcote® and Agricote®) contain ingredients to ensure longer survival of the inoculant if sowing is likely to be delayed. Insecticides can also be included in the coating to provide pasture plants with a degree of protection against some insect pests after germination (e.g. lucerne flea or red-legged earth mite).



3.4.2 Phosphorus

Phosphorus (P) helps run the 'power station' inside every plant cell and has a key role in energy storage and transfer. Phosphorus is necessary for all growth processes and for the nodulation of rhizobia bacteria and nitrogen fixation.

3.4.2.1 Phosphorus deficiency symptoms

Phosphorus deficiency symptoms include:

- Stunted growth, weak roots and shoots, fewer tillers.
- Depressed yields.
- Purple tints on small leaves.
- Small, dark green leaves on mature clover plants.

Growth of new pastures can be severely restricted when the soil is deficient in phosphorus. As animals derive their phosphorus requirements from pastures, animal production may also be affected by low phosphorus levels.

Phosphorus is a mobile nutrient within the plant and is moved to the actively growing tissue, such as root tips and growing points in the tops of plants – see Chapter 8.6.2.1. Therefore, deficiency symptoms occur first in the older leaves.

It is important that plants have an adequate supply of phosphorus to ensure recovery and regrowth after grazing. Likewise, newly sown pastures benefit from a supply of readily available phosphorus close to the germinating seed to help quickly develop a large root system.

3.4.2.2 The phosphorus cycle

When phosphorus fertiliser (for example, superphosphate) is applied to a pasture, the phosphorus enters a phosphorus cycle. As can be seen from Figure 3.4, the phosphorus can move around the system, as well as be lost from the system, via many different pathways. The P cycle is very complex, involving a great deal of interaction and chemical reactions in the soil.

The phosphorus in the soil can be taken up by plants, then consumed by animals and returned to the soil in ruminant dung. The phosphorus can also move about in the soil, changing in its chemical form and in its availability to plants.

Being hygroscopic (moisture-attracting) in nature, superphosphate granules attract moisture from the atmosphere, leading to the granule releasing P even in very dry conditions. Despite the movement shown in Figure 3.4, phosphorus in the soil is relatively immobile. Many chemical reactions take place when phosphorus is applied to the soil, and only a small proportion remains in solution and readily available to the plants (see Chapter 9.2.5). The remainder is 'bonded' (or 'fixed' or 'sorbed') in a less available form to the surface of the soil clay particles and organic matter. A proportion of this fixed phosphorus does become available over a period of time and is referred to as the soil phosphorus reserve – See [Section 3.4.2.3.3](#) 'Soil sorption'.

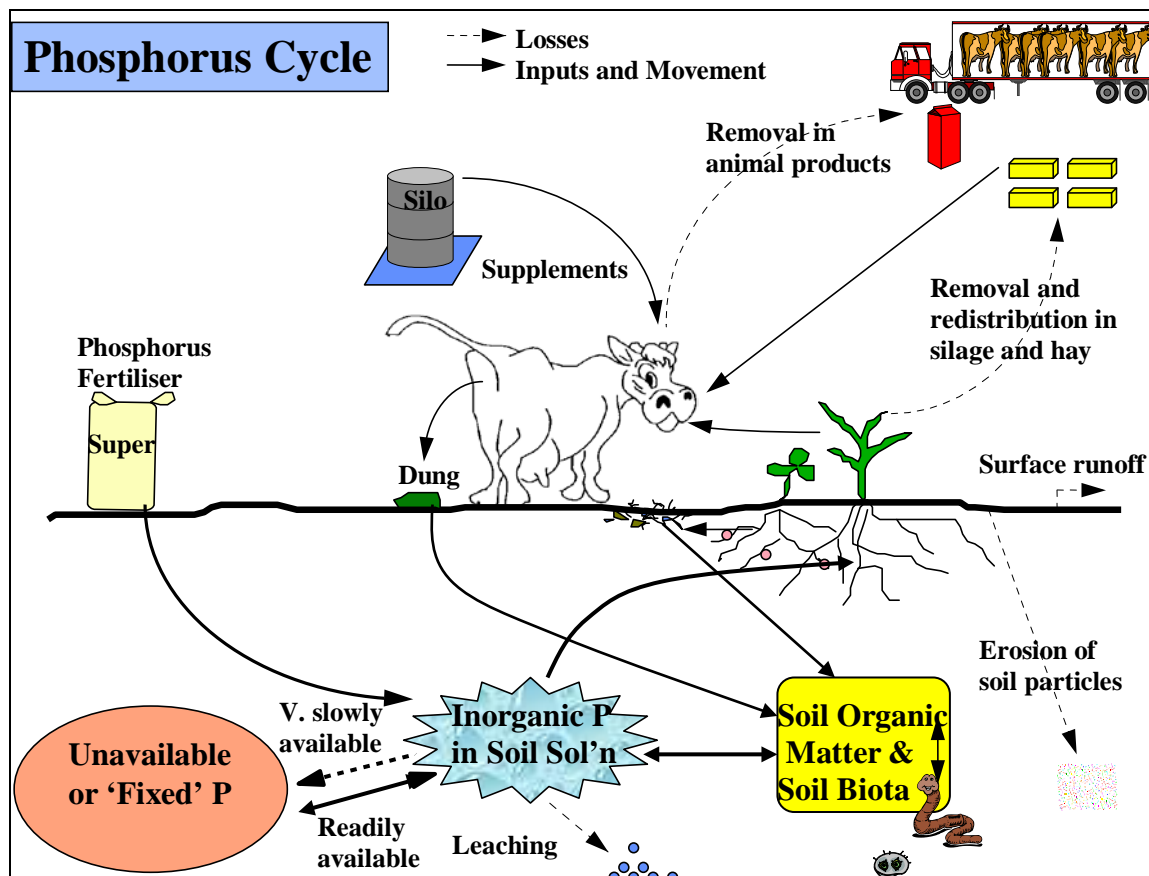


Figure 3.4 The phosphorus cycle of a dairy pasture

3.4.2.3 Losses of phosphorus

Phosphorus; supplied either as fertiliser applications or naturally from the soil, undergoes losses by various mechanisms. These losses occur by:

- [Product removal.](#)
- [Redistribution of ruminant dung.](#)
- [Soil losses:](#)
 - [Leaching.](#)
 - [Surface runoff.](#)
 - [Soil sorption](#) (fixation).
 - [Erosion.](#)

3.4.2.3.1 Removal of phosphorus in plant and animal products

Phosphorus is lost from the pasture in plant and animal products (milk and meat). Cutting hay or silage on a paddock and not feeding it back on the same paddock can very quickly 'mine' the paddock's fertility. Product removal off farm will result in a certain amount of phosphorus leaving the farm. Milk production results in much higher removal rate of phosphorus than does beef or wool production.

3.4.2.3.2 Redistribution of faeces

Large quantities of phosphorus can be removed or relocated within the growing pasture through the behaviour and management of the dairy herd. Cows graze pasture from all over the paddock but deposit a greater proportion of dung around gateways, stock camps, feedpads, shelter belts, water troughs, and other places where cattle gather. Dung dropped on the dairy yard and laneways can account for approximately 10% of total dung. The amount will vary according to how long the animals have been off pasture and their level of harmony in the dairy shed and yard. Cattle will



deposit more dung and urine in the laneways, shed and yard if they are continually upset by dogs or operators. The nutrients contained in dung, urine, milk and those retained are listed in Table 3.2.

Table 3.2 Fate of nutrients consumed by lactating dairy cows.

| NUTRIENT | % IN FAECES | % IN URINE | % IN MILK | % RETAINED |
|----------------|-------------|------------|-----------|------------|
| Nitrogen (N) | 26 | 53 | 17 | 4 |
| Phosphorus (P) | 66 | 0 | 26 | 8 |
| Potassium (K) | 11 | 81 | 5 | 3 |

Source: During (1984).

Proportionally more of the phosphorus taken up by dairy cows when they graze pasture is retained by the cows and lost from the grazing area than is the case for potassium and nitrogen. Conversely, most of the potassium ends up in the urine. Table 3.2 illustrates just how little of what is eaten by a lactating dairy cow is actually retained. For information on cycling and losses of a wider range of nutrients see the article by [Michael Russelle \(2012\)](#).

3.4.2.3.3 Soil losses

Leaching: Despite the solubility of a single superphosphate granule in water, the phosphate ion is generally not leached (washed through the soil profile), as it is rapidly tied up in various forms soon after application. The amount of leaching that occurs in soils varies widely according to the type of nutrient, soil type, and amount of rainfall. Leaching is related to the amount of organic matter or the amount and types of clay minerals to which the phosphorus can adsorb (attach). Leaching is more of a problem in the sandy soil types (since they contain low amounts of organic matter and clay minerals), in areas of high rainfall, or when phosphorus is lost in surface runoff when fertiliser is applied just before a heavy rainfall event.

Phosphorus may also move down the profile in soils that are prone to cracking and in soils that have reached saturated levels of phosphorus.

We do not have accurate figures for this loss in most Australian soils under a pasture situation, but leaching of phosphorus is known to be relatively low in most soils types. Sulphur, boron and nitrogen are much more prone to leaching than phosphorus is.

Surface runoff on irrigated farms: As much as 11% of applied phosphorus can be carried away in irrigation water. See Chapter 10.5.2 for information on ways to reduce these losses.

Surface runoff on dryland farms: A small amount of applied phosphorus may be lost via surface water carrying away minute amounts of dissolved phosphorus in the short term; especially if highly water soluble fertiliser forms e.g. superphosphate are used. Most phosphorus lost in runoff is phosphorus present in pasture residues and other soil biota. This amount of dissolved phosphorus is much higher if a heavy rainfall occurs soon after applying the fertiliser. Research has shown that, on clay loam soils, the loss of P in surface runoff is reduced by 50% if rain falls 4 days after application and by 75% if rain occurs after 7 days, compared to when rain falls immediately after application.

The major effect of this loss is that phosphorus is carried to dams and lakes and, in combination with the plentiful supply of nitrogen in these areas, allows blue-green algal blooms to occur. Losses from phosphorus dissolved in soil moisture, especially following heavy rain, are dependent on the time since application of fertiliser, soil type, rainfall intensity, slope, etc. This is an area that has attracted much research with the **Phosphorus Environmental Risk Index (PERI)** now providing an indication as to the amount of phosphorus held in the soil that is adequate for pasture or crop



production, with anything above this being excessive and at risk of leaching into waterways. See Chapter 10.5.2 for tips on how to reduce these losses.

Sorption by soil: Phosphorus tends to undergo sequential reactions that produce phosphorus-containing compounds of lower and lower solubility when applied to both acidic and alkaline soils. Therefore, the longer the P remains in the soil, the less soluble it is and the less available it becomes for plant uptake.

The primary factors governing the sorption of P in the soil profile include:

- Soil pH; the more acid the greater the retention,
- Distribution of soil particle sizes; soil texture with sandy soils having greater leaching ability,
- Presence of reactive iron (Fe) and aluminium (Al),
- Organic matter incorporation,
- Nature of adsorbed cations as well as anion adsorption.

When phosphorus is first applied to soil, a rapid reaction removes the soluble P from soil solution. Slower reactions then continue to gradually reduce P solubility for months or even years as the phosphate compounds age.

Imagine a fountain cascading down a series of steps with the steps indicating time and decreasing availability of P to plants. The soluble P, applied at the top, becomes much less available to plants over time due to an ever-increasing strength of P sorption by soil compounds such as iron, aluminium and manganese phosphate, from the top of the cascade to the bottom.

Soils high in organic matter or clay content have a stronger phosphorus-fixing capacity than do sandy soils. Some clay soil types (for example, krasnozems, or red soils) adsorb more phosphorus than other clay soils because of the type of clay mineral in the topsoil. Most of this adsorbed phosphorus is not available to the plant, although some may become available over time.

Soils with high aluminium and iron levels, such as red soils of volcanic origin, usually have a very high phosphorus-fixing (or sorbing) capacity. In these soils, the phosphorus reacts with the aluminium or iron to form relatively insoluble chemical compounds, which results in a higher proportion of applied phosphorus being locked up and unavailable to plants.

Soils vary widely in the amount of phosphorus (and other nutrients) 'fixed' in soils. The **Phosphorus Buffering Index** (PBI) has been developed and has been widely adopted across many states and industries to help with differentiating soil P-fixing ability - see Chapters 9.2.5.1 and 15.5.2.

Erosion of soil particles: Since phosphorus binds quickly to soil particles (in other words, becomes particulate P), it is obvious that soil erosion can result in phosphorus losses. Such erosion losses can occur along stream banks; via tunnel, gully or sheet erosion; from newly renovated or laser-graded irrigation areas; and from severely pugged pastures or sacrifice paddocks. The quantity of P lost by erosion is usually low but may be a significant contributor to the environmental problem of eutrophication (high levels of nutrients) causing unwanted and large growth of water weeds or an algal bloom of, say, blue-green algae.

Recent research has provided some indication of the extent of this loss and is providing some guidelines for reduction of P losses. Obviously, any management that reduces loose soil particles entering waterways will achieve this. Accurate figures for this loss of phosphorus are difficult to assess for individual farms. It is small but should be reduced or completely stopped, if possible.



3.4.3 Potassium

Potassium (K) is needed for a wide range of important processes within the plant, including cell wall development, flowering and seed set. Potassium has a key role in regulating water uptake and the flow of nutrients in the sap stream of the plant. It helps legumes fix nitrogen and also helps the plant to resist stress from weather, insects and diseases.

3.4.3.1 Potassium deficiency symptoms

Potassium deficiency symptoms include:

- Reduced growth (possibly up to a 50% drop in yield of some crops before deficiency symptoms appear).
- Yellowing and whitish spots along the outer margin of clover and lucerne leaves, which subsequently develop a necrosis, or deadening, of the outer leaf margins – see Figure 3.5
- In grass, a pale-green colour, which may be followed by a pronounced yellowing to browning off, beginning with the tips of older leaves (called chlorosis, or tip burn). These symptoms are not sufficiently different from nitrogen deficiency or frost effect to allow them to be used alone to identify a K deficiency in grass.
- Excess salinity may also cause brown, necrotic leaf margins, but this occurs mostly in the younger leaves.



Figure 3.5 Lucerne leaves showing varying degrees of potassium deficiency. *Source:* David Hall.

Potassium is very mobile in the plant, and deficiency symptoms initially occur in the older leaves – see Chapter 8.6.2.1. Deficiencies are most obvious at times of peak potassium demand; in other words, Spring. Potassium deficiencies may not appear if a combination of nutrient deficiencies, such as phosphorus and potassium together, are limiting growth.

Grasses tend to be more deeply rooted and have more fibrous roots than clovers and therefore can compete more strongly for potassium. A symptom of potassium deficiency is a grass-dominant pasture that often has an abundance of weeds. Older urine patches may show good grass or clover growth; if clover is present in the pasture, as 80% to 90% of the potassium in pasture consumed by stock is excreted in urine.

Deficiencies of potassium are most likely to occur on lighter sandy soils and regular ‘day’ paddocks and particularly in paddocks that have been repeatedly cut for hay or silage.



3.4.3.2 The potassium cycle

Potassium in the soil-pasture system (Figure 3.6) is cycled in a similar way to phosphorus. Animals grazing pastures recycle most of the potassium they take in as urine. However, they concentrate this potassium return around water troughs, stock camps and yards. Hay-making and silage-making are the major ways that potassium reserves are removed or redistributed – See Appendix H for nutrient contents of feeds.

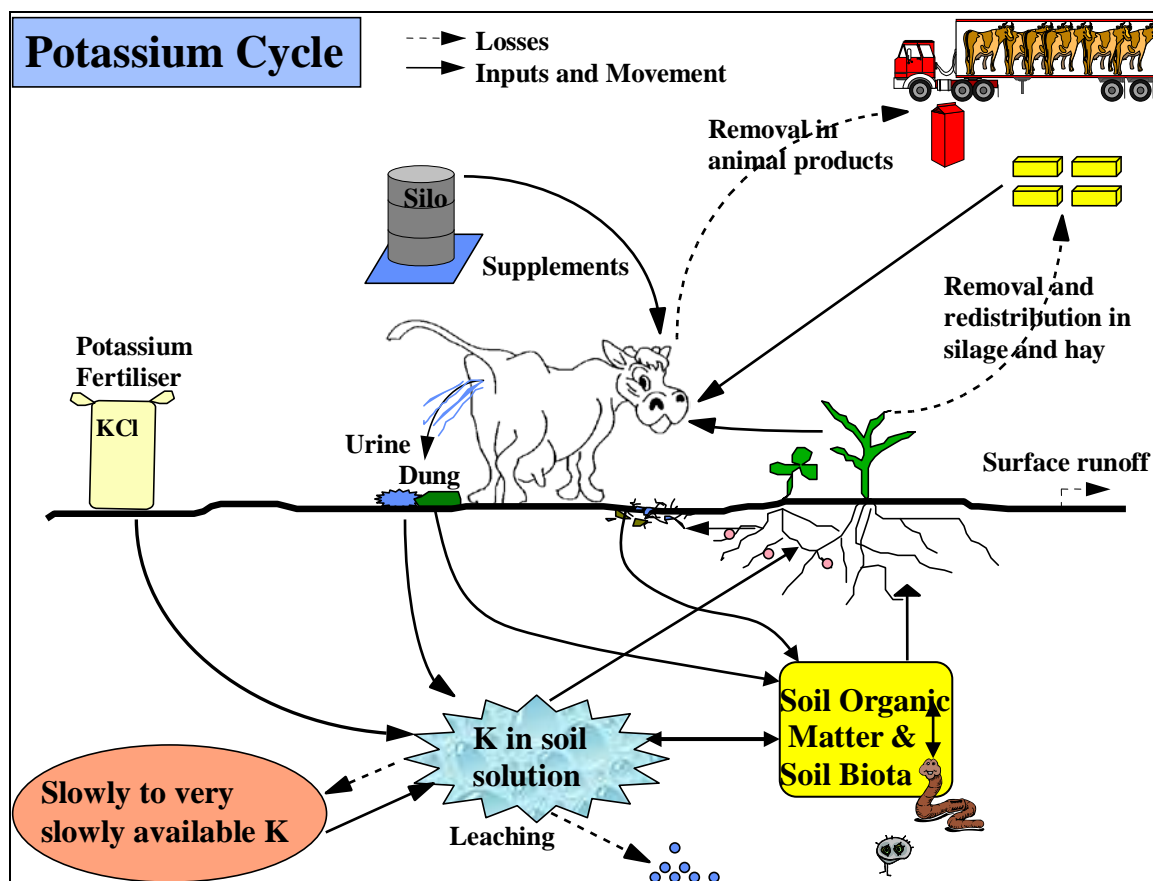


Figure 3.6 The potassium cycle of a dairy pasture

Unlike phosphorus, when potassium is applied as a fertiliser it does not react with the soil to form insoluble compounds. However, like phosphorus, potassium does not form any gases that could be lost to the atmosphere like nitrogen does. The soil's cation exchange properties and mineral weathering influence its behaviour in the soil. Potassium, unlike P and N, causes no off-site environmental problems, such as eutrophication, when it leaves the soil system.

Potassium can be temporarily held in clay particles as exchangeable potassium and becomes available for plant uptake when it moves back into the soil solution. Dry soil immobilises potassium, thereby reducing its availability temporarily. Waterlogging also reduces K uptake due to lack of oxygen. Unlike the P in single superphosphate, if K is applied to dry soils, it will not be utilised until rain or irrigation occurs.

Potassium is found in four forms in the soil: mineral non-exchangeable potassium, non-exchangeable potassium, exchangeable potassium, and potassium in soil solution (water-soluble potassium) - see [Figure 3.7](#). The total amount of K present in each form will depend on the potassium content of the parent material, extent of weathering and leaching, redistribution by plants (fodder) and animals, and the amount of applied potassium.

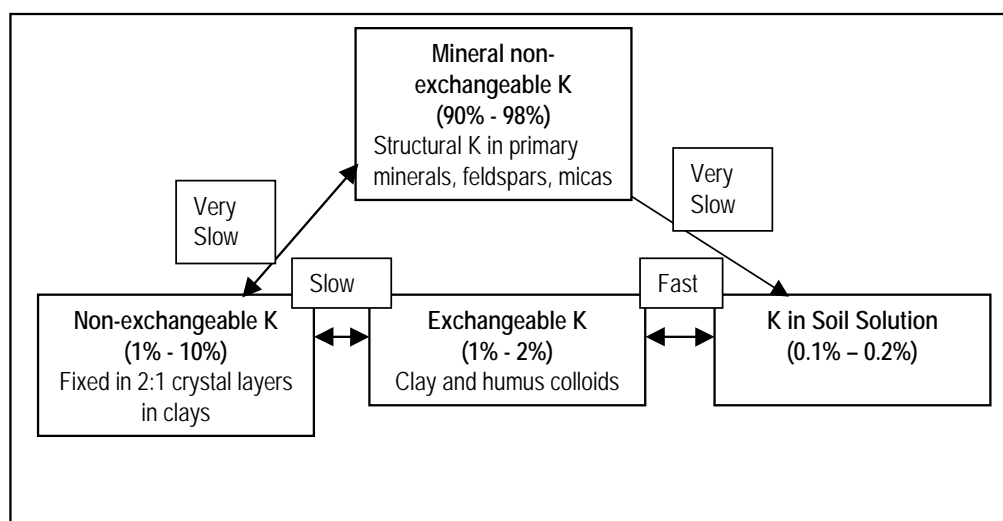


Figure 3.7 Forms of potassium in the soil and their plant availability.

Approximately 90% to 98% of the total soil K is in the non-exchangeable form, although some becomes available very slowly due to weathering. In the non-exchangeable form it is part of the internal structure of clays, mineral particles and parent rock material. This form is not available for plant uptake. Approximately 1% to 2% is in the exchangeable form and is lightly bound or held (retained) on the surface of clay particles and organic matter. This form becomes available rapidly and easily to plants when it exchanges with other cations and moves back into the soil solution. Hence, it is referred to as '**exchangeable K**' when it is measured in a soil test - see 'Exchangeable potassium' in Chapter 9.2.9.5. Approximately 0.1% to 0.2% is in the soil solution and readily available for uptake by plants. Both the soil solution and exchangeable potassium are measured in a soil test as '**available K**' - see Chapter 9.2.6.

3.4.3.3 Losses of potassium

The potential for fixation or leaching of potassium depends largely on the soil clay content and its mineralogy; the level of soil organic matter; and the climate, particularly rainfall or irrigation levels.

In sandy soils low in clay, potassium largely remains in the soil solution and can be leached below the plant root zone and potentially into the ground water. Such lighter soils, especially in high-rainfall districts or under high irrigation levels, are more prone to potassium deficiencies due to this leaching effect.

Heavy soils (such as clays) or soils high in organic matter are usually high in potassium. However, some can be low in potassium.

3.4.3.4 Responses to potassium fertilisers

In rainfall-dependent pastures, soil testing and test strips provide an excellent prediction of likely potassium responses. If a response is to be seen, it will occur in the spring following an autumn or early winter application because of the rapid demand for potassium in spring. The value of soil testing versus plant tissue testing for potassium needs to be assessed in light of soil texture and extent of the following rainfall. Light textured (sandy) soils can leach the soil potassium below the pasture root zone, so in these situations plant testing will be more reliable.

It must be recognised that dairying is an intensive system and significant rates of potassium are being removed, so responses to potassium may occur sometime in the future.



3.4.3.5 Animal health implications

High rates of potassium fertilisers can cause low plant calcium and magnesium levels, which may induce the metabolic disorders hypocalcaemia (**milk fever** – see [Section 3.4.5.2](#)) and hypomagnesaemia (**grass tetany** – see [Section 3.4.6.2](#)) respectively. It is important to understand that dairy cows can acquire the grass tetany disorder from grazing pastures that contain excessive potassium; whether from fertiliser or inherent levels, in particular from effluent fields that accumulates in some cases very high soil potassium levels. For more information about grass tetany follow the links:

- <http://www.dairyaustralia.com.au/Animals-feed-and-environment/Animal-health/Animal-health-fast-facts/Downer-cows/Grass-tetany.aspx>
- http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0013/111334/Grass-tetany-in-cattle.pdf
- <http://www.dpiw.tas.gov.au/inter/nsf/WebPages/RPIO-4ZM89P?open>

3.4.4 Sulphur

Sulphur (S) is required for the formation of several amino acids, proteins, and vitamins and for chlorophyll production. It also helps the plant to resist stress from weather, insects and diseases.

3.4.4.1 Sulphur deficiency symptoms

Sulphur deficiency symptoms include:

- Plants appear stunted.
- Plants tend to become spindly with thin stems and petioles on legumes.
- Small, pale, yellow-green leaves with lighter coloured veins.
- Poor development and low numbers of nodules on legumes.

Plants severely deficient in sulphur show similar symptoms to nitrogen deficiency. The major difference between sulphur deficiency and nitrogen deficiency is that sulphur is immobile within the plant, and deficiency symptoms appear first in the younger leaves, whereas nitrogen deficiency affects the older leaves first. This is true for grasses, however S is more mobile in subterranean clover so the whole plant rather than young leaves typically becomes lemon yellow and, if the deficiency is severe, clover leaves cup upwards. When sulphur levels are low, grasses, because of their larger root system, will compete very strongly for the available sulphur, to the detriment of the legumes. This results in a grass-dominated sward and reduced pasture quality.

3.4.4.2 The Sulphur cycle

The sulphur cycle is shown in [Figure 3.8](#). Significant amounts of sulphur are removed through meat and plants harvested for fodder, but only small amounts are removed through milk - see Appendix H.

In the past, sulphur deficiencies have been rare because most farmers used low-analysis fertilisers, such as single superphosphate, which contains high levels of sulphur (11%) – see Chapter 11.3.1. However, if high-analysis fertilisers, such as triple superphosphate and Diammonium Phosphate (DAP) are used, then the potential for sulphur deficiencies may increase because these fertilisers contain much lower levels of sulphur. For example, triple superphosphate contains only 1% S.

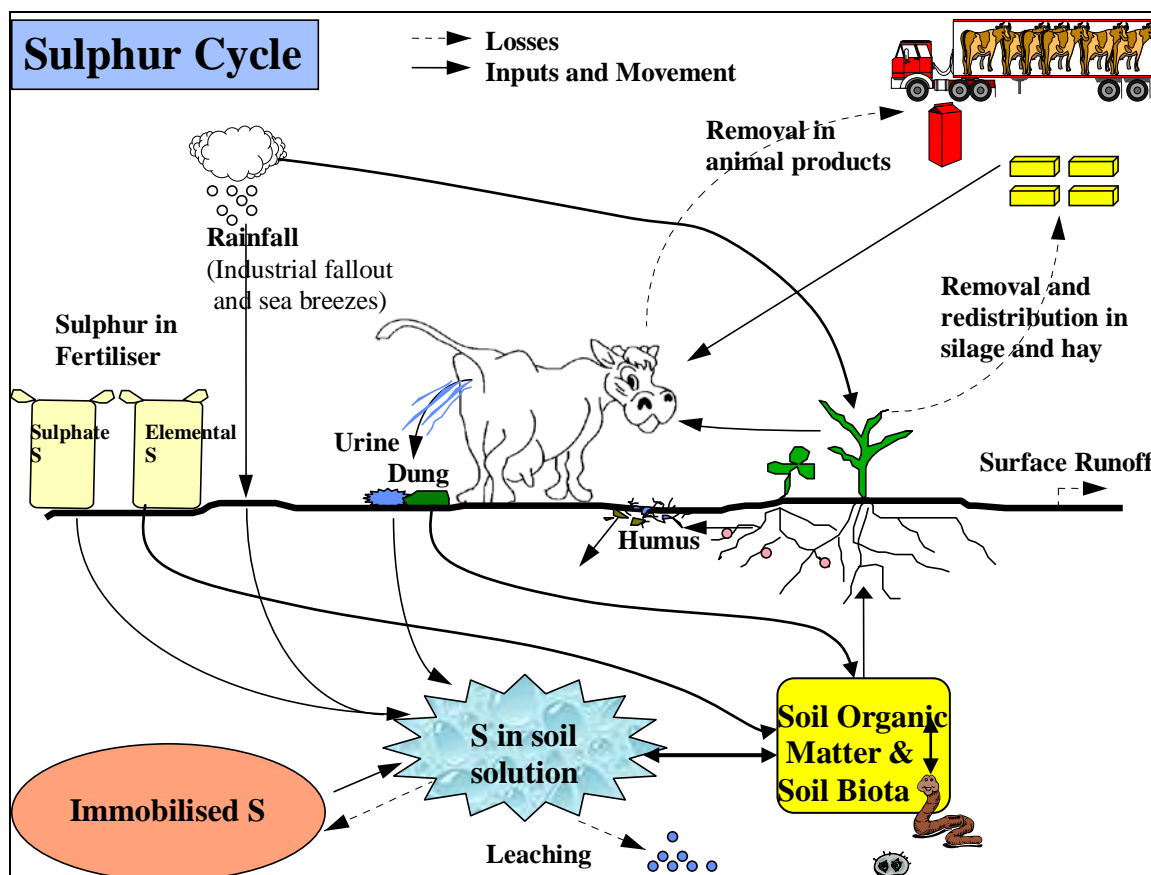


Figure 3.8 The sulphur cycle of a dairy pasture

Most sulphur in soils is derived from soil organic matter and must be mineralised (converted to the inorganic sulphate form, SO_4^{2-}), before it can be taken up by the plants. In this form, it is very soluble and may be more readily leached, particularly from sandy soils or in high rainfall conditions or under high levels of irrigation. In some soils, the sulphate is adsorbed on (fixed to) soil particles, which reduces leaching. This adsorbed sulphur becomes available as it is released back into the soil solution - see Chapter 9.2.7.

3.4.4.3 Forms of sulphur

Two forms of sulphur are used in fertilisers. They are sulphate sulphur (SO_4^{2-}), such as in superphosphate, and elemental sulphur (S elemental). Sulphate sulphur (SO_4^{2-}) is readily available for plant uptake and more effective on very deficient soils. The elemental form (S elemental) must be converted by bacteria in the soil to the sulphate form before it is readily available to the plant. Therefore, this more slowly available form of sulphur (S elemental) may be more suitable on sandy soils that have less organic matter and are susceptible to leaching. Where a soil test reveals a sulphur deficiency, then the sulphate form (SO_4^{2-}) will provide a quicker response.

Elemental sulphur (S elemental) applied at a rate of up to about 30 kg/ha has negligible effect on soil properties but, if applied in large quantities (over 800 kg/ha), can lower the pH of soils. The extent of pH reduction and reaction rate is influenced by the pH buffering capacity of the soil and the original pH level. The rate at which elemental sulphur converts to sulphate sulphur depends on the type of sulphur applied, particle size of the material, soil temperature, soil moisture content and population levels of the sulphur-oxidising bacteria.

If soil sulphur levels are high, then it is usually a lower-cost option to use a low-sulphur phosphorus fertiliser, such as triple superphosphate.



3.4.5 Calcium

Calcium (Ca) is usually in adequate supply for plant growth. It is involved in the proper functioning of growing points (especially root tips), maintaining strong cell walls, and seed set in clovers.

3.4.5.1 Calcium deficiency symptoms

Deficiency symptoms are rare because calcium is common in the earth's surface. It is also a component in many fertiliser products and in lime and gypsum. Soils low in calcium usually have associated adverse conditions, such as low pH and high aluminium, iron, and manganese - see 'Exchangeable calcium' in Chapter 9.2.9.3. In very rare situations, heavy applications of potassium may induce a calcium deficiency, particularly on very acid soils, possibly resulting in hypocalcaemia, or milk fever.

Deficiency symptoms can also occur in strongly acidic peaty soils, where the calcium content may be less than 0.1%.

3.4.5.2 Animal health implications

Milk fever is caused by low levels of calcium in the blood stream of cattle. This often occurs at or soon after calving when the cow's requirements for calcium are high. When high rates of potassium (for example, muriate of potash - MOP) and nitrogenous fertilisers that produce ammonium ions (for example, DAP) are used together, the potassium or ammonium ions interfere with plant root uptake of calcium, thereby raising the risk of inducing milk fever - see [Figure 3.9](#). However, nitrogenous fertilisers applied on their own do not cause this problem.

For more information about milk fever follow the links:

- <http://www.dpi.vic.gov.au/agriculture/pests-diseases-and-weeds/animal-diseases/beef-and-dairy-cows/milk-fever-hypocalcaemia-in-cows>
- <http://www.dairyaustralia.com.au/Animals-feed-and-environment/Animal-health/Animal-health-fast-facts/Downer-cows/Milk-fever.aspx>
- http://www.daff.qld.gov.au/27_15479.htm
- <http://www.dairyaustralia.com.au/Levy-investment/Case-studies/Transition-cow-management.aspx>

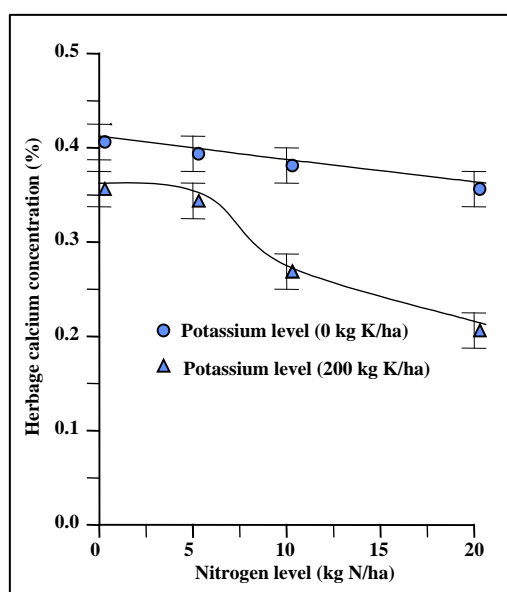


Figure 3.9 Effect of DAP plus MOP on calcium concentration in pasture.
Source: Bolan (1998).



3.4.6 Magnesium

Magnesium (Mg), like calcium, is usually present in sufficient quantities in the soil for plant growth; and pasture deficiencies are rare. It is an essential component of chlorophyll and is required for the transport of phosphorus around the plant.

3.4.6.1 Magnesium deficiency symptoms

Magnesium deficiency symptoms, rarely seen in most Australian states include:

- Yellowing of leaves while the leaf veins remain green.
- Abnormally thin leaves.
- Older leaves mainly affected and affected first.

Magnesium is mobile within the plant, and a deficiency presents itself in the older leaves first.

The main source of magnesium for pasture deficiencies is dolomite (a compound mineral of calcium carbonate and magnesium carbonate containing 8% to 13% Mg).

As with calcium, magnesium plays an important role in the cation exchange capacity in the soil - see 'Exchangeable magnesium' in Chapter 9.2.9.4. However, magnesium is more exchangeable than calcium, and the magnesium ion is more soluble and susceptible to leaching.

3.4.6.2 Animal health implications

In most pasture situations, magnesium is present in adequate quantities for plant growth. However, the level of magnesium in the grass may be too low to meet the animals' requirements and may lead to a condition known as **grass tetany**. Pasture magnesium levels are highest in summer and lowest in late winter and early spring. Grasses, which contain less magnesium than legumes do over most of the year, are usually dominant in late winter and early spring. Thus, grass tetany has typically occurred in late winter and early spring. Also, low temperatures and wet soils can reduce magnesium levels in forage.

However, high application rates of potassium fertilisers or dairy shed effluent can result in a **luxury consumption** of potassium. In other words, the plant takes up more soluble K than it requires and no yield increase occurs. This high concentration of plant potassium can often result in a lower proportion of other nutrient cations in the plant, such as calcium, sodium and, in particular, magnesium. These low magnesium levels may induce hypomagnesaemia, or grass tetany, in cattle. With more farmers applying more potassium and potassium blends in early spring, there appears to be anecdotal evidence that grass tetany is becoming more prevalent in the following autumn.

Grass tetany may also be caused by applying high rates of nitrogenous and potassium fertilisers, thus releasing ammonium ions and potassium ions together – see [Figure 3.10](#). The ammonium and potassium ions both compete with the uptake of magnesium ions by the plant root, thus resulting in a lower magnesium concentration the plants. The use of nitrogenous fertilisers on their own does not cause this problem.

Also, animals consuming pasture or fodder high in potassium concentration can often upset the magnesium movement through the rumen and intestinal walls, consequently inducing a magnesium deficiency leading to grass tetany.

The cation exchange section of your soil tests can be used to determine the ratio of magnesium to potassium in the tested paddocks - see 'Exchangeable magnesium' in Chapter 9.2.9.4.

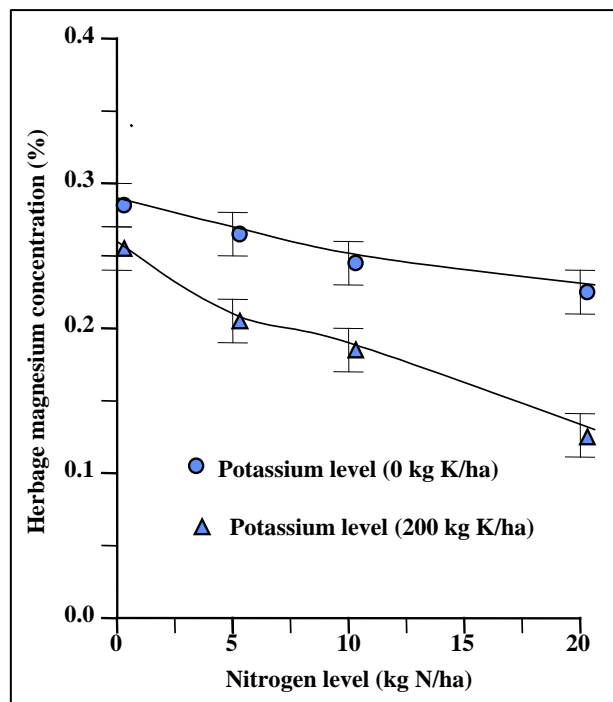


Figure 3.10 Effect of DAP plus MOP on magnesium concentration in pasture.
Source: Bolan (1998).

Grass tetany can be largely prevented by feeding animals a magnesium supplement at a rate of 60 grams/head/day mixed with hay or a grain supplement, or dusted on pasture. The main sources of magnesium used in this way are Granomag, Magox or Causmag (magnesium oxide containing 50% to 56% Mg) and Epsom salts (magnesium sulphate containing 9.6% Mg).

For more information on grass tetany, refer to the web links listed in [Section 3.4.3.5](#).

3.5 Minor nutrients or trace elements

Although only required in small amounts, minor nutrients (micronutrients, or trace elements) are essential for plant growth. These nutrients often act as catalysts in chemical reactions. It is possible to have toxicities of trace elements, as well as deficiencies.

The micronutrients essential for plant growth are listed in [Table 3.1](#). (See also Table D.1 in Appendix D.) Particular trace element deficiencies are generally restricted to specific soil types or localities.

Many products in the market place extol the virtues of trace elements that are 'absolutely needed' by plants. Some companies use soil tests to determine whether trace elements are deficient in the soil. On the basis of many field and laboratory experiments and much experience, the Department of Primary Industries Victoria has found that soil tests are not a reliable method of detecting a trace element deficiency. Plant tissue tests (see Chapter 8.4) are far more reliable for assessing what was available for plant uptake, but even these are not always correct and must be taken at the appropriate times of the year to increase their accuracy and reliability. In addition, recommendations should be based on research conducted in Australian soils or on Australian plants, not on overseas data.

Some of the micronutrient deficiencies in plants can cause nutrient deficiencies in the animals that graze those plants. In some cases (for example, copper and manganese), these micronutrients are also essential for plant growth. In other cases (for example, selenium), they are not required by the



plant. Thus, in many cases of animal nutrient deficiency, it may be better to treat the animal rather than to apply fertilisers to pastures to overcome the problem. It is therefore important to discuss trace element issues with your local veterinarian.

Though plant testing is the recommended method for testing for trace element disorders in plants, it is usually unreliable for trace element requirements for animal nutrition. Testing body fluids (blood, urine, saliva) and tissues (liver, bone) is often required to determine whether animals have a trace element disorder. Seeking veterinary advice in addition to, or instead of, plant tissue testing is recommended.

This manual only touches on the complex issue of trace elements and their deficiency and toxicity implications. Several high-quality publications containing colour photographs of deficiency and toxicity symptoms and descriptions are recommended for additional reading. See the [References](#) at the end of this chapter.

Some of the more common trace elements likely to be deficient in Australian soils are discussed in this section.

3.5.1 Molybdenum

Molybdenum (Mo) is essential for the health of the rhizobia bacteria associated with the legume root nodules that are responsible for atmospheric nitrogen fixation.

Molybdenum is also directly involved in nitrogen metabolism and specifically implicated in the electron-transfer system (for example, nitrate reductase and enzyme nitrogenous reactions). Molybdenum is the least abundant of the trace elements in the soil and the least required by plants with the exception of nickel.

3.5.1.1 Molybdenum deficiency symptoms

Molybdenum deficiency symptoms may look similar to a nitrogen deficiency (see [Section 3.4.1.1](#)), and legumes will have green or grey to white nodules rather than the pinkish-coloured nodules of healthy plants.

Consequently, a lack of molybdenum will reduce the nitrogen-fixing ability and growth of legumes. In effect, molybdenum-deficient plants cannot properly metabolise nitrate nitrogen, even though their tissues may contain considerable amounts of nitrates.

Molybdenum is not sorbed by soil when soil pH (1:5 CaCl₂) is greater than 5. Sorption occurs when soil pH is below 5, with sorption increasing as soil pH increasingly falls below 5. Therefore, deficiencies are more likely in acid soils. The application of lime increases soil pH improving the effectiveness of naturally occurring molybdenum present in soil, thereby increasing availability for plant uptake. However, peat soils, which are usually acidic, should not require additional molybdenum, as these soils usually have high levels of molybdenum held within the organic matter. The application of lime to the peaty soils in the Koo-wee-rup area of southern Victoria has been sufficient to rapidly increase the availability of molybdenum and sometimes induce a copper deficiency in livestock.

Correcting a molybdenum deficiency can be by the application of a fertiliser to the soil or in water. Fertiliser products such as superphosphate can be used that have molybdenum added. However if lime is being applied the increase in soil pH may increase the solubility of soil molybdenum preventing any further application.



Applications of 50 to 200 g Mo/ha every 3 to 10 years are required for correcting pastures deficiencies and 50 to 60 g Mo/ha every 5 to 7 years are required on responsive soils for field crops. However, a plant tissue test (see Chapter 8.4) may show that Mo is not required at the 'due time'.

3.5.1.2 Animal health implications

A complex relationship exists between copper, molybdenum, and the sulphates in animal nutrition.

Copper and molybdenum are mutually antagonistic in plant uptake; that is, if one is applied, uptake of the other may be reduced. Conversely, an oversupply of copper can induce a molybdenum deficiency in animals, particularly on lighter-textured soils or when animals are stressed.

Molybdenum toxicity (molybdenosis in ruminants) is not thought to be significant in plants, but excessive molybdenum levels in plants (forage crops) or high rates of molybdenum applications in fertilisers can sometimes induce copper deficiency in livestock. There are complex reactions in the animal's rumen involving molybdenum, sulphur and copper; generally forming a complex product with copper becoming unavailable to the animal. Often these conditions can be subclinical and difficult to diagnose. Therefore copper:molybdenum ratios of animal diets should be monitored and maintained with suitable ranges (5:1 to 10:1).

Sulphate can also sometimes restrict molybdenum uptake by plant roots when the two nutrients are applied together. A high molybdenum content in plants can be dramatically lowered by the addition of sulphates. To avoid copper deficiency in grazing animals, it is generally recommended that copper should be applied when molybdenum is being applied in a fertiliser. However, if plant levels of copper (as determined by a plant tissue analysis; see Chapter 8.4) are at satisfactory levels or higher, then molybdenum can be applied without copper.

In addition, molybdenum should not be applied to pastures limed within the past 12 months, as the combination of applied molybdenum plus the molybdenum released from the soil by the lime may raise the molybdenum levels enough to cause copper deficiencies in livestock.

3.5.2 Copper

Copper (Cu) is required for the formation of enzymes for chlorophyll production, nutrient processing and the plant's exchange of water and oxygen for carbon dioxide. It is also required for seed setting of legumes. Plant responses (in other words, additional growth) due to copper are rare. Like most trace elements excessive quantities of copper can interfere with the uptake of other trace elements like iron; therefore producing iron deficiency symptoms.

3.5.2.1 Copper deficiency symptoms

Copper deficiency symptoms are not very specific in plants, although 'dieback' is common, showing up first in the young growth. Copper deficiencies commonly occur in highly leached acid sands (such as coastal sandy and sandy loam soils), in loams from sandstone, in peat soils, and in highly calcareous alkaline soils. Heavy clay type soils are least likely to be copper deficient.

Copper deficiencies can be corrected by either soil or foliar applications. Copper can be applied as an impurity in some common phosphorus fertilisers, but generally copper is broadcast onto pastures annually using superphosphate with copper as an additive. Broadcasting copper fertiliser is less effective than incorporation as a band into the soil prior to planting, due to its immobility. Because copper is immobile it remains in the soil for plant uptake.

Foliar applications of copper sulphate (bluestone) can be effective in correcting copper deficiency in an existing crop or pasture, however caution should be exercised as the mixture can burn under adverse environmental conditions (e.g. hot dry windy conditions).



Rates of 1.5 to 2 kg Cu/ha applied as fertiliser every 3 to 6 years are required for deficient soils.

3.5.2.2 Animal health implications

Problems with copper are more commonly associated with animal deficiencies than with plant deficiencies. Because animals have a higher copper requirement than plants do, animals may become deficient at copper levels that are sufficient for normal plant growth. Imbalances with excessively high trace elements in the soil (e.g. iron, molybdenum – see [Section 3.5.1.2](#)) can induce copper deficiencies in animals with the animal showing typical unthrifty symptoms increasing as body reserves are depleted.

Copper deficiency symptoms are also more obvious in livestock than in plants. The symptoms appear as hair or coat abnormalities (red-coated animals tend to be pale-red or orange), retarded growth and skeletal defects, infertility, and diarrhoea.

It may be necessary to treat the animals directly, particularly if copper deficiency symptoms are evident in livestock.

3.5.3 Zinc

Zinc (Zn) is associated with the formation of chlorophyll and of several enzyme systems required for protein synthesis. It also has a regulatory role in the intake and efficient use of water by plants.

3.5.3.1 Zinc deficiency symptoms

Zinc remains in the older green leaves as it is poorly mobile, so as the deficiency increases symptoms will appear in the middle to younger leaves, deficiency symptoms include:

- Small bronze spots on older leaves of legumes; as spots enlarge, leaves develop a mottled appearance.
- Branching of small, dark green, distorted leaves in the centre of legume plants (called the 'little leaf syndrome' and noted at Yanakie, South Gippsland).
- White stripes in younger leaves of grasses (See Figure 3.11)



Figure 3.11 Showing white stripes; typical of zinc deficiency symptoms in young maize plants
Source: David Hall



Typically, zinc deficiency is associated with leached acidic sandy soils, alkaline soils with considerable calcium carbonate content, and soils with high organic matter. Deficiencies may be temporarily induced by cold, wet weather and have been noted to disappear with the onset of warmer weather.

Zinc deficiency affects millions of hectares throughout Australia. It is associated with many crops and pastures grown across a wide range of soil types, including coastal pastures along eastern and Western Australia and large areas of alkaline cracking soils throughout the dairying regions of all states within Australia. Deficiencies are uncommon in pastures in southern Victoria except on the alkaline coastal soils.

Zinc availability is related to pH; and in the north-west and Goulburn Valley areas, zinc availability is often low on heavily cut laser levelled paddocks after landforming, particularly if they are planted to maize and other fodder crops. In this situation, alkaline subsoils become exposed.

Zinc deficiencies can be successfully corrected by either soil or foliar applications. As zinc is immobile in the soil, placement of zinc close to the developing root system is important. Zinc can be applied to the soil in smaller amounts as a component of some pre-plant fertilisers (e.g. Granulock Z which contains 1% Zn), or in higher concentrations lasting for many years (e.g. zinc sulphate monohydrate which contains 35% Zn). Zinc can also be applied to existing pastures using superphosphate with zinc added. Foliar applications of a zinc sulphate or a chelated form can be applied to an existing crop or pasture to correct an existing deficiency or soil conditions that have reduced the availability of zinc.

3.5.4 Manganese

Manganese (Mn) has several plant-growth functions. It is closely associated with iron, copper and zinc as a catalyst in plant-growth processes; is essential for rapid germination; and plays a role in enzyme systems in seed and new tissues.

3.5.4.1 Manganese deficiency symptoms

Manganese deficiency symptoms include:

- Yellowing between the veins of young leaves due to immobility in plants.
- Eventually spots of dead tissue may drop out, leaving a 'ragged' leaf.
- Stunting of growth.
- Reduced flower formation.

The main factors affecting manganese availability are soil pH and seasonal variability.

The more alkaline the soil, the more likely deficiencies will occur. Conversely, very strongly acidic soils can accumulate toxic levels of manganese – see [Section 3.5.4.2](#). Occasionally, a manganese deficiency can be induced by excessive liming on these acid soils.

Manganese deficiency is more often associated with coastal calcareous soils and deficiencies are more likely to occur in highly alkaline soils with high organic matter.

Due to the seasonal availability of manganese, symptoms may be more prominent in the cooler wetter months and disappear during the warmer months – see [Figure 3.12](#)

There is no evidence in Australia of manganese deficiency affecting pasture growth; however it is more common on alkaline cropping soils during the cooler months. Manganese deficiency in pastures can be treated by applying manganese sulphate.



3.5.4.2 Manganese toxicity symptoms

Manganese toxicity symptoms include:

- In sensitive plants (Lucerne and clover), symptoms of toxicity appear in late autumn, initially as a light brown discolouration of the leaf margins, which later become reddish. Waterlogging or root rot can produce similar symptoms, so a plant tissue analysis may be necessary to determine the true problem.
- The plant may die in cases of severe toxicity.

Although rare, manganese toxicity can occur during the warmer months in high rainfall, acid soils (<4.3 pH CaCl₂) inherently high in manganese. Figure 3.12 shows the variation in manganese availability with seasonal conditions.

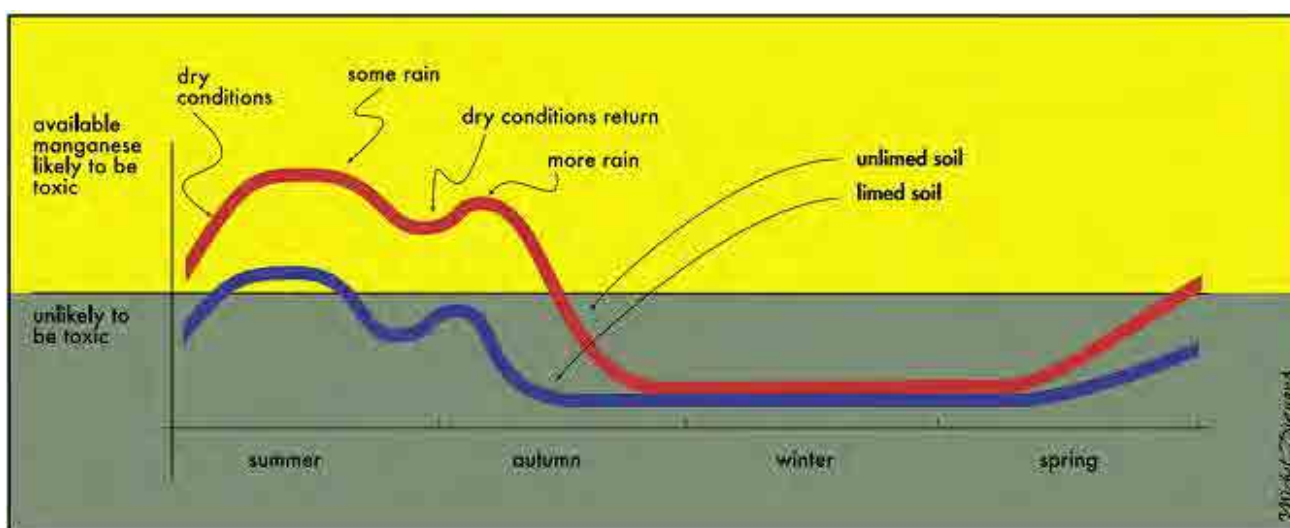


Figure 3.12 Variation of manganese availability with season.

Source: http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/167209/soil-acidity-liming.pdf

Manganese toxicity has been found in the northern tropical regions of Australia where high rates of acidifying fertiliser have been used on already acid soils. In these regions, there can be a five-fold increase in manganese availability during the warmer wetter months, and possible toxicity.

Manganese toxicity is also more likely when grazing lupins as they can accumulate high concentrations of manganese. Soil compaction and waterlogging (both of which result in inadequate soil aeration) can produce manganese toxicity in plants; especially in more susceptible crops like canola, lucerne, phalaris and annual medics. – See Table 3.3.

Table 3.3 Tolerance to manganese (Mn), and critical levels* of manganese for pasture plants.

| TOLERANCE TO MANGANESE (Mn) | PLANT SPECIES | PLANT CRITICAL LEVEL* OF Mn (mg/kg) |
|-----------------------------|---------------------------------|-------------------------------------|
| Highly sensitive | lucerne, barrel and burr medics | 200 - 400 |
| Sensitive | white and strawberry clovers | 400 - 700 |
| Tolerant | sub clover | 700 - 1000 |
| Highly tolerant | most pasture grasses | > 1000 |

* The critical levels of manganese in this table are the levels in the youngest fully developed leaf that are sufficient to cause a 10% decline in growth.

Source: NSW Agriculture Agfact AC.19 Soil Acidity and Liming.

Manganese toxicity can be reduced by working lime into the soil to a depth of 100 to 150 mm and by correcting waterlogging and soil compaction.



3.5.4.3 Animal health implications

Livestock are susceptible to both manganese toxicities and manganese deficiencies.

A lack of manganese is commonly associated with infertility in cows and impaired growth and bone development. There have been no confirmed cases of manganese deficiency in grazing animals in Australia.

Deficiencies in livestock can be corrected with manganese supplements. Check manganese levels via a plant tissue analysis of mixed herbage if concerned about manganese deficiency in livestock - see Chapter 7.3.2)

3.5.5 Iron

Iron (Fe) is associated with the production of chlorophyll and helps to carry oxygen around the plant cells. Iron is also involved in reactions that convert nitrates to ammonia in the plant.

3.5.5.1 Iron deficiency symptoms

Iron deficiency symptoms include:

- Chlorosis (yellowing) between the leaf veins of the youngest leaves.
- Tips and margins of leaves remain green for the longest time.
- Affected leaves curve upwards.
- Stunting and abnormal growth.

Iron is very immobile in the plant. Thus, deficiency symptoms affect the youngest leaves first.

Deficiencies usually occur on high-pH calcareous soils, waterlogged soils or in soils that have been heavily limed. The correction of iron deficiencies is generally through the application of foliar iron fertilisers; iron sulphate or iron chelate. If iron is applied to the soil it can be converted to an unavailable form, particularly when applied as iron sulphate.

3.5.6 Boron

Boron (B) is mainly involved in the movement of sugars throughout the plant and in seed production in legumes. It is also an important nutrient in the metabolism of nitrogen, carbohydrates, and hormones and is involved in the uptake and efficient use of calcium in the plant.

Boron may induce both toxicities and deficiencies in Australia.

3.5.6.1 Boron deficiency symptoms

Boron deficiency symptoms include:

- Distorted and chlorotic leaves with darker pigmentation along the leaf margins.
- Red and yellow discolouration, particularly in sub clover.
- Poor growth.
- Low seedset.

Deficiencies often tend to disappear after rainfall since plant roots may be unable to access soil boron in dry soils. Lucerne is the main crop in which boron deficiency has been identified in Australia

Boron deficiencies may occur in humid regions, in highly leached acid sands, in organic (peaty) soils, and in calcareous (alkaline) soils and becomes less available in poorly drained soils.

Occasionally, liming may heighten a boron deficiency. Boron deficiency can be induced in turnip fodder crops by lime application, usually at 3.5 t/ha or higher during seedbed preparation. Boron



starts to be sorbed by soil at pH (1:5 CaCl₂) values greater than 7-8, with sorption thereafter increasing as pH values increase.

If plant tissue analysis (see Chapter 8.4) indicates a deficiency, then apply boron with a fertiliser application and retest in 2 to 3 years. Seek expert advice to determine the appropriate boron types and application rates. A problem with boron is that amounts required to overcome a deficiency and amounts causing toxicity for plant production are relatively close; so avoid applying too much fertiliser boron. Once induced, toxicity is difficult to ameliorate.

3.5.7 Chlorine

Chlorine (Cl) is thought to stimulate carbohydrate metabolism, some plant enzymes, chlorophyll production, and the water-holding capacity of plant tissues. Chlorine seems to be more important for animals than for plants. Deficiencies of chlorine seldom occur as the chloride ion is continually replenished via rain water, the amount increasing with rainfall quantity and closeness to the sea.

3.5.8 Nickel

Nickel (Ni) is a naturally occurring element found in soil, water, air and biological materials. Its availability in soils is very pH dependant, with the nutrient becoming soluble and therefore plant available when less than pH 6.5 (water). Because nickel is required by plants in such small concentrations (0.1 to 5 mg Ni/kg dry weight) detection of plant deficiencies is difficult in the field.

Nickel is a very mobile nutrient within plants with large proportions being rapidly translocated to seeds from shoots. Nickel has the following roles in plants:

- As a component of the enzyme urease, it is involved in nitrogen metabolism
- Involved in nitrogen translocation within plants
- Involved in bacterial enzymes; including nitrogen fixation.
- Involved in the seed germination and vigour
- Influences plant disease resistance

Nickel is unlikely to become deficient in soils due to its small plant requirement and natural presence throughout most soils. A nickel deficiency, however, could be exacerbated by excessively high applications of other nutrients (zinc, copper, manganese and iron); root damage by nematodes; and cold wet conditions. Nickel is present in cow's milk at 0.1 mg Ni/L and in normal circumstances would not be required as a separate dietary component. However, if it is not present in the animal in sufficient quantities, the main adverse effect is a reduced feed intake and reduced growth.



3.6 Summary

- Nutrients are necessary for plant growth.
- There are two categories of plant nutrients: macronutrients and micronutrients.
- The major nutrients, or macronutrients, supplied by the soil are nitrogen, phosphorus, potassium, sulphur, magnesium and calcium.
- The minor nutrients; also referred to as micronutrients or trace elements, supplied by the soil are molybdenum, copper, zinc, manganese, iron, boron, nickel and chlorine.
- Fertilisers are required to overcome nutrient deficiencies and to replace the nutrients that are lost or removed from the soil and pasture.
- Nutrient cycling (soil-plant-animal) involves nutrients:
 - Being brought onto the farm in various forms.
 - Undergoing ongoing reactions in the soil.
 - Being consumed by animals via the plants.
 - Being lost to the farm system by various means.
- Nutrients are required for a number of tasks associated with plant growth.
- A deficiency in any one of the 17 essential nutrients will reduce pasture growth and animal production.
- Various trace elements are deficient in some dairying areas.
- Although grazing animals receive most of their essential nutrients from pasture; plants and animals have different essential nutrient needs. In regard to trace elements, it is sometimes better to treat animal nutrient deficiencies directly rather than supply the nutrient indirectly through the pasture.



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Chapter 4

Soil Properties

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4 Soil Properties

4.1 Introduction

In this Chapter;

[Physical properties](#)

[Chemical properties](#)

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[Soil formation](#)

The components which make up a mineral based soil include inorganic particles or minerals, organic matter, living organisms and water and air (pore spaces) as shown in Figure 4.1.

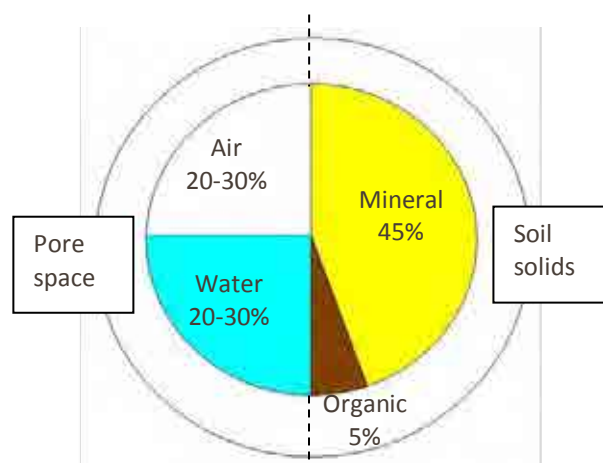


Figure 4.1 Composition of a loam surface soil when conditions are good for plant growth (adapted from Brady and Weil 1999, pg. 15)

Each soil has different types and arrangements of these components which creates unique soil properties or 'soil types'. Soil properties affect;

- plant growth responses
- fertiliser requirements
- the soils' response to management
- land use capability (i.e. suitability for different land uses such as grazing versus cultivation)
- drainage and water runoff
- nutrient loss and leaching
- soil erosion

Understanding soil properties is essential for nutrient planning and can be applied to land-use decisions.

Soil properties such as [soil structure](#), depth, [texture](#), [salinity](#), [acidity](#), [waterlogging](#) or compaction can limit plant growth even when the soil has adequate nutrients. Before applying fertiliser, consider what is actually limiting plant growth. Is it really a nutrient deficiency or is it a soil property? Soil properties can be observed in the paddock or measured through soil testing.



A soil's properties are largely determined by its parent material and weathering during its formation (Refer to [section 4.6](#)). Topography, age and agricultural practices can also affect a soil's properties.

Three groups of soil properties influence plant growth:

- [Physical](#), or the [texture](#) and [structure](#) of the soil.
- [Chemical](#), which affects both the fertility of the soil and its physical properties.
- [Biological](#) or the organisms in the soil, such as bacteria, fungi, insects and earthworms – See [Chapter 5](#) for more information on soil biology.

It is the combination of these properties that determine soil health and the ability of the soil to provide ecosystem services.

Soil properties influence plant growth and guide fertiliser decision making. Information relating to soil properties can be used to help guide investment decisions on-farm to maximise the benefit, for minimal investment.

4.2 Physical properties

Physical properties of a soil that affect a plant's ability to grow include:

- [Soil texture](#), which affects the soil's ability to hold onto nutrients ([cation exchange capacity](#)) and water. Texture refers to the relative distribution of the different sized particles in the soil. It is a stable property of soils and, hence, is used in soil classification and description.
- [Soil structure](#), which affects aeration, water-holding capacity, drainage, and penetration by roots and seedlings. Soil structure refers to the arrangement of soil particles into aggregates (or peds) and the distribution of pores in between. It is not a stable property and is greatly influenced by soil management practices.

4.2.1 Soil texture

Soil texture, or the 'feel' of a soil, is determined by the proportions of sand, silt, and clay in the soil. When they are wet, sandy soils feel gritty, silty soils feel smooth and silky, and clayey soils feel sticky and plastic, or capable of being moulded. Soils with a high proportion of sand are referred to as 'light', and those with a high proportion of clay are referred to as 'heavy'.

Soil texture classes

The names of soil texture classes are intended to give you an idea of their textural make-up and physical properties. The three basic groups of texture classes are sands, clays and loams.

A soil in the **sand group** contains at least 70% by weight of sand. A soil in the **clay group** must contain at least 35% clay and, in most cases, not less than 40%. A loam soil is, ideally, a mixture of sand, silt and clay particles that exhibit light and heavy properties in about equal proportions, so a soil in the **loam group** will start from this point and then include greater or lesser amounts of sand, silt or clay.

Additional texture class names are based on these three basic groups. The basic group name always comes last in the class name. Thus, loamy sand is in the sand group, and sandy loam is in the loam group (see Figure 4.2).

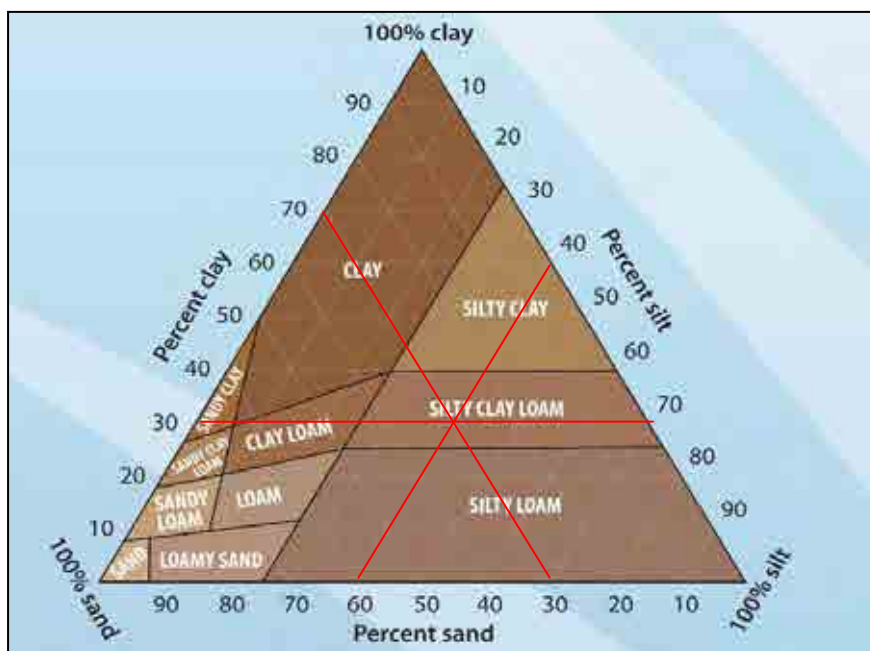


Figure 4.2 Soil Texture Triangle. Source: Image adapted from Hunt and Gilkes (1992) https://s3.amazonaws.com/soilquality-production/fact_sheets/28/original/Phys_-_Measuring_Soil_Texture_in_the_Lab_web.pdf

Particle size distribution can be determined by laboratory analysis, with the results shown in percentages. The texture is determined by drawing lines from the percentage point on the relevant axis parallel to the side of the triangle at the zero end of the same axis. Where the 3 lines intersect indicates the soil texture. A soil with 40% silt, 30% clay and 30% sand is a silty clay loam - See the red lines on Figure 4.2.

Soil texture influences many soil physical properties, such as water-holding capacity and drainage. Coarse-textured sandy soils generally have high infiltration rates but poor water holding capacity. Silt particles are much smaller than sand, have a greater surface area, and are generally quite fertile. Silts do not hold as much moisture as clay soils, however more of the moisture is plant available. Fine-textured clay soil generally has a lower infiltration rate but a good water holding capacity.

Soil texture also influences the soil's inherent fertility. More nutrients can be adsorbed by a gram of clay particles than by a gram of sand or silt particles, because the clay particles provide a much greater surface area for adsorption. Clay is the active part of the soil. It is where soil nutrients are held and largely from where they are exchanged. The clay fraction also has a large effect on soil structural stability, and therefore erosion risk. See [Section 4.3.1](#) Nutrient availability and cation exchange capacity for more information.

The texture of a soil can be easily estimated in the field by using the soil texture key – See Table 4.1. First, knead a small handful of soil into a ball about 4 cm in diameter, after removing any stones and plant material. Then slowly wet the soil and mould or press it into a ribbon between your thumb and forefinger. The length of the ribbon and the properties of the ball let you estimate the soil's texture class.



Table 4.1 Soil characteristics indicative of soil texture. *Source:* Euroconsult 1989, McDonald et al 1990 cited in Moody & Cong 2008.

| SOIL TEXTURE | DESCRIPTION | LENGTH OF SOIL RIBBON (mm) |
|--------------|--|----------------------------|
| Sand | The soil stays loose and separated, and can only be accumulated in the form of a pyramid. | < 15 |
| Sandy loam | The soil contains enough silt and clay to become sticky and can be made into the shape of a fragile ball. | 15 – 25 |
| Silty loam | Similar to the sandy loam, but the soil can be shaped by rolling into a small, short cylinder. Soil has a 'silky' feel. | 25 |
| Loam | Contains almost the same amount of sand, silt and clay. Can be rolled into a 15cm long (approximately) cylinder that breaks when bent. | 25 |
| Clay loam | Similar to loam, although the cylinder can be bent into a U shape (without forcing it) and does not break. | 40 – 50 |
| Fine clay | The soil cylinder can be made into the shape of a circle but shows some cracks. | 50 – 75 |
| Heavy clay | The soil cylinder can be shaped into a circle without showing any cracks. | > 75 |

4.2.2 Soil structure

Soil structure refers to the arrangement of soil particles (sand, silt and clay) and pores in the soil and to the ability of the particles to form aggregates.

Aggregates are groups of soil particles held together by organic matter or chemical forces. **Pores** are the spaces in the soil.

The pores between the aggregates are usually large (**macropores**). Their large size allows good aeration, rapid infiltration of water, easy plant root penetration, good water drainage, as well as providing good conditions for soil micro-organisms to thrive. The smaller pores within the aggregates or between soil particles (**micropores**) hold water against gravity (capillary action) but not necessarily so tightly that plants cannot extract the water.

A well-structured soil forms stable aggregates (aggregates that don't fall apart easily) and has many pores of varying sizes – See Figure 4.3a. A well-structured soil is friable, easily worked and allows germinating seedlings to emerge and quickly establish a strong root system.

A poorly structured soil has either few or unstable (readily broken apart) aggregates and few pore spaces – See Figure 4.3b. A poorly structured soil can result in unproductive, compacted or waterlogged soils that have poor drainage and aeration. Poorly structured soil is also more likely to slake and to become eroded.

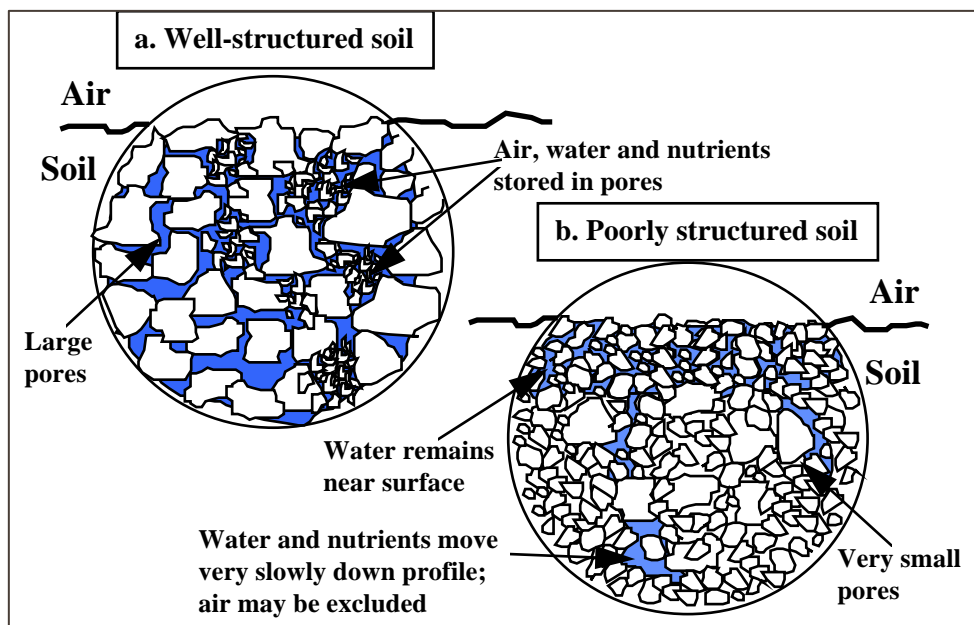


Figure 4.3 Soil structure

4.2.3 Pore spaces

The spaces between soil particles (clay, silt, and sand) and between and within aggregates (clusters of soil particles) are called **pore spaces**. They are the portion of the soil occupied by air and water. Water displaces air in the soil, and consequently the air content of a soil is inversely related to the water content. High water content in soils means there is less air within the soil. This results in higher levels of carbon dioxide and lower levels of oxygen within the soil which is not favourable for plant growth. These conditions also favour denitrification, the biological process that converts nitrate-nitrogen to the greenhouse gas, nitrous oxide.

Soil air differs to atmospheric air as the composition is more variable within the soil, can be more humid and has a higher carbon dioxide and lower oxygen content than the atmosphere.

The number and size of pore spaces are determined by the size of the soil particles (soil texture) and the arrangement of the soil particles into aggregates (soil structure). The larger pores (**macropores**) allow air and percolating water to move easily through the soil. The smaller pores (**micropores**) don't allow air to move easily and also largely limit water movement.

Soil biology also plays a role in helping to bind soil. An example of this is the secretions of glomalin from arbuscular mycorrhizal fungi - See [Chapter 5](#) for further information. A sandy soil may have insufficient organic matter to bind the sand grains into larger aggregates. In this case, the soil will have many large pore spaces and very few small pores. The plant roots will have plenty of air, but water will drain freely through the soil with very little storage. On the other hand, a compacted, heavy clay soil will have many small pores and few large pores. Plants suffer as water is so tightly bound in the small pores that plant roots are unable to extract it from the soil. The soil is poorly aerated, and drainage is poor. Consequently, the oxygen is exhausted.

4.2.4 Soil water

Water within the soil strongly influences plant growth and the biological functioning of the soil. It provides a medium for substances to dissolve into, including nutrient elements, allowing them to be accessible to plant roots. Water also enables nutrients to be transported off the farm, and contributes to erosion and weathering processes. The soil texture influences how water is held within the soil and also the rate that water will infiltrate the soil - See [Section 4.2.1](#).



| | |
|--|--|
| | <p>Too much water</p> <p>When all the soil pores fill with water during rainfall or irrigation the soil can become saturated or waterlogged. Plants require both air and water within the soil. When a soil is waterlogged, especially for periods longer than a couple of days, plants can suffer. Plants require oxygen to respire and produce energy, without this they can't grow. When soils are waterlogged fertiliser application should be avoided.</p> |
| | <p>Too little water</p> <p>As the soil dries out, the soil particles (particularly clay) tend to hold onto water more tightly than the plant is able to extract water. Therefore water is held in the soil with increasing strength as soil dries out. At this point, when the plant is unable to extract enough water it wilts and doesn't recover. This is called the wilting point or the lower extractable limit.</p> |
| | <p>The right balance of air and water</p> <p>Just after the soil has been saturated and starts to drain, the large pore spaces have air again and there is ample water available for plants. This is when the soil is at field capacity. Field capacity varies depending upon soil texture. Once plants have used up the water that's readily available, the soil reaches refill point. The soil moisture level between the refill point and field capacity is called the readily available water (RAW). RAW is the water that plants can easily extract from the soil, and is also the level that irrigators aim to maintain, unless they are intentionally stressing plants. Figure 4.4 shows that sandy soils require less water before the water is available to plants compared to clay soils which require wetting up before water is available to plants.</p> |

Illustrations above adapted from Food and Agriculture Organisation of the United Nations 1985

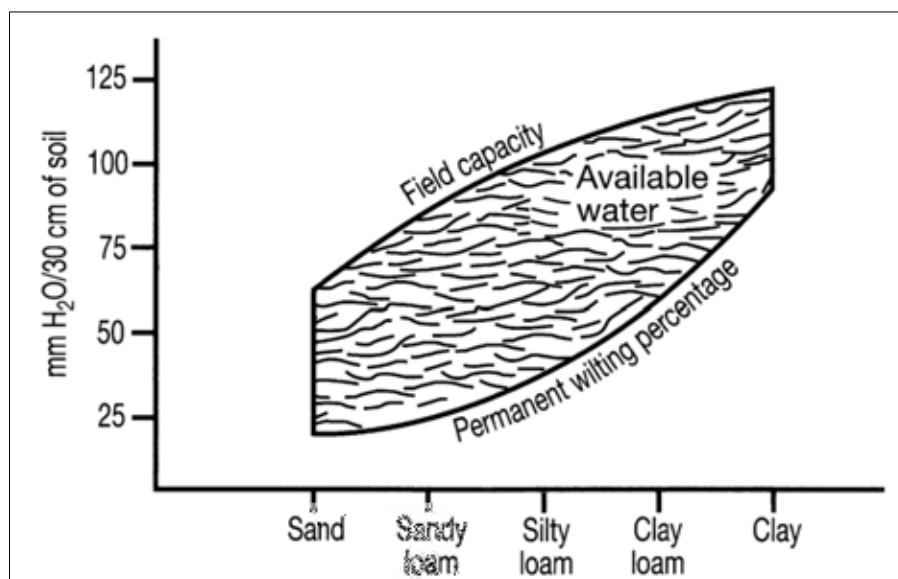


Figure 4.4 Relationship between soil texture and water availability.
 Source: Fertiliser Industry Federation of Australia 2006 pg.4



4.3 Chemical properties

The chemical properties of soils that are important to plant growth are:

- [Nutrient availability and cation exchange capacity](#), which affect the soil's inherent fertility and its ability to hold nutrient cations such as calcium, potassium and magnesium.
- The chemical characteristics of the [soil solution](#), which affect [pH](#) and [salinity](#).
- The [sodicity](#) of the soil, which affects soil stability and nutrient cation supply.

4.3.1 Nutrient availability and cation exchange capacity

In the soil, a large portion of plant nutrients are bound up in complex compounds that are unavailable to plants. The smaller portion is in simpler, more soluble forms, which are useable by plants. The complex compounds are gradually changed into the simpler compounds by chemical weathering and biological processes. Thus, the chemical fertility of a soil depends in part on how easily the plants can access the nutrients in a form they require. This is referred to as the **availability of a nutrient**.

The availability of nutrients within the soil is also dependent on a range of factors such as soil pH, soil solution, soil type and the plant age, type and root system of the plant.

Plant nutrients are composed of single elements (for example, potassium (K)) or compounds of elements (for example, ammonium nitrate (NH_4NO_3)). In all cases, the nutrients are all composed of atoms.

Mineral nutrients are absorbed by plants from the soil solution as ions. An **ion** is an electrically charged particle formed by the removal or addition of electrons from an atom or molecule. An ion with a positive electrical charge is called a **cation**. An ion with a negative electrical charge is called an **anion**. Cations include sodium (Na^+), potassium (K^+), calcium (Ca^{++}), magnesium (Mg^{++}) and aluminium (Al^{+++}). Anions include chloride (Cl^-), nitrate (NO_3^-), sulphate (SO_4^{--}), carbonate (CO_3^{--}), phosphate (H_2PO_4^-) and boric acid (BO_3^{--}).

One plus sign or one minus sign means an ion has one positive or negative electrical charge. Two or more plus or minus signs means an ion has two or more positive or negative charges.

Phosphorus availability is greatly influenced by adsorption reactions with calcium, aluminium, iron, manganese and reactive surfaces of certain clay minerals. These reactions can 'fix' the phosphorus and make it less available to plants. The degree of fixation depends on pH. In alkaline soils the phosphorus will combine with calcium, and in acid soils the phosphorus will combine with iron and aluminium, and in both cases less phosphorus is available to the plant.

Cations and anions are not equally held by the soil particle. More positive charges mean an increasing ability to bond with a negatively charged surface. More negative charges mean an increasing ability to bond with a positively charged surface. The order of strength of adsorption is; $\text{Al}^{3+} > \text{H}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ > \text{NH}_4^+ > \text{Na}^+$. For example, plant root cells can secrete H^+ ions that can displace weaker ions like K^+ which then are available for plants to take up.

The cations and anions can be:

- Absorbed (taken up) by plant roots.
- Leached from the soil via the soil water.
- Adsorbed (attached) to the surfaces of negatively and positively charged soil particles.

The soil's capacity to **adsorb** nutrients in the form of cations is called its **cation exchange capacity** – See Figure 4.5). Cation exchange capacity is measured by a soil test which is discussed further in [Chapter 9.2.9](#).

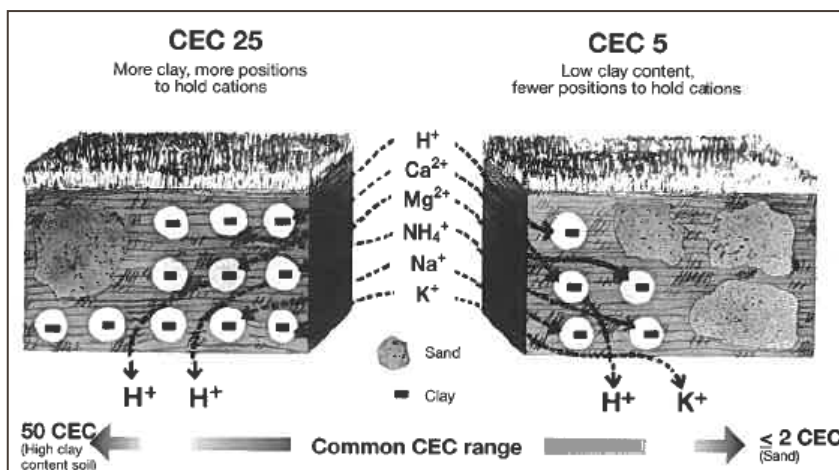


Figure 4.5 Illustration of cation exchange processes. *Source:* Fertiliser Industry Federation of Australia 2006, pg. 6.

The cations are held on the surface of soil minerals and organic matter and within the crystalline framework of some clay minerals. The greater the surface area available to adsorb cations, the higher the soil’s inherent fertility. Thus, soil texture has an effect on soil fertility because of the sizes of the particles that make up the various soil texture classes and so does the amount of organic matter – See Table 4.2. Please note, on the edge of some clay minerals there is also a positive charge, which attracts and holds anions.

Table 4.2 Surface area of soil particles and organic matter. *Source:* CSIRO (1979).

| PARTICLE | SQUARE CM PER GRAM |
|------------------------|--------------------|
| Coarse sand | 23 |
| Fine sand | 90 |
| Very fine sand | 230 |
| Silt | 450 |
| Clay | around 8,000,000 |
| Organic matter (humus) | around 8,000,000 |

As you can see, soils with a high clay or organic matter content provide a much greater surface area for cations to adsorb onto.

As long as the nutrient cations and anions are adsorbed onto the soil particles, they cannot be absorbed by plants or leached from the soil, unless the whole clay particle is carried away via erosion. However, they are not held too tightly and can be exchanged with other ions of a like charge that are in the soil solution. Within these exchanges some cations (such as Ca²⁺) are held more tightly than other cations such as Na⁺ and Mg²⁺. Once the nutrients are in the soil solution, they can be absorbed by the plant’s roots, used by soil biology or lost to leaching.

4.3.2 The soil solution

Soil water is the water held within the soil pores. **Soil solution** is the soil water together with its dissolved salts (cations and anions). The soil solution is the medium by which most soil nutrients are supplied to growing plants. It also has a role in soil salinity and pH - See [Section 4.2.4](#).

4.3.2.1 Soil Salinity

Soil salinity is an increased concentration of salts in the soil solution. In general, as soil moisture is reduced, especially by evaporation, the concentration of soluble salts of sodium, calcium,



magnesium, and potassium in the soil solution increases. These salts may already be present in the soil solution or they can be carried upward from the ground water by capillary action if the watertable rises.

The concentration of soluble salts can become so high as to interfere with the growth of plants. Soils that have a salt concentration in the plant root zone that is sufficient to interfere seriously with plant growth are called **saline soils**.

Salinity can occur on dryland farms and on irrigated farms. The salinity that occurs is the same in either case, only the initiating causes and management methods may be different. See [Chapter 7.5](#) for information on managing salinity and [Chapter 9.2.10](#) for information on salinity as measured by a soil test.

4.3.2.2 Soil pH

The soil solution can be neutral, acid, or alkaline. This is called the soil pH. The pH measures the concentration of positively charged hydrogen ions (H⁺) in the soil solution on a logarithmic scale ranging from 0 to 14. When a soil solution contains more H⁺ ions, it is **acidic**. When there are fewer H⁺ ions [i.e., more hydroxyl (OH⁻) ions], the soil solution is **alkaline**.

The level of acidity or alkalinity in a soil affects the availability of soil nutrients and the activity of soil micro-organisms and can affect the level of exchangeable aluminium. See [Chapter 7.6](#) for information on managing acidity and alkalinity, [Chapter 9.2.4](#) for information on pH as measured on a soil test and [Chapter 5](#) for information on soil micro-organisms.

4.3.3 Sodicity

The sodicity of the soil refers to the amount of exchangeable sodium cations compared to other cations adsorbed onto the soil. A soil with 6% or more of its exchangeable cations as sodium is called a **sodic soil**.

Excessive exchangeable sodium can cause clay particles to disperse when in contact with water - See [Chapter 7.2](#). A typical sign of dispersion is the blue-grey puddles found in winter in the older basalt areas around lake margins and where drainage is poor.

Sodic soils have poor structure and disperse readily when wet. Seedlings have difficulty penetrating a drying dispersed surface, with consequent poor germination and survival.

Dispersion is caused by weak positive charges, such as sodium, and responds to gypsum application, which replaces the sodium ions with calcium ions.

Traffic on and grazing these soils while wet can make the situation worse. - See [Chapter 7.2](#) for information on managing slaking and dispersion.



4.4 Biological Properties

In this section;

[Living organisms](#)

[Organic matter](#)

4.4.1 Living Organisms

Many living organisms are found in healthy soil, from large creatures, such as earthworms, to the smallest bacteria. Soil organisms help to decompose organic matter. The burrowing habit of the larger organisms incorporates the organic matter into the soil and also creates large pore spaces that aerate the soil and allow faster water infiltration. The smaller organisms, such as bacteria, actinomycetes, fungi, yeasts, algae and protozoa, further decompose the organic matter, which releases nutrients in a form that plants can use.

Living organisms are an important fraction of the soil. Their presence is encouraged by high organic matter levels, adequate soil moisture, and good drainage and aeration.

In a healthy soil, the domestic animal weight above the ground surface is substantially exceeded by the weight of the organisms living in the soil. For example, the earthworms alone can weigh from 100 kg/ha to more than 1500 kg/ha, depending on the suitability of the soil for earthworm survival (Brady & Weil 1999). A normal population of fungi weighs between 1000 and 15,000 kg/ha (Brady & Weil 1999). Please refer to [Chapter 5](#) for further information.

4.4.2 Organic matter

Organic matter is anything that is living or the remains of a living thing. However, in the context of soil composition, **organic matter** is a build-up in the soil of decayed plant and animal residues.

Organic soils, such as peats, contain from 20% to as much as 95% organic matter. **Mineral soils** contain anywhere from a trace to 15% or 20% organic matter. Organic matter is composed of about 57% organic carbon.

Australian mineral soils contain up to 10% of organic matter, but most range from 1% to 7%. However, the influence of organic matter on soil properties, and consequently on plant growth, is much greater than this small portion might indicate.

The benefits of organic matter in the soil include improving soil structure and increasing the nutrient and water holding capacity of the soil. Organic matter also provides a food supply for soil biology. Soils with low organic matter can have 'poor' structure, hold little water, and erode or leach nutrients easily. The exception is cracking clay soils where clay minerals have the main effect on structure. Soils with high organic matter levels have 'good' structure, good water-holding capacity, and reduced erosion and nutrient leaching.

Organic matter plays a key role in nutrient cycling in the soil - Refer to [Chapter 5](#) for more information.

When the organic matter is fully broken down, one of the things that is left is **humus**. Humus ranges in colour from brown to black, and the intensity of its colour is influenced by climate (rainfall and temperature) rather than by the amount of organic matter in the soil.

Humus has some useful qualities in that it adsorbs nutrients, adsorbs much higher quantities of water than clay can, and improves soil structure due to its low plasticity and good cohesion. Thus, organic matter also plays an essential role in maintaining a loose, friable soil structure.



4.5 The soil profile

A soil profile describes the various layers within the soil and can be seen as a vertical section through the soil - See Figure 4.6. Each of the layers in the profile can affect plant growth due to differences in soil physical, chemical and biological properties. A soil profile can be created by digging a hole with a shovel, excavator or with an auger. Where there are distinctive layers within the soil, the profile can be divided into [horizons](#).

4.5.1 Soil depth

The depth of soil or 'soil depth' is the material that favours plant growth. Physical and chemical barriers and high water tables can restrict rooting depth which can affect plant growth. For example hard pans, or gravel layers. Pastures and crops therefore prefer deep well drained soils with good texture and structure.

Each **horizon** is a layer within the soil profile that has distinct characteristics, such as colour, texture or structure that are different from the layer above or below it – See Figure 4.6. Where there are no distinct horizons, this soil is referred to as a gradational soil. Please refer to [Chapter 6](#) for further information.

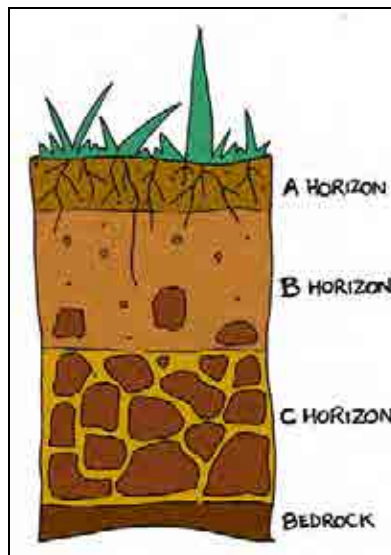


Figure 4.6 An example duplex soil profile

4.5.2 Soil profile descriptions

Soils are called gradational, duplex or uniform based on how the soil texture changes from the A to the B horizon. In a **gradational** soil, the clay content gradually increases, so that the change from the A horizon to the B horizon is indistinct – See Figure 4.7a. In a **duplex** soil, a sharp contrast in texture occurs between the A and B horizons, and the two horizons are easily distinguished – See Figure 4.7b. In a **uniform** soil, the texture change throughout the profile is very small or nonexistent; in general, no textural boundaries can be found in the profile. Figure 4.7 shows two very different soil profiles which have formed through differing geological processes and weathering.

Soil profiles can also be used to classify soil types. In Australia the Australian Soil classification is the method used for determining soil type - Refer to [Chapter 6](#) for more information.

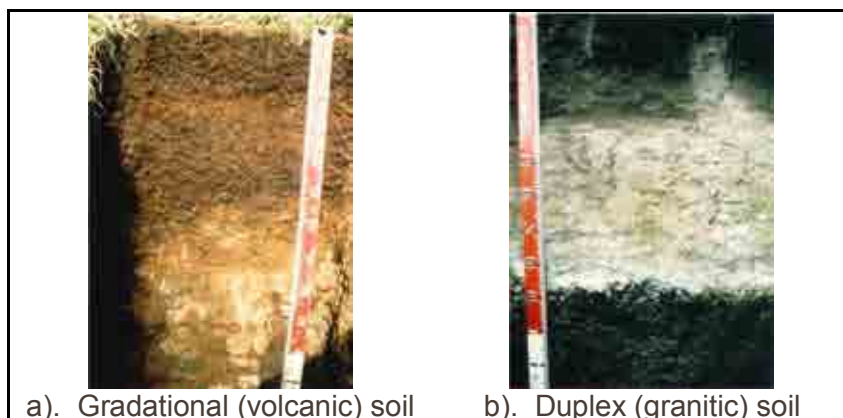


Figure 4.7 Examples of different soil profiles

4.6 Soil formation

Understanding the soil formation and composition of your soil is important, as the parent material will dictate how the soil will behave. Understanding soil formation also helps in understanding which parts of the landscape certain soil types are likely be found. Having this understanding can help to guide land-use decisions and management.

4.6.1 How soils are formed

Soil formation is a function of regional climate, parent material, topography, relief, biological factors and time. Parent material and landform are the initial reference states for a soil and climate and biological factors determine the rate of soil development. Time determines the stage of the soil forming processes as per Figure 4.8 below.

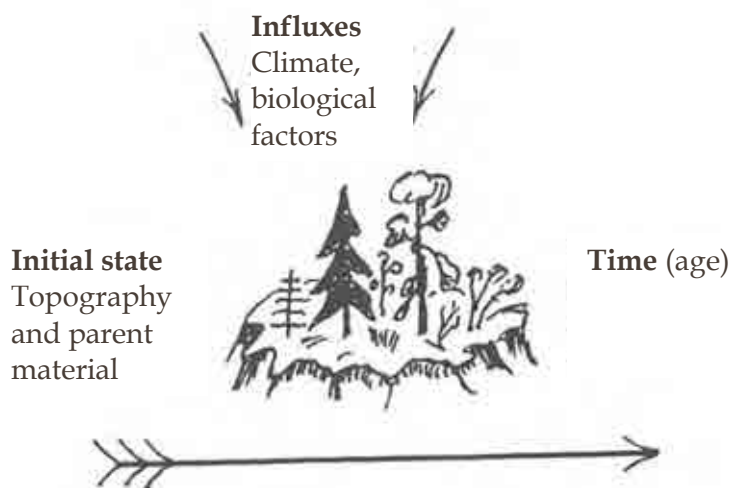


Figure 4.8 Factors that determine soil formation. Source: Hans 1980, pg. 10.

Soils are formed when inorganic matter (minerals) and organic matter breaks down into small particles during a weathering process. Weathering can be a mechanical, chemical or biological process.

Inorganic particles are classified by size as gravel or stone, sand, silt, or clay. The size of the inorganic particles determines soil texture.



The inorganic portion of the soil is formed over many years from solid rock (bedrock) found in the earth’s crust. These rocks are classified as:

- **Igneous rock** such as granite and basalt, formed from volcanic lava.
- **Sedimentary rock**, such as limestone, sandstone, mudstone, shale, dolomite and conglomerates, formed from the deposit and cementation of the weathering products of other rocks.
- **Metamorphic rock**, such as gneiss, schist, quartzite, slate and marble, formed from igneous or sedimentary rocks subjected to high temperatures or pressures.

Weathering of the original bedrock produces **parent material** for mineral soils. Weathering of the bedrock causes fragments to break off and when subject to further weathering become mineral particles. As the mineral particles continue to weather, they are further decreased in size and also release soluble materials, some of which become plant nutrients – See Figure 4.9.

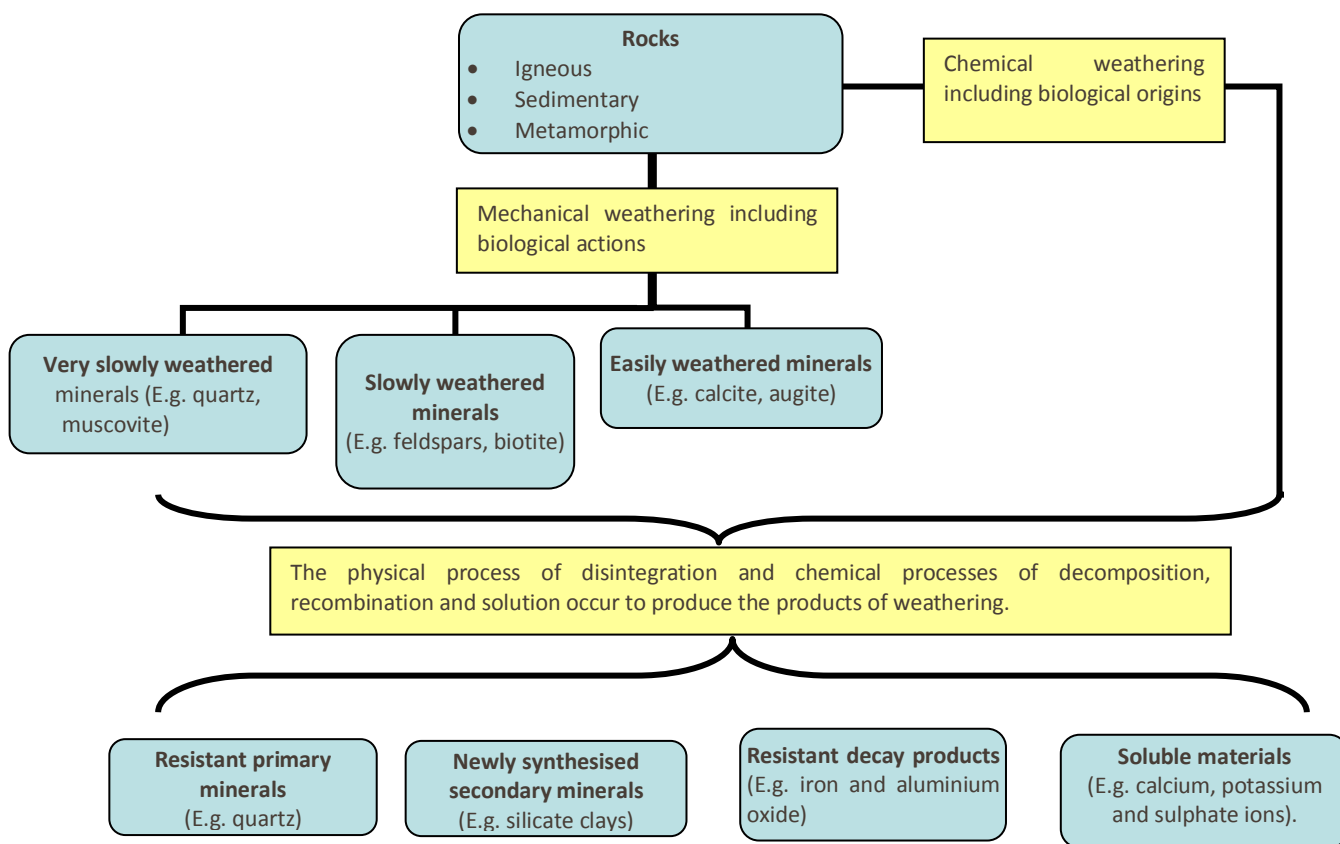


Figure 4.9 Trends in weathering conditions that take place under acid conditions common in humid-temperate regions. *Source:* Adapted from Buckman and Brady (1960).

4.6.1.1 Mechanical weathering

Mechanical weathering is caused by:

- Temperature changes, such as freezing of the water in a rock or the different rates of expansion of the minerals composing the rock.
- Erosion and deposition from water, ice and wind.

Mechanical weathering essentially breaks the bedrock into smaller and smaller pieces and may move it from its place of origin, but it doesn’t change its chemical composition.



4.6.1.2 Chemical weathering

Chemical weathering is caused by:

- Hydrolysis – the reaction between water and a compound
- Hydration – the chemical union of water and an ion
- Carbonation – where carbon dioxide is dissolved into a liquid
- Oxidation – the loss of an electron by a substance, therefore gaining a positive charge.
- The solvent action of the soil solution (water and its soluble salts).

Chemical weathering continues to reduce the size of rock fragments and mineral particles and also changes their chemical composition.

4.6.1.3 Biological weathering

Biological weathering involves chemical or physical weathering processes caused by an organism. For example;

- Mechanical weathering of rocks by plant roots or burrowing animals
- Chemical weathering caused by lichen releasing chelating agents

Mechanical weathering also determines whether the parent material is considered to be sedentary or transported – See Figure 4.10. **Sedentary** parent material is either still at its original site above the bedrock from which it was formed (residual soils) or has been moved by gravity down a slope (colluvial soils). **Transported** parent material has been moved by water (alluvial, marine, or lacustrine soils), ice (glacial soils) or wind (aeolian soils) from its place of origin.

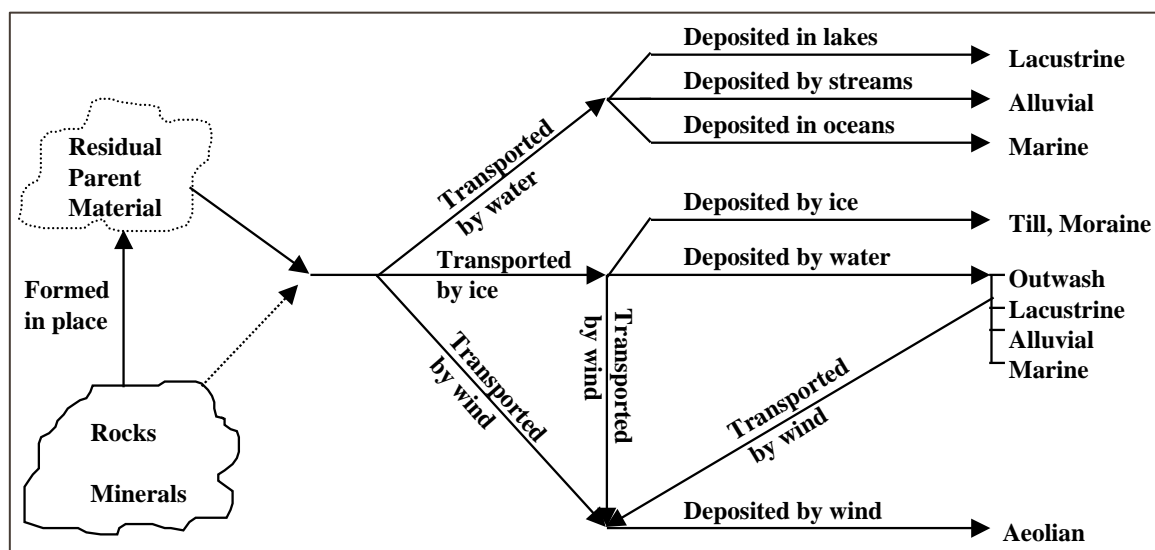


Figure 4.10 Diagrammatic representation of sedentary and transported soils.

Source: Adapted from Buckman and Brady (1960).

4.6.2 How soil formation affects soil properties

The parent material that forms a soil will affect its properties. For example, a quartz-based granite will weather into a sandy soil, which will have a lower water-holding and nutrient-holding capacity than a loam or clay soil. Soil formed from limestone may be alkaline (have a high pH) because limestone consists largely of the mineral calcite (CaCO₃).

The weathering process that forms a soil also affects its properties. For example, less chemical weathering occurs in arid (low rainfall) regions than in humid (higher rainfall) regions. This results in the formation of less clay particles and nutrients in arid zones. Rainfall also acts to leach nutrients in higher rainfall areas. This is part of the reason why arid regions often have alkaline soils, and



humid regions often have acid soils. It also helps to explain why high rainfall areas often have soils with poor fertility: many of the nutrients have been chemically weathered and then leached from the soil.

The weathering process also influences the soils ability to hold onto nutrients. As soil particles develop during formation, silt and sand sized particles remain relatively inert; however clay sized particles can develop a negative charge. This charge can attract and hold positively charged particles called **cations** and can be measured as the **cation exchange capacity** of the soil.

4.7 Summary

- Soils are composed of weathered minerals, organic matter, living organisms and pore spaces.
- A soil's texture describes the amount of sand, silt and clay particles in the soil.
- A soil's structure is determined by the size and arrangement of aggregates and pores.
- A healthy soil is stable and friable and contains a reasonable level of organic matter and a large and varied population of soil organisms



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Chapter 5

Understanding & Managing Soil Biology

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5 Understanding and Managing Soil Biology

5.1 Introduction

This chapter aims to provide an overview of soil biology including; [what it is](#), [what it does](#), [why it is important](#), [what affects it](#), and [how to manage](#) this resource to support profitable and sustainable dairying.

5.2 Soil Organic Matter

Soil Organic Matter (SOM) is the common feedstock that supports soil biology.

It is derived from plants and animals, with the primary source coming from plant residues. Soil organic matter includes all the organic substances in or on the soil (Figure 5.1).

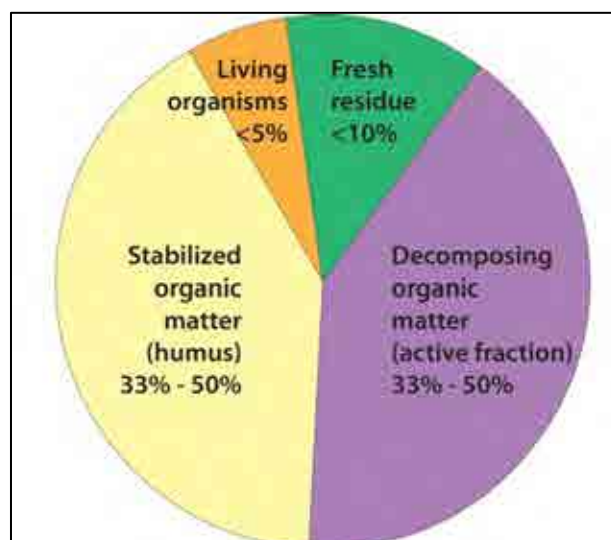


Figure 5.1 Make up of soil organic matter (NRCS, 2013a)

SOM has a number of significant functions (Lal, 2004). These are:

- substrate for energy for soil biota;
- source and sink of principal plant nutrients (e.g. N, P, S, etc.);
- promoter of improved nutrient and water use efficiency;
- significant contributor to cation exchange capacity;
- absorbent of water at low moisture potentials leading to increase in plant available water;
- promoter of water infiltration and reducing losses to runoff;
- promoter of soil aggregation improving soil structure;
- source of strength for soil aggregates, reducing susceptibility to erosion;
- buffer against fluctuations in soil pH;
- moderator of soil temperature through its effect on soil colour.



The most important part of SOM is its carbon component. Soil organic carbon (SOC) is equivalent to about 58% of the SOM.

SOC is made up of four pools, defined chemically as:

- dissolved organic carbon,
- particulate organic carbon,
- humus, and
- recalcitrant organic carbon.

The living organisms usually make up 5% of the soil carbon pool and are responsible for transforming all SOC pools and releasing nutrients for plant uptake. *Dissolved organic carbon* is found in the soil solution and represents a small fraction of SOC. *Particulate carbon* includes recently added plant or animal debris which usually still has a recognisable cellular structure. *Humus* comprises both organic molecules like proteins and cellulose, and molecules with no identifiable structure (humic and fulvic acids and humin) but which have reactive regions which allow the molecule to bond with other mineral and organic soil components. Humus is usually the largest SOC pool, except in pasture systems where humus and particulate carbon can be found in roughly equal quantities. In Australian soils, *recalcitrant carbon* is mainly comprised of charcoal due to the history of fire.

In simple terms, particulate carbon typically lasts for weeks to a year or more in the soil; humus lasts for decades to centuries while recalcitrant carbon can persist for thousands of years. However, current understanding suggests that persistence of organic carbon in soil has more to do with ecosystem properties than molecular properties. This means that the persistence of soil carbon is closely associated with the capacity of the soil to protect the carbon from microbial degradation (Schmidt et al, 2011). This highlights the benefits of perennial systems where soil disturbance is minimised.

SOC's contribution to biological processes is governed by how available the energy in the carbon is to microbes. Dissolved and particulate carbon are most readily available. Although humus is also important as a biological energy source, it can be more resistant to break down and therefore nutrients are released more slowly. However, as a source of plant nutrients, humus is the main storehouse in the soil. Recalcitrant carbon, like humus, is dark in colour and influences the soil's thermal properties.

5.3 Components of the soil biological community

Soil biology may be described by size, taxonomic group and the functions they perform (Figure 5.2). The smallest – the microflora and microfauna – are microscopic in size, that is, they can only be seen using high powered magnification. The meso- and macrofauna may be seen with lower level magnification, a hand lens, or the naked eye.







| Group | Organisms | Size range | Functions | Microscopes required |
|------------|---|--|--|--|
| Microflora | Bacteria Actinomycetes Fungi Viruses | 0.02-5µm 1-2µm (hyphae less than 1µm thick) Hyphae 1-4µm thick and can cover km distance 50-100nm | <ul style="list-style-type: none"> Organic matter turnover Nutrient mineralization Aggregate formation Disease incidence Disease suppression Degradation of pollutants Greenhouse gas production | Research microscopes Electron microscopes  |
| Microfauna | Protozoa Nematodes | 5-200µm 10µm-2mm | <ul style="list-style-type: none"> Regulate bacterial and fungal populations (predation) Nutrient cycling Disease suppression Disease incidence | Stereo microscopes Research microscopes  |
| Mesofauna | Collembola Mites | 250µm-2mm 100µm-2mm | <ul style="list-style-type: none"> Nutrient cycling Regulation of bacterial and fungal populations Fragment plant residues Create biopores Aggregate formation (faecal pellets) | Stereo microscopes Powerful magnifying lens  |
| Macrofauna | Earthworms Beetles Ants Termites | Visible to naked eye | <ul style="list-style-type: none"> Fragment plant residues and organic matter distribution in the profile Stimulate microbial activity Can affect fungal pathogen inoculum Create biopores and modify drainage Aggregate formation and soil structure | Stereo microscopes Powerful magnifying lens  |

Figure 5.2 Elements and functions of soil biological communities

Source: Gupta <http://www.csiro.au/Outcomes/Food-and-Agriculture/SoilOrganismsPoster.aspx>

5.3.1 Functions of biota in natural soil processes

There are three levels of participation by biota in *natural* soil processes (Figure 5.3):

- [Ecosystem engineers](#) (e.g. earthworms, termites & ants);
- [Litter transformers](#) (e.g. microarthropods); and
- [Micro-food webs](#) (e.g. microbes and microfaunal predators)

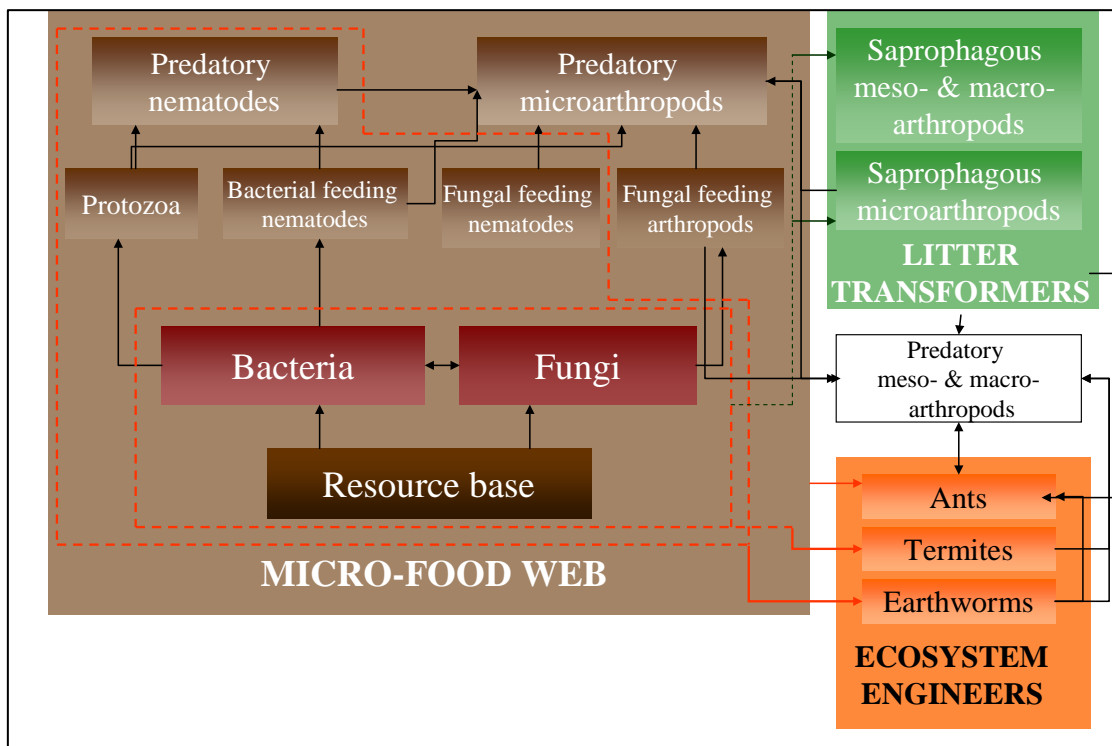


Figure 5.3 Roles and relationships; soil micro-, meso- and macro-organisms (redrawn from Wardle, 2002)

5.3.1.1 Ecosystem engineers

Ecosystem engineers alter the physical structure of soil by the action of earthworms, beetles and ants physically rearranging and pushing soil particles together. They also move organic materials from the surface of soils below ground. In addition, the movement of macrofauna up and down the soil profile creates semi-permanent channels through which air, water and roots can penetrate deeply. Improved aeration and infiltration, together with the deposition of organic materials below ground, create additional sites for soil microbes to chemically break down organic compounds, thereby releasing nutrients for plant uptake – a process known as mineralisation. In this way, the ‘ecosystem engineers’ have a strong influence over rates of nutrient cycling and energy flow in soils.

5.3.1.2 Litter transformers

Litter transformers are those organisms which are capable of shredding and ‘pre-digesting’ organic materials. Collembola (springtails) and oribatid mites are potentially numerous in productive agricultural soils. Through the action of their chewing mouthparts, plant litter is fragmented and its surface area expanded to improve availability of nutrients to microbes (Franzluebbers, 2004).

5.3.1.3 Micro-food webs.

In contrast to the larger organisms, bacteria, archaea and fungi decompose plant litter through enzyme action. Enzymes are released outside the cell and break down litter and any other suitable substrate, thereby releasing nutrients for uptake by other microbes, and plant roots. In their turn, bacteria, archaea and fungi provide a food source for predatory protozoa, nematodes and many of the arthropods such as collembola and mites (Franzluebbers, 2004). Predatory organisms regulate soil populations, maintaining stability within a community. They may also control numbers of disease causing organisms - a phenomenon referred to as ‘disease suppression’. Suppressive soils are identified as having potentially damaging levels of pests or disease, yet the pest or disease is either expressed at a sub-economic level, or not at all, due to the presence of certain beneficial organisms.



5.3.2 Where are soil organisms located in soils?

Soil organisms are not uniformly distributed. The factors that influence their distribution are principally access to suitable substrate, air and moisture. Typically, larger populations of soil organisms are found around decomposing residue and in the rhizosphere (root zone) of plants where readily available food sources are located (Schmidt et al, 2011).

Soil organisms may be more evenly distributed in cultivated soils that are thoroughly mixed, particularly with successive cultivations. In dairy soils, which can remain undisturbed for many years, populations can be discontinuous and centred around food resources such as pasture roots. However, given the high earthworm populations commonly found in many dairy soils, the degree of bioturbation (the mixing of soils through the action of the 'ecosystem engineers') in the topsoil can result in a higher degree of soil mixing than might otherwise be found, thereby increasing the distribution of soil organisms throughout the topsoil.

5.4 Why is soil biology important to dairy farmers?

Soil biology mediate critical soil functions by:

- [nutrient cycling](#)
 - regulating plant nutrient supply and loss (e.g. N, P, K, Zn, Mn etc.),
 - capturing and releasing greenhouse gases such as carbon dioxide, methane and nitrous oxide.
- decomposing plant residues,
- [improving soil structure](#) (aggregate stability),
- [degrading pesticides and herbicides](#), and
- [regulating water quality](#) (e.g. nutrient filter).

5.4.1 Nutrient cycling

Given that dairy farms have a high nutrient requirement and that all nutrient transformations in soils are biologically-mediated, diverse biological populations are required to support optimum nutrient cycling from both organic and inorganic sources.

5.4.1.1 The Carbon Cycle

The breaking down of organic materials and the release of bound nutrients for plant uptake are important parts of the carbon cycle (Figure 5.4).

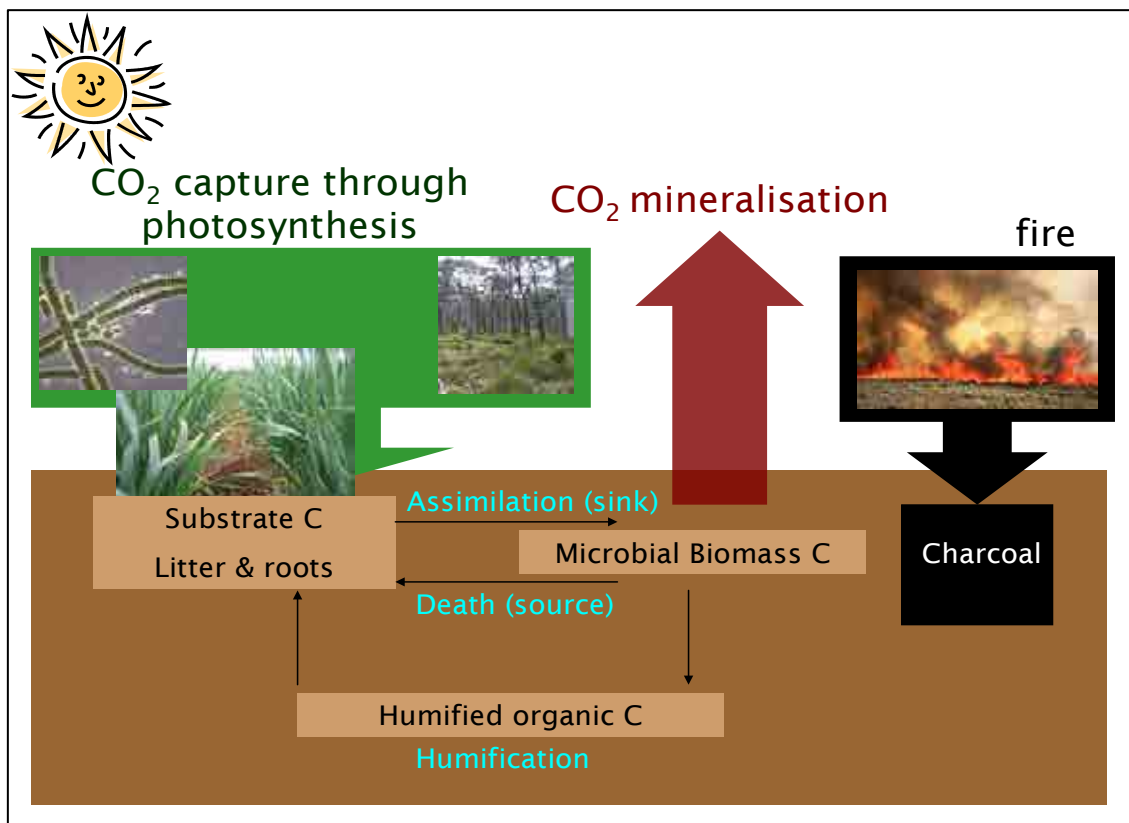


Figure 5.4 The Carbon Cycle (Mele, from www.dpi.vic.gov.au/vro/soil)

In photosynthesis, sunlight drives a biochemical process in plants that splits atoms of carbon dioxide and water and re-combines them as carbohydrates to form the basic units of the terrestrial (land-dwelling) food chain. A large proportion of these carbohydrates are then available to the carbon decomposing soil biota as plant litter or in the form of root exudates. Some of this carbon cycles quickly through the soil (*particulate or labile carbon*) while a usually larger component becomes *sequestered* as microbial biomass carbon, or *humified* carbon and will have a longer residence time. Charcoal can be a significant component of soil carbon if the land had a previous history of fire. This form of carbon can have very long residence times in soils, but ultimately all organic carbon will become mineralised and will be returned to the atmosphere as carbon dioxide.

One aspect of the carbon cycle that is of current concern involves the large return of carbon dioxide (CO₂) to the atmosphere. CO₂ is a potent greenhouse gas and is produced through cellular respiration - the metabolic process that takes place within cells through which organisms obtain energy from organic molecules.

5.4.1.2 The Nitrogen Cycle

Another important cycle is significant in dairy systems, not only because it drives production, but because it is also implicated in the production of greenhouse gases. This is the nitrogen cycle (Figure 5.5).

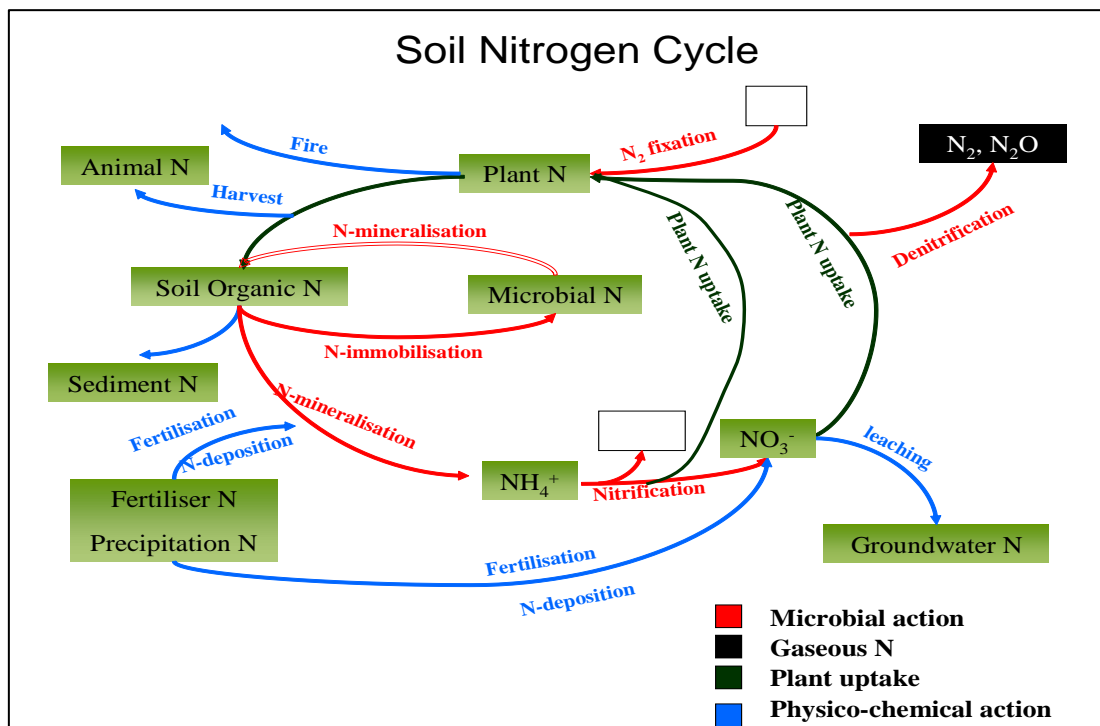


Figure 5.5 The Soil Nitrogen Cycle (Adapted by Mele in www.dpi.vic.gov.au/vro from E.Paul, 2007)

Depending on the phase of the nitrogen cycle, nitrogen can exist in the atmospheric dinitrogen (N_2) form, the ammonia (NH_3) form, the ammonium (NH_4^+) form, as nitrite (NO_2^-), as nitrate (NO_3^-), or as nitrous oxide (N_2O). It can also exist as mono-nitrogen oxides (NO_x) produced from the reaction of nitrogen and oxygen gases in the air during fires.

As the different forms of nitrogen move from one phase to the next, their conversion is mediated by biological processes either in the body of a plant or animal, or via microbial action in the nitrogen fixing, mineralising, immobilising, nitrifying or de-nitrifying stages in the soil (red arrows in Figure 5.5). Plants can only take up N as inorganic N forms (nitrate or ammonium), so organic forms of N need to be mineralised by soil microbes before they can be taken up by pasture. Conversely, ammonium and nitrate can also be *immobilised* back to the organic form when the nitrogen is taken up by plant or microbe. The relative speed of the nitrogen cycle in the soil is dependent on temperature and moisture. This means that warm, moist conditions favour the release of nitrous oxide (a potent greenhouse gas) from soil so care is required with regard to the form of nitrogen fertiliser used and its application rate – Refer Chapter 12.1.2.

Pasture legumes, such as subterranean clover, provide high quality feed for grazing animals and can contribute substantial quantities of nitrogen to dairy systems. This nitrogen is essentially provided at no cost. Atmospheric nitrogen is biologically ‘fixed’ by **rhizobia bacteria** living in association with legume roots and the availability of this fixed or reactive nitrogen can make the legume independent of soil/fertiliser nitrogen – See Chapter 3.4.1.3. Rhizobia cannot form survival structures (‘resting bodies’) like spores and this makes all rhizobia very sensitive to environmental stresses. They can easily be killed by exposure to stresses such as heat, extreme pH, and chemicals such as some fertilisers or fungicides (Drew *et al*, 2012). Rhizobia are aerobic organisms and need oxygen for respiration, moderate temperatures, moisture and food (Table 5.1).

**Table 5.1** Rhizobia needs for growth and survival (from Drew *et al*, 2012)

| REQUIREMENT | COMMENT |
|-------------------|--|
| Food and energy | Usually carbohydrates (sugars such as glucose) |
| Mineral nutrients | Essential macro and micro nutrients |
| Water | Rhizobia can only grow in moist conditions |
| Temperature | Preferred range is 15 to 30°C |
| pH | Preferred range is pH 6.0 to 7.5 |
| Air | Rhizobia are aerobes and need oxygen for respiration |

Popular legume varieties for dairying in southern Australia include lucerne, red clover and white clover. All require soils with good fertility, and for lucerne in particular, good drainage. A 2012 review found that annual N₂ fixation rates in Australian dairy pastures are generally low – usually less than 50kg/ha. This is due to low pasture legume content with typical legume contents of grazed pastures less than 30% of total pasture biomass production – See Chapter 12.2.1. Other factors that could positively influence N₂ fixation input (i.e. nutrition, acidity or moisture) were found to have little impact until the proportion of legume in the pasture increased. Potential (maximum) N₂ fixation is governed by legume total dry matter production which is dependent on mineral N availability, soil fertility, and the quality and quantity of the rhizobia (Unkovich, 2012).

Over application of inorganic nitrogen fertiliser can reduce the contribution of organic nitrogen from legumes to a low level, representing a potentially unnecessary cost to the farmer (Unkovich, 2012). At low soil nitrate levels (below 50kg N/ha.) legume reliance on N fixation is high. As soil nitrate levels increase, biological N₂ fixation becomes more suppressed to a point above 200kg N/ha when nodulation and nitrogen fixation will be close to zero (Drew *et al*, 2012). Maintaining legume levels in mixed pasture swards requires a combination of appropriate grazing management, and attention to the factors discussed above for maximum N₂ fixation – See Chapter 12.6.3 for more information.

Free-living nitrogen fixing bacteria can contribute additional nitrogen per hectare per year. These bacteria, typically species of the *Azospirillum* and *Azotobacter* genera, are found in many Australian soils. Their proliferation is dependent on availability of soil C and relatively low nitrogen levels (Gupta *et al.*, 2011; Gupta & Paterson, 2006). Their contribution to dairy soil nutrient budgets is therefore not likely to be large in dairy systems.

5.4.1.3 Phosphorus cycle

Like the nitrogen cycle, the P cycle is very complex, involving many interactions and chemical reactions in the soil. The rate by which organic phosphorus becomes inorganic and plant available in the soil solution will depend on the *mineralisation* process driven by soil microorganisms and their enzymes. As with nitrogen, whilst in the soil solution in this soluble form, phosphorus is also subject to being *immobilised* by soil microorganisms back into an organic form.

Plants and soil organisms have co-evolved symbiotic associations whereby plants can signal a range of needs (e.g. nutrients, plant defence) through the form of plant root exudates produced (Rasmann & Agrawal, 2008).

Soil organisms such as **mycorrhizal fungi** have developed specific attributes, such as phosphorus solubilisation and transport, to make P more available to plants.



High rate application of inorganic sources of fertilisers can interrupt this process and reduce biological nutrient cycling. Conversely, a reduction in phosphorus application rates on high P soils has not resulted in loss of production suggesting a resumption of P solubilising functions.

5.4.2 Improving soil structure

Soil biology has a particularly important role in promoting and maintaining soil structure and aggregate stability. Soil structure is influenced by the amount of clay and organic carbon in soils, and the amount and proportion of cations (particularly calcium and magnesium) – See Chapter 4. The cations help flocculate soils into microaggregates and also build bridges between the mineral fraction of the soil and the organic fraction. However, this flocculation alone is not sufficient in most cases to ensure good aggregate stability and good structure. A Cornell University soil scientist, Richard Bradfield, recognised back in 1950 that ‘aggregation is flocculation – plus!’ The ‘plus’ refers to what he called ‘cementation’ – the physical enmeshment of soil aggregates by plant roots and fungal hyphae, and the ‘gluing’ of soil particles by bacterial and fungal exudates (Hillel, 1998). An example of this is the secretions of glomalin from arbuscular mycorrhizal fungi.

5.4.3 Degrading pesticides and herbicides

Soil organisms have the capacity to degrade applied biocides including pesticides, fungicides and herbicides. The concern over the persistence of organochlorines (e.g. DDT, dieldrin, chlordane) in agricultural and horticultural soils relates to their toxic effect on microorganisms (Lal & Saxena, 1982). Modern biocides are, in general, of lower persistence in soils due to the ability of organisms to degrade the chemicals into harmless compounds (UWA, 2013). Without this soil function, the repeated application of herbicides and pesticides would result in these compounds accumulating in soils to levels that would threaten the health of terrestrial and aquatic ecosystems.

5.4.4 Regulating water quality

Another important function of soil biology is the filtering of excess nutrients (within the limits of a given system) thereby contributing to improved groundwater quality before its passage into surface creeks and rivers.

5.5 What regulates Soil Biology?

There is growing awareness of the importance of soil biology to efficient soil function. It is therefore helpful to understand what regulates soil biological populations so that favourable management practices can be used to promote biological function.

There are two levels of regulation of soil biology. The [primary regulators](#) are environmental and include [air](#), [water](#), [temperature](#), and [soil type](#). In the context of a habitat all of these features are related such that the texture and porosity of a soil determines the water and air available for growth. The [secondary regulators](#) relate to [organic matter quality and quantity](#), the [amount and frequency of soil disturbance](#), and the [inputs used to manage production](#) (fertilisers, herbicides, lime etc.).

5.5.1 Primary Regulators

5.5.1.1 Soil air

The movement of air into and out of the soil is critical to the survival of aerobic organisms, and the functions they perform. There exists therefore, a strong relationship between soil structure and soil biological functions.

Given that most nutrient cycles are biologically-dependent, meeting the needs of microorganisms for air, water and food through management practices that support good structure, and avoid damaging compaction, will promote efficient nutrient cycling.



5.5.1.2 Soil water

Aerobic microbial activity responds to soil water potential assuming soil temperature is not limiting. Figure 5.6 shows that microbial biomass is closely aligned with soil moisture content with populations rising with available moisture when food and temperature are not limiting. Above field capacity, the loss of soil oxygen due to inundation would see a reduction in microbial biomass.

Of the microorganisms, fungi are generally more tolerant of lower soil moisture than bacteria as bacteria are less mobile and rely on diffusion to obtain nutrients (NRCS, 2013b). Earthworms are generally numerous on dairy farms but populations fall off below 500-600mm annual rainfall with relatively few individuals remaining below 300mm (Mele & Carter, 1999).

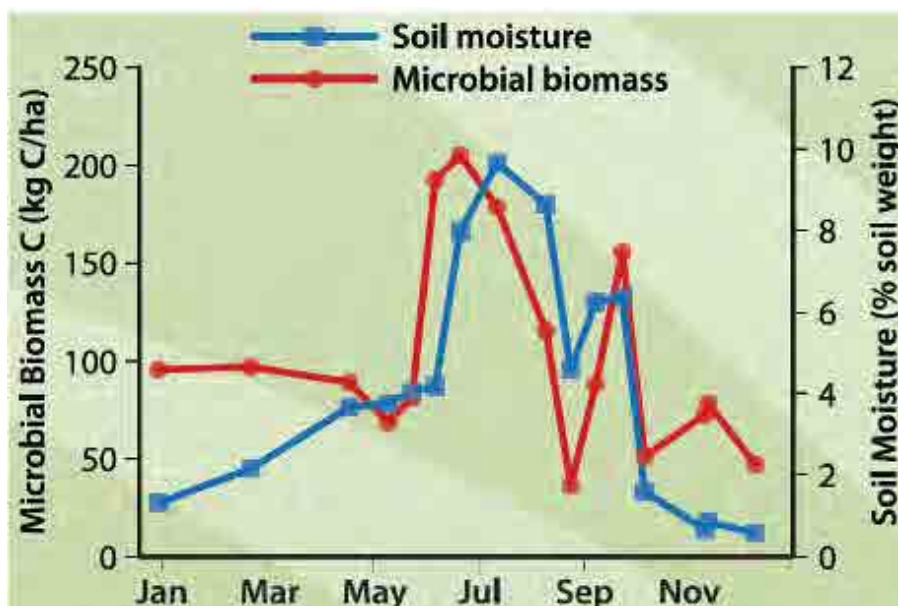


Figure 5.6 Microbial biomass activity as influenced by the level of soil moisture (<http://soilquality.org.au/factsheets/microbial-biomass>)

5.5.1.3 Soil temperature

Plants as well as soil organisms require certain minimum temperatures in order to grow and carry out their activities. Biological activity and associated growth and development occurs more quickly at higher temperatures, as evidenced by growth rates of pastures speeding up in spring and slowing as winter approaches.

In the soil, biological functions, such as breaking down of organic matter or cycling of nutrients, are similarly affected by temperature. This is why it is generally not a good idea to soil test for nitrogen in spring because the increase in biological activity releases nitrogen from stores of organic matter resulting in an inflated account of the true quantity of N in dairy soils.

5.5.1.4 Soil type

Soil type strongly influences microbial populations for a number of reasons. Clay soils have the potential to hold more water and for longer than a sandy soil. For this reason, they generally hold more organic carbon than sandy soils. Well-structured clay soils will have a higher number of micro- and macro-aggregates, thereby providing more potential habitat for soil organisms of varying sizes. A diversity of habitat will ensure maximum protection for soil organisms against predation.

Note that while clay soils have potential to support higher microbial biomass, this potential will only be realised if other regulators (primary and secondary) are not limiting. Most obviously this means that if the clay soil is poorly structured, its carbon capture potential, air-filled porosity, drainage, and numbers of micro-aggregates will be sub-optimal and production in such a soil is also likely to be below potential. So, even though clay soils have potential to support high microbial biomass, a



heavy clay soil that has been used for cropping, or that was poorly managed in wet conditions may not be well structured and may have lower microbial biomass than a lighter loamy soil. Figure 5.7 shows two different soil types under two different land uses. Higher clay, and less disturbance results in higher microbial biomass. Actual microbial biomass on individual farms will be strongly influenced by management practices.

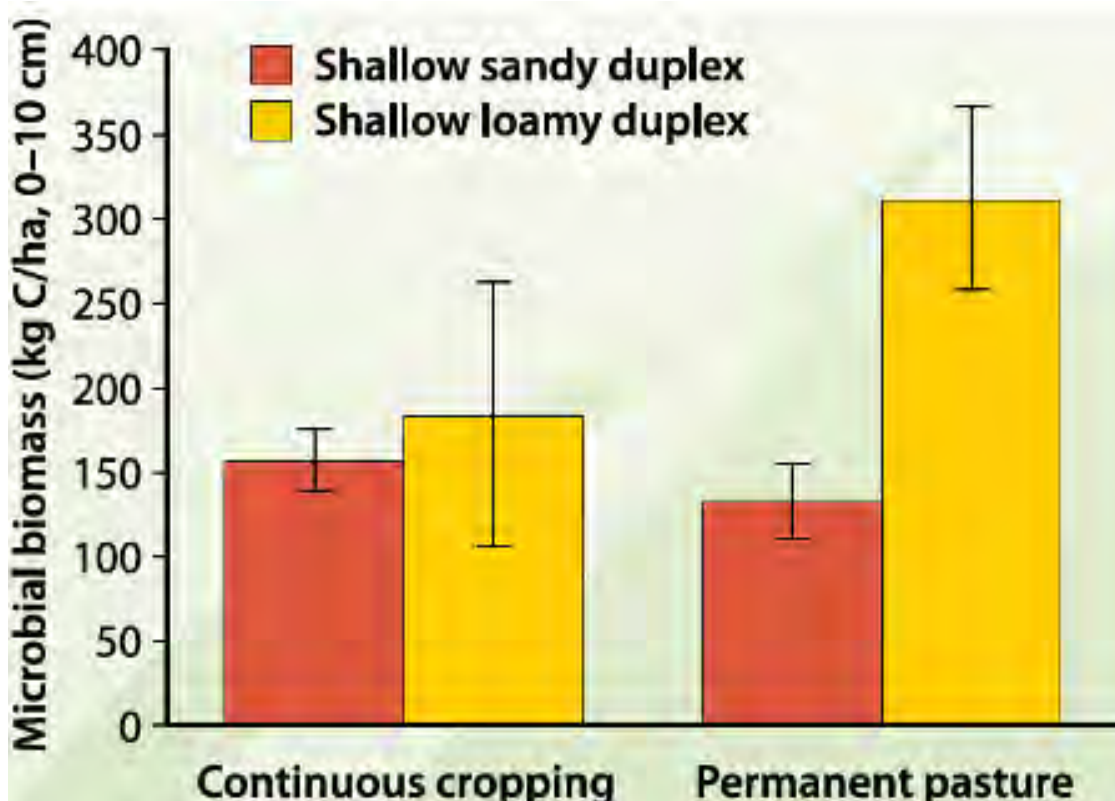


Figure 5.7 Microbial biomass carbon in soils with differing clay contents and management practices (<http://soilquality.org.au/factsheets/microbial-biomass>).

5.5.1.5 Survival strategies

Bacteria are simple organisms consisting of a single prokaryotic (no cell nucleus) cell. They are extremely responsive to changes in their environment either rapidly dying back or reproducing at a very high rate depending on conditions. Under favourable conditions bacteria may divide every 20 minutes. This could result in exponential growth where one bacterium could produce 10 million in just 10 hours (Agrios, 1988). However, this is unlikely to occur to this degree in soils due to reduction in food supply or accumulation of metabolic wastes. When conditions change to be less favourable, most bacteria can quickly develop a range of 'resting bodies' which can survive extended periods until such time as conditions again favour growth and development.

Fungi usually have plant-like vegetative bodies called mycelia (singular mycelium). The mycelium consists of elongated, branched, microscopic filaments termed *hyphae*. They are higher order eukaryotic (possessing a membrane-bound nucleus) organisms, the vast majority of which are saprophytic, that is they live on dead organic matter. Fungi reproduce primarily by means of spores. Fungi are not as responsive to environmental changes as bacteria due to their larger physical size allowing access to a wider range of soil resources. However spores may be produced as resting bodies when unfavourable conditions persist. Fungi may regrow from severed hyphae resulting from tillage but their recovery is slower than that of bacteria – food, water, air and nutrition notwithstanding.

This generally results in higher populations of bacteria in annual systems and equal or higher proportions of fungi in long-term perennial systems.



5.5.2 Secondary Regulators

5.5.2.1 Organic matter quality and quantity

Organic amendments:

The carbon to nitrogen ratio (C:N) is a good measure of likely mineralisation (release of N by microbes) or immobilisation (tie-up of N in microbial biomass) in soil. A soil's C:N should be in the order of 12:1. If the C:N is greater than 25:1, immobilisation of nutrients is likely. If the C:N is less than 25:1, mineralisation is likely. This means that if microbes (mainly bacteria and archaea) are in a high nitrogen environment (low C:N) they can use that nitrogen to breakdown organic matter in soils to access nutrients, including carbon, as a food resource, and their population will likely increase thereby turning over N for plant access. However, in low C:N soils, soil carbon is at risk of declining if sufficient carbon is not re-introduced into the system by growth (e.g. plant roots), or application (e.g. manures or compost). In low C:N soils, microbes will use available nitrogen to degrade soil carbon which is released as CO₂.

Conversely, in a high C:N soil, bacteria will access all available nitrogen to breakdown excess C and as they are superior competitors for soil N compared to plant roots (Owen & Jones, 2001), the plant will be deprived of nitrogen because it is immobilised in the bodies of bacteria and other soil microorganisms. This is termed 'nitrogen draw down'. It is usually a temporary phenomenon and is overcome when bacteria die off due to resource depletion, or another nitrogen source is introduced.

The C:N concept is important when adding organic amendments to soil. Table 5.2 shows average C:N ratios of common organic materials. As mentioned above, if an amendment has a C:N of less than 25:1 it will progressively release nutrients and should have a fertiliser effect. If the material has a C:N ratio of more than 25:1, it is likely that nitrogen will be immobilised and nitrogen draw down will occur.

Table 5.2 C:N ratios of common organic amendments (Charlesworth, 1997).

| MATERIAL | C:N |
|-----------------|------------|
| Urine | 2:1 |
| Dried blood | 4:1 |
| Pig manure | 5:1 |
| Poultry manure | 10:1 |
| Farmyard manure | 14:1 |
| Seaweed | 19:1 |
| Horse manure | 25:1 |
| Weeds | 30:1 |
| Straw | 80:1 |
| Sawdust | 500:1 |

Microbial diversity:

Microbial diversity refers to the number and variety of soil microorganisms. As a general rule, the more diverse the above-ground crop or pasture mix, the more diverse will be the micro-biological



communities in the soil. Wilhelm (1973) cites the 'Elton Principle' which holds that the greater the complexity of a microbiological community in terms of total number and species of organisms, the greater the stability of the community. As shown in Table 5.2, organic amendments can vary considerably and their application to the soil will have different effects on the soil biological community. In the same way, crop and pasture mixes will also influence microbial composition and activity.

Plants vary in the size and structure of their root systems, in the quantity and quality of root exudates, and in the degradability of crop or pasture residues. This results in differences in microbial density and diversity in the plant rhizosphere (root zone) and near crop and pasture residues. Some plants possess chemicals that inhibit the growth of other plants, or have negative effects on soil organisms. Likewise, some microbes possess strategies that enhance their competitive advantage. This has particular relevance when we consider suppressive soils. The term 'suppressive soil' has been used to describe soils in which a pathogen is present but is not causing economic damage. Suppression of a pest or disease is the mechanism by which one or several organisms are antagonistic to a pathogen through the antibiotics they produce, competition for food, or through direct parasitising of the pathogen (Agrios, 1988). As an example, the production of isothiocyanates in canola has a suppressing effect on soil microorganisms. Isothiocyanates possess fungicidal, bacteriocidal, nematocidal and allelopathic properties (Fahey, 2001).

5.5.2.2 Tillage

Organic matter persists in soils to the degree that it is protected from microbial attack (Schmidt *et al.* 2001) or because prevailing moisture and temperature conditions are unfavourable for microbial decomposition. Tillage of any kind impacts on these protective mechanisms and renders the organic matter vulnerable to degradation by soil organisms. Tillage mixes the soil bringing microbes into more intimate contact with organic matter. It also improves (however temporarily) air and water movement into the soil – elements important for the growth and development of soil biology. Tillage can also be used to incorporate and distribute plant residue into the soil profile, again bringing food resources into close contact with soil organisms.

Tillage favours bacteria in view of their superior ability to respond quickly to changes in the environment. Fungal populations tend to be negatively impacted in view of the damage to the hyphal networks – See [Section 5.5.1.5](#).

The incorporation of large quantities of organic material into soil can be a positive undertaking provided follow up actions maximise the use and sequestration potential of incorporated organic matter. For example, discing in crop residues will help to capture much of the carbon turned into the soil and will benefit the establishment and growth of perennial pasture.

The development of minimum- or no-till systems recognises the value of minimising soil disturbance. Stubble retention or surface applied organic materials will support slower decomposition and nutrient mineralisation, favour fungal growth to aerobically degrade lignocellulose compounds, promote better aggregation and soil structure, and improve the potential for SOM accumulation (Scott *et al.*, 2010; de Boer *et al.*, 2004)

5.5.2.3 Chemical impacts on soil biology

The large number of chemicals registered for use on farms makes it difficult to discriminate between those that are benign and those that are harmful to soil biology. While some have little effect, others do negatively impact on soil biology. Bunemann *et al.* (2006) reviewed the impact of agricultural impacts on soil organisms and found that:

- fertilisers generally enhanced soil biological activity due to increases in production;
- the acidifying effects that can occur with the use of certain nitrogenous fertilisers resulted in negative impacts on soil biological activity;



- organic amendments generally enhanced soil biological activity;
- microbial inoculation, with the exception of nitrogen fixing microbes, appears to have little long-term effect;
- the negative effects of pesticides and fungicides were more commonly reported;
- negative effects of herbicides were less commonly reported.

Roget & Gupta (2004) found that the negative impact on soil biological activity of many herbicides is reversible i.e. given sufficient time, the soil biology bounces back. However, with some chemicals, repeated applications delays or removes that reversibility. They recommended that:

- The short-term impacts of most of the herbicides tested are reversible, so it may be possible to develop management options to reduce non-target negative impacts;
- An appropriate recovery period for soil biota should be allowed between herbicide applications;
- Soils with a healthy biota could recover from short-term negative effects of herbicide application. Appropriate use of herbicides could be less destructive to soil biota if management practices that improve biological activity are promoted.

Grains Research and Development Council (GRDC) funded research from South Australia found specific effects of herbicides on soil N fixing bacteria with reductions in nodulation that resulted in reduced N benefit to the system (Drew *et al*, 2006).

Lime application and the associated increase in soil pH are strongly correlated with changes in microbial communities (Nelson & Mele, 2006). Lime has also been shown to influence functioning of the nitrogen cycle. Molecular techniques were used to target a section of the N-fixing gene in a wheat rhizosphere soil. The results suggest an increase in abundance of N-fixing rhizobacteria from which an increase in N fixation could be inferred. Research undertaken on acid soils in North-East Victoria showed an increase in ammonium N oxidisers following the application of lime.

Lime also impacts on soil structure by increasing aggregation of soil particles and the creation of a greater diversity of macro and micro pore spaces for improved habitat. Air and water movement through soil is also enhanced. In addition, biological access to food resources can be improved (Chan & Heenan, 1999).

5.6 Measurement of soil biology

Currently there are relatively limited options for commercial testing for soil biology.

Some tests assess microbial populations using direct observation via microscopy while, more recently, tests employing phospholipid fatty acid assays have become commercially available. While these tests provide some insight into soil biological populations, understanding of how to use this information is currently limited.

More sophisticated analytical tools using the science of genomics to target microbial genes to determine the functions that are active, or are potentially active in a soil, are being used to address R&D hypotheses. Testing for genes involved in the nitrogen cycle provides an insight into the potential nitrogen mineralisation or immobilisation that might occur in a given soil (Hayden *et al*, 2010). These tests can also show the presence or absence of genes involved in disease expression or control.

The future of soil biological testing is likely to focus on short term information relating to the potential for a soil to support efficient nutrient cycling for the coming season, or to the risk associated with pest or disease pressure. Longer term monitoring will reveal patterns in microbial community structure and function, the management of which will be aligned with recommended management



practices. For example, biological testing may provide specific information on the effects of tillage, crop rotation, residue management, nutrient availability, or the use of a particular biocide. Such information will require calibration for different soil types and different climatic zones, but will be important for management and investment decisions.

5.7 Managing soils to improve biology

Opportunities to improve microbial biomass and biological function require management – in so far as possible – of the primary and secondary regulators.

5.7.1 Managing primary regulators

Primary regulators such as air and habitat can be managed through protection and enhancement of soil structure. Habitat will be protected if soils remain as undisturbed as possible, if air and water movement into and out of soils is optimised, and if the soil environment is free from toxicities such as salt from primary salinity or application of high salt-index fertilisers. Other primary regulators such as soil type, water and temperature may be more difficult to influence although access to irrigation may provide some flexibility.

Management practices that support habitat protection (good soil structure) include good wet weather management to avoid pugging by livestock in grazing operations, and no-till, stubble retention and direct drilling under cropping. Some work from New Zealand reported low abundances of earthworms, collembola (springtails), and oribatid mites on dairy farms possibly due to both direct and indirect effects on the decomposer community of livestock treading. The loss of decomposer habitat is proposed as a primary factor limiting the incorporation of organic matter from the soil surface into the profile to sustain soil carbon (Schon *et al.*, 2011).

5.7.2 Managing secondary regulators

Improved management practices can influence the secondary regulators of soil biology including organic matter quality and quantity, the amount and frequency of soil disturbance, and the inputs used to manage production (fertilisers, herbicides, lime etc.). For example, heavy metals in biosolids or build-up of harmful chemical residues from repeated use of biocides should be avoided.

5.7.2.1 Managing soil organic matter

Organic matter in the form of plant residues (roots or surface litter), animal manures or composts is the substrate that provides energy to soil organisms. A diversity of inputs from diverse pastures and animal manures will promote below-ground diversity and support a range of soil functions. Diversity of plant species or rotations will also reduce pest and disease pressure through improved stability of the biological community. It is important to note that organic matter input must be maintained so that soil biology have regular and continued access to food stocks. A one-off application of animal manures will see a response from soil biology and a short term increase in soil carbon, but failure to follow up with repeat applications will see the system quickly return to previous levels of soil carbon and biological activity.

5.7.2.2 Managing chemical inputs

Although more data on the impact of fertilisers, pesticides or herbicides on soil organisms is required, available data shows that repeated use of the same biocide is likely to impact on different organisms by reducing their ability to 'bounce back' from the impact. Minimising the use of pesticides and herbicides is recommended through strategic spraying and promotion of improved soil condition and grazing management.



5.8 Microbial inoculants and biological amendments

The interest in soil biology has encouraged market responses in the form of organic amendments, biological inoculants and microbial stimulants. Organic amendments in the form of manures and composts have been in use for millennia with the current challenge being integration of these inputs into conventional fertility management planning.

Many of the newer inoculants and stimulants have not been the subject of rigorous, replicated trials in a variety of soil types or climatic zones. As a result, it is difficult for farmers to know if the product is likely to return a financial benefit – even in the long term – or if the product is a waste of money.

If farmers are persuaded by anecdotal claims of product effectiveness and wish to conduct a trial on their farm, there are a few steps to follow to determine if the product delivers on its promise and the investment is worthwhile.

Firstly, there should be a clear understanding of what the product is claimed to do and how its effectiveness should be measured. In establishing a trial, a paddock which is not the best and not the worst performing should be selected. An area for the trial should be designated and its boundaries clearly marked with a GPS or physical markers that will not be impacted by grazing animals. The trial should have an area to test the product and a similar sized adjacent area on the same soil type not treated by the product, as a control.

Soil tests / pasture tests should be taken before any other action is carried out. Most importantly, only that product to be tested should be used on the trial. If additional inputs are used – e.g. lime – it will not be possible to determine if a response is due to the product being tested, the lime, or a combination of the two. Detailed records of the trial including dates, application rates, weather, pasture responses and other observations will be necessary.

Some biological inoculants have been subject to rigorous trials with, for example, rhizobia – the bacteria responsible for nitrogen fixation in legumes – having a fifty year history of research and development, and quality assurance. Similarly, much work has been done on biocontrol agents such *Trichoderma* spp., a fungus which has demonstrated control of root rots in onions, and work is continuing on new strains of *Bacillus* spp. for biocontrol of common root diseases.

5.9 Summary

Dairy systems are generally high input and bearing in mind that all nutrient transformations – be they organic manures or inorganic fertilisers – are mediated by soil biology, any negative impact on soil biology may reduce the efficiency of nutrient and carbon cycles. Being aware of the needs of soil organisms will allow the farmer to make more informed decisions with regard to protecting and enhancing soil condition.

Soil life principally needs energy resources, together with the basics of existence – air, water and habitat – to thrive. The ages-old practice of applying organic material to soils is being recognised as vital to improving and maintaining soil condition. The issue for modern dairy farming is to integrate the twin challenges of maintaining production through judicious fertiliser application, *and* feeding the soil with regular organic inputs.



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Chapter 6

Soil Types

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6 Soil types

6.1 Introduction

It is essential to know the locations and characteristics of specific soil types on a dairy farm in order to make sound soil and fertiliser management decisions. Soil properties such as soil structure, depth, texture, salinity, acidity, waterlogging or compaction can limit crop and pasture growth even when the soil has adequate nutrients - See [Chapter 4](#), 'Soil Properties'. Soil factors limiting production must be managed to minimise their impact, so that fertiliser applications are as effective as possible - See [Chapter 7](#), 'Managing Limiting Soil Factors'.

In recent years soil maps and descriptions of the chemical and physical characteristics of soils from numerous sites across Australia have been uploaded to websites. These online resources are improving each year as additional information is uploaded. Regional soil information can be used in combination with local knowledge of the soils to help prepare a farm soil map - See [Chapter 1.1.4](#).

6.2 Soil types of the dairy regions

The following websites provide useful information on soil types across Australian dairy regions:

National

- [Australian Soil Resource Information System \(ASRIS\)](#)^[2]
- [CSIRO: Soil Mapp for iPad](#)^[3]

New South Wales

- [Soil and Land Information System \(SALIS\)](#)^[5]

Queensland

- [Soil Management, Queensland Government](#)^[11]
- [Department of Natural Resources and Mines](#)^[6]
- [Queensland Government Information Service](#)^[9]

South Australia

- [South Australia Government: ATLAS, Soils](#)^[12]

Tasmania

- [Department of Primary Industries, Parks, Water and Environment](#)^[8]

Victoria

- [Victorian Resources Online: Regional Soils Information](#)^[7]

Western Australia

- [Soil Groups of Western Australia](#)^[4]
- [Soil Guide \(Moore 2001\)](#)^[10]
- [Soils of the Swan Coastal Plain \(Bolland, 1998\)](#)^[1]



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Chapter 7

Managing Limiting Soil Factors

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7 Managing Limiting Soil Factors

7.1 Introduction

This chapter describes several soil-related factors that can limit plant growth and the management methods that can be used to remove or reduce their impact.

To get the best from fertilisers, you must first eliminate or reduce any soil-related factors that limit pasture growth.

Specific soil factors that can limit plant growth include:

[Slaking and dispersion](#) – (sodicity).

[Compaction.](#)

[Waterlogging.](#)

[Salinity.](#)

[Soil pH.](#)

Learning outcomes

At the completion of this chapter, you should:

- Recognise soil factors that limit plant growth.
- Understand the management options for minimising the limiting factors.

7.2 Slaking and dispersion

[Slaking](#) is related to soil structure and particularly to structural stability, which is the soil's ability to retain aggregates and pore spaces under various environmental conditions. Slaking is the result of lack of organic matter. [Dispersion](#) is usually a problem of soil chemistry (namely, high levels of exchangeable sodium), although it can occur in non-sodic soils due to excessive mechanical disturbance of the soil, with associated loss of organic matter. Slaking and dispersion can occur together. When this happens, both problems will have to be managed.

7.2.1 Slaking

Slaking is the breakdown of aggregates into smaller aggregates or single particles. It occurs when a dry clay soil becomes wet. The clay swells and the air within the pore spaces in the aggregates is compressed. This builds up pressure, resulting in the 'explosion' of the aggregate – See Figure 7.1, or the animation on [Victorian Resources Online](#).

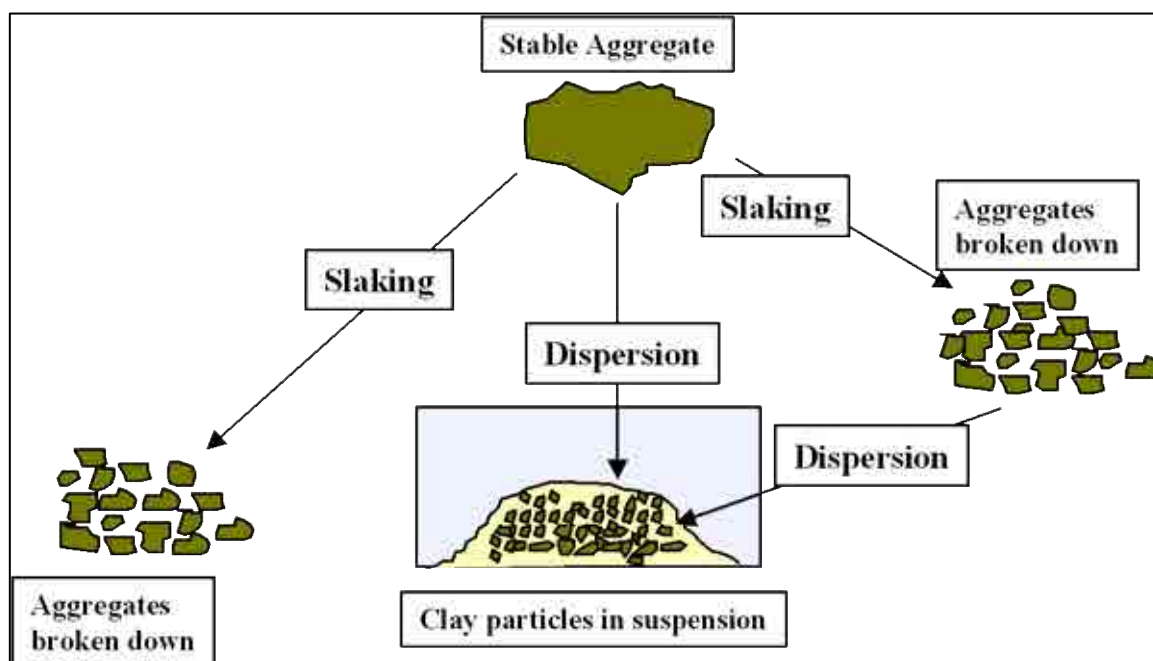


Figure 7.1 Diagrammatic illustration of slaking and dispersion

Slaking is severe in some soils with low organic matter and can occur within minutes of the soil becoming wet. When a slaked soil dries, crusting (**hardsetting**) of the soil can occur. This limits water infiltration and seedling emergence. The hardsetting can be limited to the top few millimetres of soil or can extend through the entire soil profile.

7.2.2 Dispersion

Dispersion is the separation of the clay particles from the aggregates when the soil is wet - See Figure 7.1. Clay particles carry a negative electrical charge and tend to repel each other. Calcium, magnesium, sodium and potassium all carry positive charges and are attracted to the clay particles, forming a 'bridge', or bond, between the negatively charged clay particles.

Calcium (Ca^{2+}) ions, followed by magnesium (Mg^{2+}) ions, are the strongest 'bridge formers' because they have two positive charges. Potassium (K^{+}) and sodium (Na^{+}) ions only have one positive charge, and their bonding of the clay particles is much weaker. If calcium is forming the bridge, the clay particles will hold together when they are wet. However, if sodium is forming the bridge, the bonding is much weaker and the clay particles tend to separate and repel one another when they are wet (in other words, they tend to disperse).

Cloudy or muddy water in puddles is an indication that a soil may be dispersive. A continual stream of cloudy water running out of a mole drain outlet is also indicative of a dispersive clay-type soil. Mole drainage and open drains in dispersive soils may lead to severe soil erosion.

When dispersion occurs, the dispersed clay particles fill up the pores between soil particles and aggregates; and when the soil dries out, the dispersed clay blocks up soil pores. This restricts seedling emergence, water and air movement, and root penetration. Dispersed soils are generally hardsetting and may form a surface crust - See Figure 7.2. Dispersion with no slaking results in a 'concrete-like' lump being formed.



Figure 7.2 Soil crusting due to dispersive sodic subsoil layer being exposed after flooding. (Photograph by David Hall).

Soils prone to dispersion are very susceptible to tunnel and gully erosion if incorrectly managed.

Dispersion is an indicator of **sodic soils**. Sodic soils are those that contain such a high level of sodium cations that it affects soil structure. However, ploughing or other mechanical treatment of some non-sodic soils can also result in dispersion.

7.2.3 Simple tests for determining slaking and dispersion

Place several large aggregates (5 to 10 mm in diameter) into a shallow dish containing distilled or rain water (for irrigated pastures use the irrigation water).

If the soil is a slaking soil, the aggregates will fall (or “slump”) apart within a few minutes to a few hours. Cloudy water will not appear around the slumped aggregates.

If the soil is dispersive, a cloud of clay-sized particles, or muddy water, will form around the aggregates – See Figure 7.3, or the animation on [Victorian Resources Online](http://www.vic.gov.au/vic/resources/soil/soil-dispersive). Dispersion can take several hours to occur, and a visual assessment should be made after about 2 hours and again after about 24 hours. See Chapter 9.2.2.4 to work out the Clay Dispersion Index.



Figure 7.3 Increasing levels of soil dispersion, from left to right, when dispersion is determined using deionised water.
Source: http://www.agric.wa.gov.au/PC_93842.html

Another test can be done to determine whether a soil is dispersive and will respond to gypsum. Place a small handful of soil into each of two clear glass jars half filled with distilled or rain water.



Add a small handful of gypsum to one of the containers only (label it with a marker). Shake the two jars and leave them for 24 hours. If the soil is dispersive and responsive to gypsum, the soil will settle out in the jar with gypsum and will remain cloudy in the jar without gypsum. See [Section 7.2.5](#) for further information on gypsum and dispersive soils.

7.2.4 Management of slaking soils

Slaking, which is related to soil structure and particularly to soil stability, can be managed by increasing the level of organic matter in the soil.

Organic matter reduces slaking by reducing the rate of aggregate wetting and by more strongly binding the soil particles together.

The best ways to increase the organic matter level in the soil are to:

- Grow highly productive pastures, especially perennial ryegrass and white clover and, where possible, deep-rooted legumes, such as lucerne.
- Use minimum tillage or no-tillage techniques for crop and pasture establishment.

See Chapter 5 on Soil Biology for further information on increasing organic matter levels.

Organic matter levels and stable soil aggregates can be easily destroyed by: excessive cultivation; cultivation when the soil is too dry or too wet; or stock trampling (pugging), particularly when the soils are wet. Cultivation increases the rate at which organic matter is broken down by soil organism activity (mineralisation of soil organic matter). Cultivation machinery compacts the soil, as does stock trampling. In fine-textured soils, cultivating when the soil is too wet breaks down aggregates, and cultivating when the soil is too dry creates large clods that are not easily penetrated by roots or seedlings.

7.2.5 Management of dispersive soils

In the short term, [gypsum](#) will reduce dispersion on sodic soils.

Lime can be used to reduce dispersion (to a lesser extent) on acidic sodic soils, but it is much less soluble than gypsum. In both cases, the sodium cations attached to clay particles are replaced with the stronger-bonding calcium cations. Some magnesium cations will also be replaced by calcium cations. The clay particles then bond together, or aggregate, by flocculation. However, aggregates formed solely by flocculation generally are not very stable.

In the longer term, dispersion management involves increasing the organic matter level in the soil, which will help to form stable aggregates that hold together.

See Chapter 5 on Soil Biology for more information on increasing organic matter levels.

The sodium cations that are exchanged for calcium cations on the clay particles don't disappear. They enter the soil solution, where they can reattach to clay particles when the opportunity arises. Adequate drainage; resulting in removal of sodium-rich soil water from the root zone, will give longer-term responses to gypsum applications.



7.2.5.1 What is gypsum?

Gypsum is the common name for hydrated calcium sulphate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$).

There are two basic sources of gypsum: mined gypsum (natural deposits) or by-product gypsum.

Natural deposits of gypsum occur in many parts of inland Australia and vary widely in purity. The effectiveness of these sources of gypsum depends largely on the purity of the deposit and how finely the gypsum is ground.

7.2.5.2 Classification of gypsum products

Gypsum products are classified under state legislation in Australia into three grades, based on their sulphur and calcium content:

- Grade 1 gypsum must contain a minimum of 15% sulphur and 19% calcium.
- Grade 2 gypsum must contain a minimum of 12.5% sulphur and 15.5% calcium.
- Grade 3 gypsum must contain a minimum of 10% sulphur and 12.5% calcium.

The regulations also require that the label on any gypsum product must specify the fineness by stating the percentage of gypsum capable of passing a 2-mm sieve.

For more information on gypsum refer to: <http://www.incitepivotfertilisers.com.au/en/Soil%20,-a-%20Plant%20Tests/~media/Gypsum%20Fact%20Sheet.ashx>

7.2.5.3 Uses of gypsum

The main use of gypsum is as a source of calcium to improve soil structure in dispersive soils.

Some farmers apply gypsum as a source of sulphur.

In dairying areas throughout Australia, some farmers apply gypsum on clay soils in the belief that it will help reduce waterlogging by improving soil structure. However, many clay loam soils, despite having waterlogging problems, will not improve in soil structure (and consequently drainage), after an application of gypsum. This is because these soils already contain adequate amounts of calcium ions, clay dispersion is not a problem, and adding further calcium in the form of gypsum is usually a complete waste of time and money. Soil testing is recommended to determine if calcium is required.

In the Northern Victoria irrigation areas on the red-brown earths the soils generally have low calcium levels and in some cases are also sodic (See [Victorian Resources Online](#)). In northern Victoria, particular attention should be given to laser-leveled paddocks with exposed subsoils that will have low organic matter. In laser-leveled paddocks, gypsum should be incorporated into the plant root zone before sowing. It is usually applied before the final grading.

However, in northern Victoria, good pasture cover is the priority on recently lasered permanent pastures. Gypsum topdressing is considered if pasture cover is poor (usually related to poor structure or sodic soils) or on paddocks that have been badly pugged, exposing the subsurface soils. The aim of the topdressing is only to stabilise the surface soil. This will result in the soil retaining its crumb structure and improving water penetration in the summer by not sealing over.



In the Upper Torrens region of South Australia, calcium in the form of Nutrilime™ is being applied to correct low Ca:Mg ratios. The soils here were originally high in magnesium and had a low Ca:Mg ratio. Many years of irrigation using water with very high magnesium levels has aggravated the problem and this is resulting in the collapse of the soil structure.

Reclaimed soils in the lower Murray region of South Australia are experiencing structural problems, waterlogging and poor pasture growth due to high sodium levels. These soils are also benefiting from high application rates of gypsum.

7.2.5.4 Determining the need for gypsum

Requirements for gypsum can be predicted from soil tests - See Chapters 8 & Chapter 9. However, predictions based on cation measurements alone may be inaccurate. Therefore, a clay dispersion test should also be done (see [Section 7.2.3](#) and Chapter 9.2.2.4).

7.2.5.5 Rates and application notes

Gypsum can be incorporated into the soil before sowing or before the final laser grading. Alternatively, it can be spread over the soil surface (topdressed).

Gypsum does not dissolve readily, although it dissolves more readily than lime (see Table 7.1), so it should be applied well before sowing to allow time for it to react with soil. Application rates of about 2.5 to 5 tonnes per hectare are needed on many soils, and the effect lasts from 1 to 20 years depending on the soil type and rate used.

Table 7.1 Solubility of lime and gypsum

| PRODUCT | SOLUBILITY AT 20°C (grams/100 litres) |
|----------------|--|
| Lime | 1.4 |
| Gypsum | 260 |

When only the soil surface needs to be treated with gypsum it is topdressed and lower application rates are required. Rates of 1.2 to 2.5 t/ha are commonly used, and repeat applications may be required the following year.

Note that in a topdressing situation on irrigated, southern Australian dairy pastures:

- Wait until a long rotation in the autumn.
- Graze the paddocks out completely.
- Topdress the gypsum before natural rainfall.

Cattle may be reluctant to graze the pastures until the gypsum fines have been washed off the leaves.

Gypsum and lime are both a type of salt, so application to an already saline soil may temporarily increase the total soluble salt levels.

Unless drainage is adequate, the sodium (displaced by the calcium) may not be flushed or leached beyond the plant root zone. Improved drainage may be necessary so that the excess sodium can be leached out of the soil. If drainage is not adequate, it is possible that the soils may quickly revert to their waterlogged and dispersive nature.



When buying gypsum by the tonne, it is important to know the water content of the product as well as its particle sizes when comparing products, as high freight costs may be incurred.

Pasture growth responses to topdressed gypsum on existing pasture are uncommon unless sulphur is deficient.

7.3 Compaction

A compacted soil is one in which the soil aggregates have been compressed so that the pore spaces between the aggregates have been substantially decreased.

Compaction reduces water and air infiltration, restricts pasture root growth and slows pasture growth rates.

The compacted layer may be at the soil surface as a result of wheel compaction; slightly below the surface from pugging; or at some depth in the soil profile as a hard pan, either naturally occurring or from the use of cultivation implements.

7.3.1 Naturally occurring compaction

Natural compaction is generally a reflection of a change in soil structural conditions and can occur through leaching as the more mobile soil constituents move downward and form **hard pans** at depth in the soil profile. For example, in some soils, iron is leached out of the surface layers and accumulates at depth to form a hard pan that is very difficult to penetrate. These hard pans are referred to as 'coffee rock' and are found commonly in the Heytesbury district of southern Victoria and in the southern part of the Mt Lofty ranges, South Australia. Similar 'buckshot' layers are found in the older basalt plains soils. Clay particles can also be leached downwards to form a clay-pan layer that is virtually impermeable.

Compaction also occurs naturally within the soil profile. The lower horizons are usually more compacted than the upper ones due to the weight of the upper layers and the lower organic matter content of the lower layers.

7.3.2 Induced compaction

Induced compaction is soil compaction caused by farming practices. It can make rapid and severe changes to soil porosity (the amount of pore spaces in a soil), and some of these changes can have long-lasting effects.

Dry soils are relatively strong and usually do not compact. However, when soils are wet, they have less strength and are more easily compressed. Cultivation, grazing, or fertiliser spreading at this stage will reduce the soil's ability to drain excess water away quickly, which can make waterlogging more severe. Heavier-textured soils, such as clays and loams, are more affected because they naturally drain more slowly. Management should be adjusted to take these factors into account and this could be achieved by cultivating, grazing or spreading fertiliser when soils are dry.

7.3.3 Degree of compaction

The degree of compaction of a soil affects the bulk density of the soil. Bulk density of a soil is the weight of a unit volume of dry soil and its pore spaces. It is usually measured in grams per cubic centimetre (g/cm^3) or megagrams per cubic metre (Mg/m^3). Both of these units have the same numerical values. In other cases, soil compaction may be expressed as t/m^3 .

A friable, well-aerated soil will have a low bulk density. That is, it will have more pore spaces per cubic centimetre, and therefore, a lower weight. Conversely, a compacted soil will have a high bulk density as there is more soil and fewer pore spaces.



Bulk density is related to both texture and structure. Sandy soils have a higher bulk density, because their particles tend to be closer together and sandy soils also are usually lower in organic matter. Clays and loams usually have a lower bulk density because they are made up of smaller particles that are usually well-granulated and have formed aggregates. This is assisted by their higher organic matter content. The structure of a soil is affected by the balance of macropores (large soil pores) and micropores (small soil pores). Thus, as a soil becomes less well-structured and loses macropores, it increases in bulk density. Management, as well as soil type, affects this characteristic of any soil.

Compacted layers can be easily assessed by pushing a pointed rod into the soil. Often a hard pan is found around 10 to 15 cm from the surface.

7.3.4 Managing compaction

On compaction-prone soils, management practices can reduce the likelihood of compaction.

Compaction may be avoided or reduced by:

- Increasing the level of organic matter in the soil. This will improve soil structure, reduce the bulk density of the soil and promote freer drainage when soils are wet.
- Using low-pressure tyres with a large soil contact area.
- Keeping animals and machinery off wet areas can help to reduce compaction. Cultivation of wet soils should be avoided. If grazing is restricted while the soils are wet, there may be a need for investment in hard [stand-off areas](#) to protect the soil resource.
- Overcoming waterlogging through surface and subsurface drainage (see [Section 7.4.5](#)) can substantially help to conserve the soil structure. It is imperative, where subsurface drains are installed, to allow 24 to 48 hours for excess water to drain away. Ideally, the watertable should be at least 300 mm below the soil surface before the pasture is grazed.
- Modern techniques of minimum tillage or no-tillage are less damaging to soil structure. Frequent or fast cultivation pulverised soil aggregates, breaking down soil structure and macropores, therefore hastening compaction.

A deep or shallow ripping can loosen the compacted layer. This is a 'temporary fix' if the underlying cause of the compaction is not corrected. Also, unless water can get away, the deeper cultivated or ripped soil will wet up more easily (to the tined or ripped depth) and be even more prone to compaction damage.

When mechanically aerating or ripping, ensure soil conditions are not overly dry or wet. If the soil is cultivated when it is wetter than its plastic limit, soil fracturing does not occur and the soil smears forming a plough pan or compaction layer. Soil compaction due to deformation results in a reduction in porosity and pore size, and when dry, the compacted soil presents a barrier to root penetration. Cultivating the soil when it is drier than its plastic limit allows the plough to fracture the soil producing a desirable seed bed. Soils retain moisture and if worked mechanically above a certain moisture level, deformity of the soil can occur. The point at which this occurs is called the "plastic limit".

To assess if a soil is wetter or drier than its plastic limit, collect some soil about the size of a golf ball at least 10 cm below the proposed depth of cultivation. Roll the soil between the palms of your hands and attempt to form a rod (cylinder) about 50 mm long and 4 mm thick. The soil is drier than its plastic limit if cracks appear in the cylinder and therefore the soil is suitable for cultivation. If the



cylinder stays intact then the soil is wetter than its plastic limit, and cultivation will cause compaction (Moody and Cong, 2008).

7.4 Waterlogging

Waterlogging occurs when most or all of the macropores become filled with water rather than air. It occurs more easily in soils that have a greater proportion of micropores than macropores, because the macropores promote free drainage while the micropores tend to hold on to water. Both compaction; which presses the soil particles and aggregates closer together, and dispersion; which fills the pore spaces with clay particles, tend to promote waterlogging.

7.4.1 Causes of waterlogging

Waterlogging is a common problem on many soil types, particularly in predominantly clay soils. Waterlogging may be due to periods of heavy rainfall, dispersion, compaction, poor irrigation management, rising watertables, or a combination of poor surface drainage (across the paddock) and poor subsurface drainage (down the soil profile). Figure 7.4 shows a well-aerated soil and a waterlogged soil.

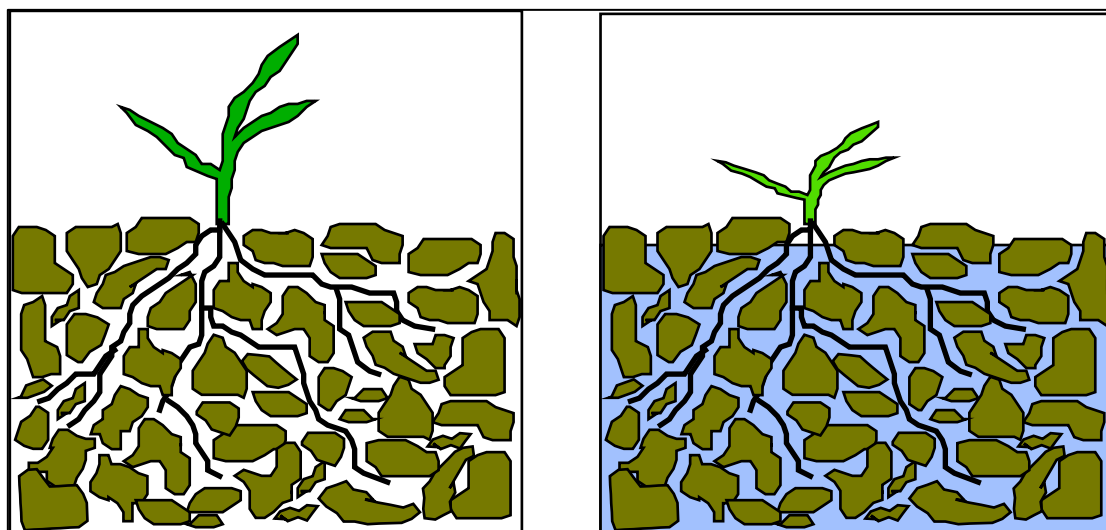


Figure 7.4 Well-aerated soil (left) and waterlogged soil (right).

In rain-fed WA dairy soils, waterlogging occurs in flat areas on soils comprising 0.5 to 2.0 m sand to sandy loam soils over a very impervious clay layer. This forms a surface aquifer and the pasture root zone is no deeper than 20 cm.

7.4.2 Effects of waterlogging

Soil strength decreases as the soil gets progressively wetter, resulting in a greatly increased potential for damage to the soil structure. Waterlogging prevents air and many nutrients from reaching the roots, thus seriously inhibiting plant growth. Also unfavourable gases and compounds are produced in the root zone due to the anaerobic (no oxygen) conditions favouring anaerobic soil micro-organisms at the expense of aerobic micro-organisms - See Chapter 5. A build-up of salt is also more likely under poorly drained irrigation pastures.

Where soil drainage is poor, numerous effects are seen. The severity of these effects will depend on things such as the duration of waterlogging and the soil texture. In light-textured soils the effects will not be as detrimental.



Waterlogging effects include:

- Plants are stunted and yellow as nitrogen is lost due to denitrification which is caused by a lack of aeration – see Figure 7.5.
- Improved pasture plants are replaced by tolerant weeds (docks, smartweed, rushes, sedges, couch, etc.).
- Pastures become fouled with mud and utilisation is reduced.
- Pasture growth rates decline.
- Soils become pugged and water ponds on the surface.
- Responses to applied fertiliser are poor.
- Nutrient balance in the pasture is upset with lower nitrogen, potassium, magnesium and chlorine in the pasture.
- Change in soil biology from aerobic to anaerobic soil organisms - See Chapter 5.



Figure 7.5 Sorghum plants waterlogged for an extended duration showing poor growth and discolouration. (Photograph supplied by David Hall).

7.4.3 Managing waterlogged soils

When waterlogging has occurred, prevention of further damage to the pasture and soil structure is the first priority. This can only be done by keeping vehicles and animals off waterlogged areas. A grazing management technique called '**on-off grazing**' can significantly reduce pugging damage and increase pasture utilisation. With the 'on-off grazing' technique, stock are only allowed to graze the paddock for a short period (2 to 4 hours) and are then held in a **stand-off area**, such as a feedpad, a laneway, an old sand quarry, or the dairy shed yard.

Long-term management involves removing the cause of the waterlogging. Waterlogging may be caused by a soil chemical or physical problem, such as dispersion (see [Section 7.2.2](#)) or compaction (see [Section 7.3](#)), or by a high watertable or poor irrigation management.



In districts where waterlogging is caused by a high watertable, management strategies aimed at controlling the level of the watertable will be required, and these are outlined in [Section 7.5.7](#), 'How can we best manage salinity', and [Section 7.4.5](#), 'Reducing waterlogging through drainage'.

If the problem is related to poor irrigation management, see [Section 7.4.4](#), 'Reducing waterlogging through irrigation management'.

7.4.4 Reducing waterlogging through irrigation management

Waterlogging is one of the most limiting factors affecting **flood-irrigated** pasture production in southern Australia. Unfortunately, white clover is the most susceptible pasture species to waterlogging.

In a flood irrigation situation, waterlogging can occur because it takes too long to get water:

[On to a bay](#)

[Off of a bay](#)

7.4.4.1 Water On

A compromise needs to be found between irrigating quickly to reduce waterlogging, and allowing enough time for adequate soakage of water into the bay. With a well-designed bay on suitable soils, the required amount of water should be applied in 2 to 4 hours. However, up to 6 hours is generally accepted as reasonable. The time needed to apply the required amount of water can be varied by adjusting the flow rate. On lighter, more permeable soils, a shorter irrigation time is appropriate to reduce water losses beyond the pasture root zone. If the area at the bottom of the bays is not producing well due to waterlogging, or there is no drainage reuse system, watering 'short' can be a water saving compromise - See [Victorian Resources Online](#).

Four factors commonly cause slow watering and can lead to a waterlogging problem. These are:

- Inadequately sized (small) farm channels and channel structures.
- Small bay outlets.
- Weeds in channels restricting the water flow.
- Irrigated ground that is high.

Any of these factors will restrict the flow of water, cause the wheel to slow down and slow down irrigation.

Leaking bay outlets may also be the cause of a waterlogging problem at the top of an irrigation bay. Refer to the Target 10 Irrigation and Drainage Reference Manual. See [Victorian Resources Online](#) to find out how to address these problems.

7.4.4.2 Water Off

Water should not be left lying on the bay. It should be drained away as quickly as practicable to prevent ponding and waterlogging. Ideally, there should be no water lying on the bay 24 hours after irrigation has commenced.

Drainage off the bay will be affected by:

- Bay slope.
- Soil type.
- Condition of the drain at the bottom of the bay.
- Length of bay.



- Evenness of slope.
- Presence of spinner cuts.
- Pasture height, type and density.

Water will stay longer on longer bays, on bays that are flat or are on heavy soil types, or where the drains at the bottom of the bay are in poor condition.

Longer bays (longer than 400 m) do not drain well, particularly in winter when evaporation rates are low. The water has to move a longer distance to reach the drain, and the bay stays wetter longer.

Spinner cuts running down the bay will improve drainage. The spacing of the spinner cuts across the bay will depend on the severity of the drainage problem. A spacing of 15 to 20 m between spinner cuts is often used.

It is important that there is a well-defined drain at the bottom of the bay. This drain should connect with the rest of the farm drainage system so that it carries runoff to a reuse system, to a regional or community drain, or to a natural watercourse.

There are a large number of factors to consider when trying to overcome an irrigation waterlogging problem. Developing a [whole-farm plan](#) provides a means to ensure that an irrigation layout is well planned and well designed. A good irrigation layout is essential to minimise waterlogging problems and optimise pasture production.

7.4.5 Reducing waterlogging through drainage

Overcoming waterlogging through drainage may help preserve soil structure.

In high-rainfall dairy pastures, increases in pasture utilisation of 40% to 60% have been measured on drained ([subsurface drainage](#)) compared to undrained paddocks.

Improved pasture yields and pasture composition have also been measured on drained paddocks. Soil salinity levels are also often lowered by subsurface drains because the drained water removes some of the salt.

Drainage systems need to be planned, constructed and maintained effectively to have a long-term, positive effect on both the on-farm and off-farm environments.

Because the drainage water often has to flow onto neighbouring properties, drainage works are best done in cooperation with the neighbouring landholders and in conjunction with the relevant water authorities.

Drainage of the soil can reduce waterlogging effectively but at a cost. Other strategies, such as 'on-off grazing' (see [Section 7.4.3](#)) and agistment, are used on some farms.

7.4.5.1 Surface drainage

Improvement in surface drainage should be investigated first, as it is the simplest and cheapest option. Surface drainage involves maintaining existing drains and installing additional drains that are adequately sized and positioned, usually placed along fence lines or through depressions. If possible, emphasis should be placed on preventing water from the upper paddocks flowing over onto the lower paddocks.



However, many farmers mistakenly believe their waterlogging problems are due to surface water alone, when they are actually often due to subsurface water or to a combination of surface and subsurface water. In these cases, a combination of surface and subsurface drainage may be required.

7.4.5.2 Subsurface drainage

Poor subsurface water movement is caused by an impediment to the water moving down the soil profile. Possible impediments include a heavy soil texture, compacted layers, and natural or induced hard pans in the profile (which can create a raised watertable). Poor subsurface water movement can also be caused by subsurface water moving downhill from upper slopes or by springs.

In irrigation areas, groundwater pumping is a common form of subsurface drainage.

In high-rainfall areas of Australia, the main forms of subsurface drainage are [subsurface pipe drains](#) or [mole drains](#) or a combination of both. The type of drain installed depends on soil characteristics, rate of drainage required, and topography.

Note: In irrigation areas, your irrigation supply authority should be contacted before installing subsurface drainage. In some regions, permission is required from the local irrigation supply authority to discharge water from subsurface drainage systems off the farm.

Subsurface pipe drains

Free-draining topsoils with an impermeable layer at a depth of more than 0.7 metres, or deep, free-draining soils subject to rising watertables, require pipe drains. Pipe drains are constructed by placing a slotted PVC or corrugated plastic pipe in a trench and then surrounding the pipe with a permeable backfill, such as stone or gravel - see Figure 7.6.

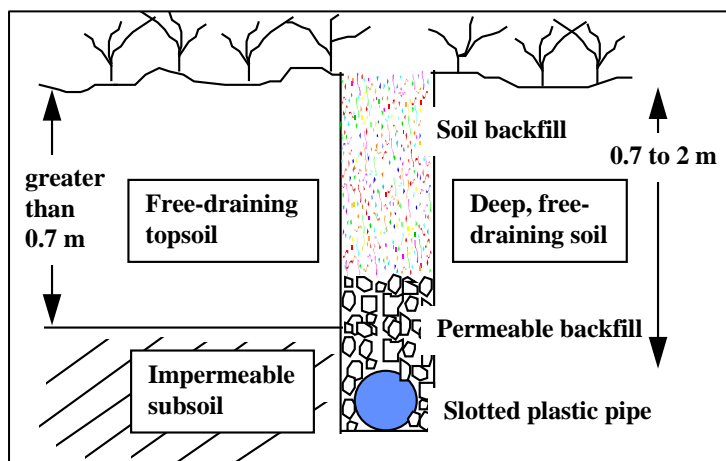


Figure 7.6 Subsurface pipe drain

Subsurface pipe drains are expensive to install but are very effective and economically viable in the correct situations. They can last for many years, provided they are correctly installed and consistently maintained.



Mole drains

Clay and clay loam soils with poor natural drainage and with clay less than 40 cm from the surface are generally suitable for mole drainage – see Figure 7.7. A mole drain can be made simply by pulling a metal object (i.e. a ripper blade with cylindrical foot, or mole plough) through the soil, leaving an open channel. Mole drains cost less than tile drains but require more maintenance.

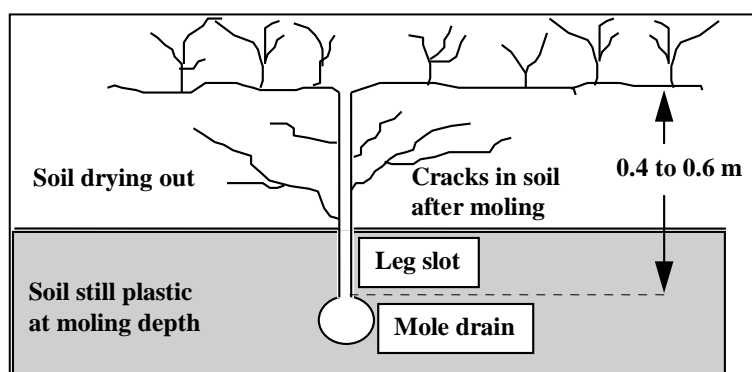


Figure 7.7 Mole drain

The clay through which the mole is pulled must be plastic when wet (retains shape of mole) and stable (not prone to cracking, dispersion or slaking). If installed correctly in appropriate soil, mole drains may function adequately for 3 to 7 years. For more information on mole drainage see http://www.agric.wa.gov.au/objtwr/imported_assets/content/lwe/water/drain/bulletin4610.pdf

7.5 Salinity

7.5.1 What is salinity?

When we refer to salinity in agriculture, we are referring to the level of salt in the soil and the soil solution.

The most frequently found salt in saline conditions is common salt, more correctly known as sodium chloride (NaCl). Other dominant salts found are sodium carbonate and sodium bicarbonate and to a lesser extent sulphates of sodium, calcium, magnesium and potassium and chlorides of calcium, magnesium and potassium.

Saline soils are those with sufficiently high levels of salt in the root zone to adversely affect plant growth.

High salt levels affect plant growth in two ways:

- They reduce the plant's ability to take up water (an osmotic effect).
- They cause toxicities (usually chloride and sodium) and nutrient imbalances by changing the plant's ability to take up a wide range of nutrients.

Natural saltland (primary salinity) existed in Australia before European settlement; however, the extent and severity of salinity has increased markedly due to changes in the management of land and water (secondary salinity).

7.5.2 The processes of salinity

The processes of salinity are shown in Figures 7.8 (dryland) and 7.9 (irrigation).



Rainfall or irrigation water can leave the soil surface in several ways. It can be used by plants or removed by runoff and evaporation. The remaining water seeps through the soil until it reaches a dense rock layer (often referred to as bedrock) or a clay or other hardpan layer that it cannot penetrate. The soil then begins to fill up with water, starting from this layer. The top of the saturated zone in the soil is known as the **watertable**. **Recharge**, or groundwater recharge, is the name for water added to the watertable in this way.

When the watertable rises to within 1 or 2 metres of the soil surface, the water can move into the plant root zone by capillary rise. **Capillary rise** occurs when drier soil on top of the watertable sucks up the ground water, similar to the action of a sponge. The **capillary zone** is the area above the watertable that is affected by capillary rise.

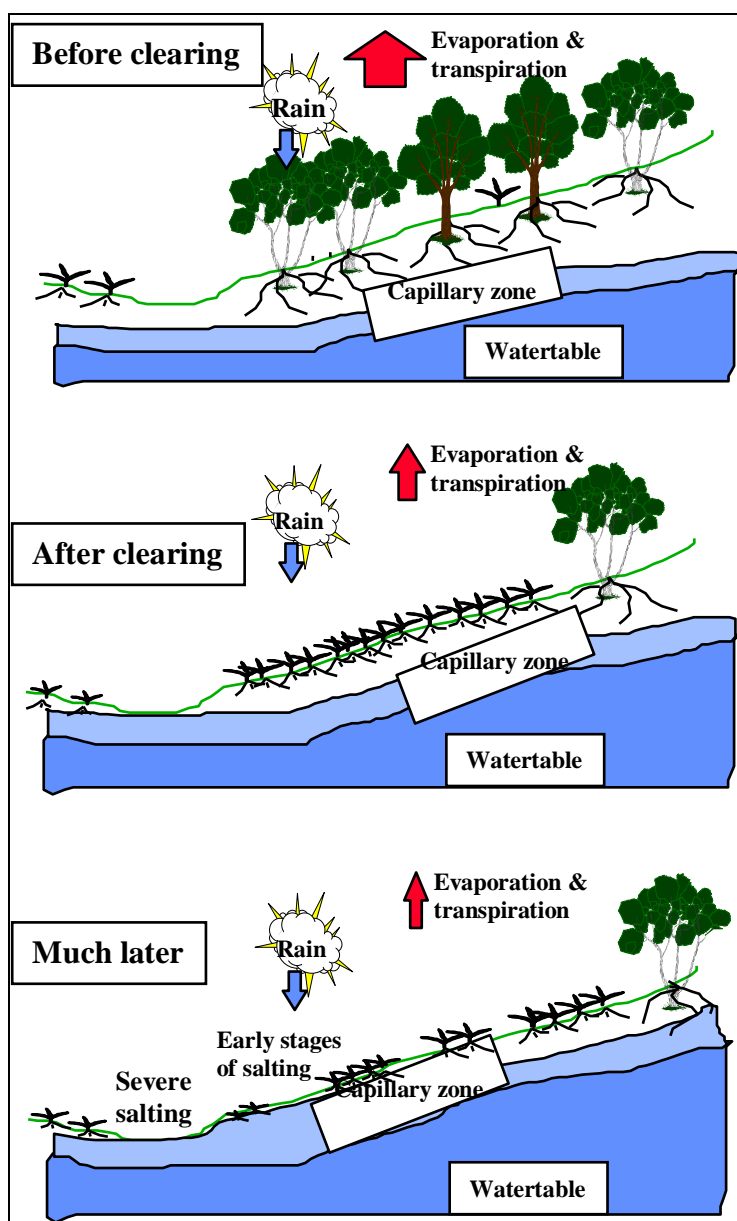


Figure 7.8 Processes and causes of dryland salinity

The height of capillary rise depends on the soil type. It is greatest in loam soils, which have a variety of particle and pore sizes. In sandy soils, there are bigger spaces and the force needed to lift water through them is greater. In clay soils, small pore size slows water movement.



As the watertable rises, the salts in the soil are dissolved. If capillary rise brings salty water into the plant root zone, the plants are affected by the salts. In extreme cases, capillary rise will bring the salty water to the soil surface. This is known as **discharge**. The salt makes it hard for the plants to take water from the soil, and the plants may show signs of water stress. Eventually, they may die of dehydration if the salinity levels are too high. Pastures suffering from the effects of salinity can become invaded by salt-tolerant weeds; and as salinity increases, the proportion of salt-tolerant grasses increases.

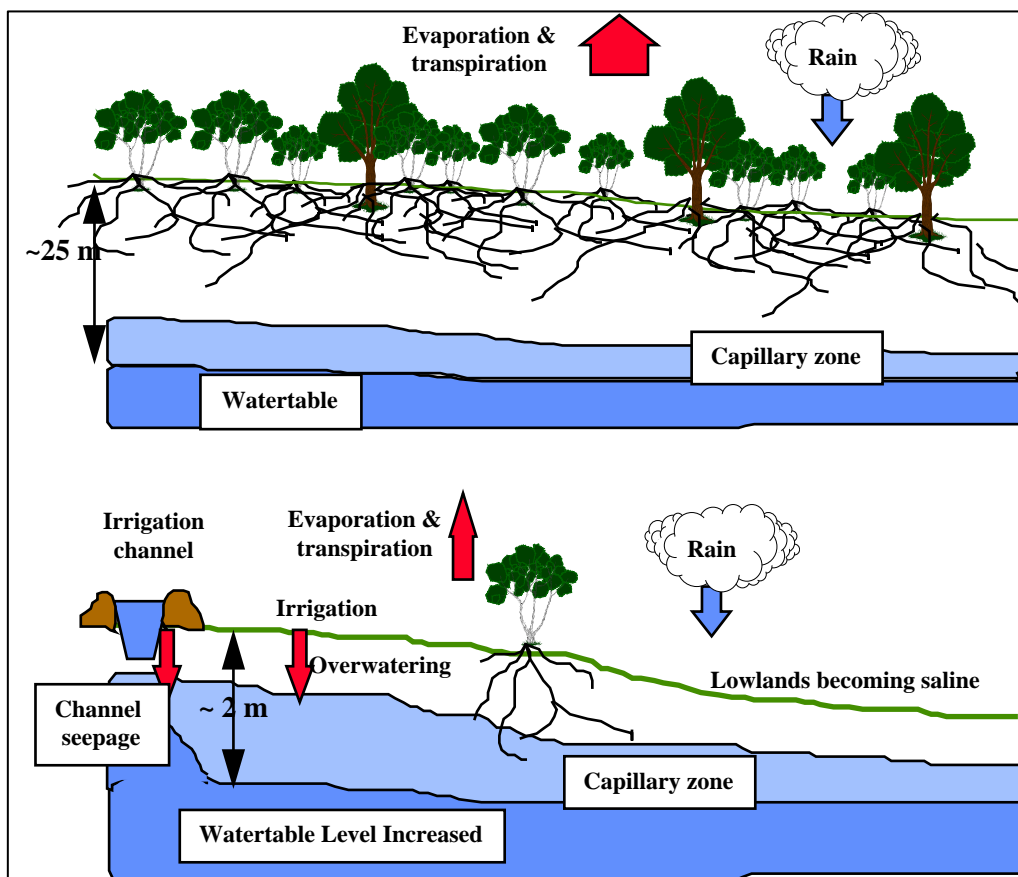


Figure 7.9 Processes and causes of irrigation salinity

The early symptoms of salinity are often incorrectly thought to be caused by something else, such as waterlogging or a lack of fertiliser; and a yield loss of up to 30% can occur before definite signs of salinity become visible.

7.5.3 The causes of secondary salinity

The main cause of many of the secondary **dryland salinity** problems is the clearing of deep-rooted native trees from recharge areas. Trees and other large vegetation use and transpire much more water than pasture or cropping does. When these large plants are cleared from the recharge area, more water seeps into the watertable.

The main cause of **irrigation salinity** is poor irrigation methods, such as slow watering, that allow water to pond for long periods and seep into the soil. In addition, seepage from irrigation channels and drains and from dams results in recharge.



7.5.4 Soil classification and salinity measurement

Soils have been divided into five classifications to help identify the degree of the salinity problem. The classes range from very low to extreme levels of salinity and are named A+ (very low), A, B, C and D (extreme) – See [Figure 7.10](#). Most of the Northern Victoria irrigation area is type A+ or A soil, but there are significant areas of classes B, C and D, particularly to the west. The growth of most pasture species is unaffected by salinity levels of class A or B soils. Only salt-tolerant plants like barley grass grow in class D soils.

Salinity is measured by determining the **electrical conductivity** (EC) of a water or soil sample. Electrical conductivity is a measure of the capacity of soil or water to carry an electric current. The main unit of measurement for soil salinity is deciSiemens per metre (dS/m). **EC_e (dS/m)** is a salinity measure used by researchers that allows for the effect of soil texture on salinity. Further information about measuring salinity is provided in Chapter 9.2.10.

The estimated returns from applying irrigation water to dairy pastures growing on soils with different degrees of salinity are shown in Table 7.2. This shows how large an effect soil salinity can have on economic returns. Similar economic effects would occur with the application of fertiliser to the various classes of saline soil.

Table 7.2 Estimated returns from applying 1 megalitre of irrigation water to different classes of saline land (1992 data)

| SOIL SALINITY CLASS | EC _e (dS/m) | APPROX. AMOUNT OF SALT (ppm) | SPECIES THAT WILL GROW | GROSS MARGIN |
|---------------------|------------------------|------------------------------|---|--------------|
| A+ Very low | Less than 1.8 | n.a. | All pastures and clovers | \$170 |
| A Low | 1.8 to 3.8 | Less than 1800 | Most pastures, crops, legumes | \$120 |
| B Moderate | 3.8 to 6.5 | 1800 to 3000 | Grass, some legumes | \$55 |
| C High | 6.5 to 8.6 | 3000 to 4000 | Grass, not clover | \$5 |
| D Extreme | More than 8.6 | More than 4000 | Salt tolerant plants, some barley grass | -\$15 |

Source: Adapted from Norman *et al.* (1995).

Soil salinity levels determine what grows in the soil and are a major reason for lower productivity. Lower salinity soils give better return for your money. Therefore, in salt-affected areas, it is important to know the classifications of your soil so areas of C and D class can be managed differently to the more productive A and B class soils.

7.5.5 What does salinity look like?

Salinity will affect plants differently depending on their stage of growth. They are usually most at risk during seedling emergence and early seedling growth. If salinity weakens them at an early stage in their growth, they are more prone to stress caused by other problems, such as poor soil structure, disease, insects, nutrient deficiencies, or waterlogging. Plants may die from the combined effect of several of these rather than just one.

The leaves of salt-affected plants can initially appear smaller and darker than normal. Shoot growth is also reduced. As salinity levels increase, the effects become more pronounced. Low germination rates and seedling deaths reduce establishment, and surviving plants grow more slowly. The tips of leaves can appear burnt, and this can spread until the whole leaf is yellow. The photos in [Figure 7.10](#) show examples of A, B, C, and D soil salinity classes and the effect of their salt levels on productivity.



Figure 7.10 Soil salinity classes A, B, C and D and their effect on productivity in the Kerang Irrigation Region of northern Victoria



7.5.5.1 General pasture symptoms

- Plant growth is poor and uneven.
- Grasses dominate because they generally are more tolerant to salinity than clovers and other legumes.
- Animals may lick and graze salty areas.

7.5.5.2 General soil symptoms

- White salt crystals may appear on bare soil surfaces in extreme cases.
- The surface soil may remain moist and greasy.
- Clay soils may appear loose and crumbly and when cultivated may have a soft and spongy texture.

7.5.6 Plant tolerance to salty conditions

The tolerance of the various pasture species to salinity does vary. In some cases, specific varieties may be recommended to assist more severe salinity problems because of their better tolerance to the particular conditions. Table 7.3 indicates the relative salt tolerance of some pastures and crops.

Table 7.3 Tolerance of some pasture and crop plants to various levels of salinity

| SALT TOLERANCE | PLANT SPECIES |
|----------------|---|
| Low | Clover (White, Sub, Persian, Crimson, Balansa) |
| Medium | Ryegrass (Perennial, Annual) Phalaris Tall Fescue Lucerne (<i>Sensitive to salinity until established</i>) Clover (Berseem, Strawberry) Millet |
| High | Barley Wheat Oats Barley grass Tall wheat grass |

7.5.7 How can we best manage salinity?

The solutions to the salinity problem are not a matter of just treating the symptoms but of managing all the factors that influence the well-being of the water catchment.

As a whole, the community can help in lowering the watertable. Management of the whole catchment assists everyone's problems and so benefits everyone. Some of the practices available are mentioned below.

Community surface drainage reduces accessions to the watertable as well as providing a wide range of benefits on farms. Surface drainage programs in irrigation areas provide financial and technical support to survey, design and construct subregional community drainage schemes.



Subsurface drainage removes excess water from below the ground surface. Common methods are groundwater pumping from suitable shallow aquifers (in irrigation areas) and tile or mole drainage (see [Section 7.4.5](#)).

Whole-farm plans can be used to protect and enhance environmental features while increasing farm profitability. A whole-farm plan is a drawing or photograph of the farm showing existing natural and built features and details of the improvements to be made on the property, such as fencing by soil salinity class, drainage plans, or improved irrigation management.

Trees strategically planted on recharge areas, along laneways and fence lines and on irrigation reuse systems and channel banks provide several benefits. A significant one is the consumption of ground water by the trees, which assists in lowering the watertable; others include providing shade and shelter for livestock, improving property values and providing wildlife habitat. In irrigation areas, incentives are sometimes available to producers and community groups for each of these four practices. For more information contact your regional catchment management authority or natural resource management group – See <http://www.nrm.gov.au/about/nrm/regions/vic-mall.html>

As long as untreed recharge areas and irrigation practices continue to upset the natural water balance, the salinity problem will remain. Only when improved land and water management practices slow the rate of recharge to the groundwater system will it be possible to control salinity.

7.5.7.1 Practices for managing dryland salinity

Salinity is not a widespread problem in dryland dairying areas at present. However, steps that dryland farmers can take to manage dryland salinity include:

- Using more water in recharge areas by:
 - Retaining any remaining native vegetation.
 - Planting perennial pasture species, as they are deeper-rooted and use more water than annual species.
 - Replanting catchment areas with trees, which can be used for livestock fodder, firewood, posts and poles, sawlogs, honey, windbreaks, wildlife habitat, and erosion control.
- Controlling grazing in recharge areas so that as much pasture growth as possible remains on the soil.
- Fencing off saline areas and planting them in salt-tolerant trees or pasture species. These plants will help to keep the soil profile drier by using the saline water and will also help to prevent soil erosion, which often occurs on saline areas when the existing vegetation cover is killed by the salt.

In many cases, salinity in dryland areas is caused by problems on recharge areas that are not on the property on which the salinity occurs. In such cases, a catchment-wide approach to salinity management will be necessary, involving cooperation with neighbouring landowners and your local catchment management authority or natural resource management group.

7.5.7.2 Practices for managing irrigation salinity

All irrigation farmers can take steps to improve irrigation management. These include:

- Using a whole-farm plan for a structural approach to farm development.
- Matching and monitoring the water application to the needs of pastures and crops.
- Improving pasture and crop growth to use more soil water.
- Watering paddocks in less than 6 hours.



- Draining paddocks as quickly as possible after irrigation.
- Reusing all drainage water in future irrigations.
- Make sure that soil fertility and soil health is optimum
- Minimise soil compaction
- Monitor the soils salinity levels at various depths within the plants rooting zone (either by soil tests or installed monitoring devices e.g. gypsum blocks)

For more information on soil salinity refer to the Salinity Management Handbook, 2nd Edition.
http://www.derm.qld.gov.au/salinity/managing_salinity.html

7.6 Soil pH

Soil pH is a measure of the concentration of the positively charged hydrogen ions (H^+) in the soil solution. When a soil solution contains more H^+ ions, it is **acidic**. When there are fewer H^+ ions, the soil solution is **alkaline**.

The pH scale ranges from 0 to 14; a value of 7 is neutral – See Figure 7.11. Values less than 7 are acidic, and greater than 7 are alkaline. As the soil pH value decreases, the level of acidity increases. In other words, the soil solution becomes more acidic. As the pH value increases, alkalinity increases or in other words, the soil solution becomes less acidic).

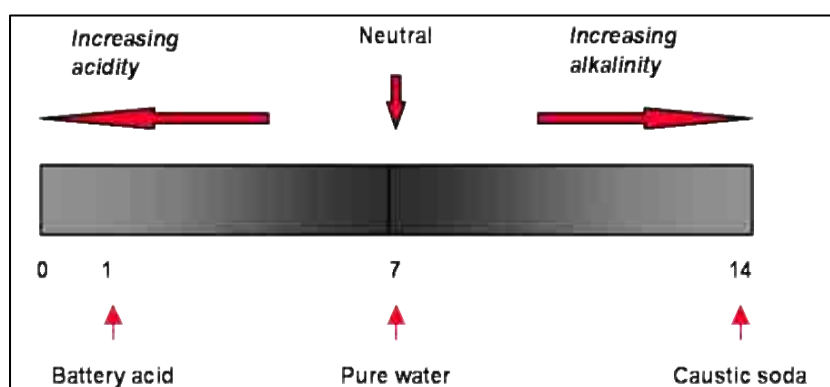


Figure 7.11 The pH scale

The pH scale is 'logarithmic'. A one-unit decrease in the pH value signifies a tenfold increase in acidity. So a soil with a:

- pH of 6 is 10 times more acidic than a soil at pH 7.
- pH of 5 is 100 times more acidic than a soil at pH 7.
- pH of 4 is 1000 times more acidic than a soil at pH 7.

7.6.1 Measuring pH

See Chapter 9.2.4.



7.6.2 Causes of soil acidification

Soil pH is influenced by many factors, including soil type, organic matter, rainfall, fertiliser use and farming practices.

Soil acidification is a natural process in which the soil pH decreases over time.

Many of our farming practices increase the rate of acidification.

Soils with a light texture (in other words, a high sand content) and low organic matter content are most susceptible to acidification, particularly if high levels of nitrogen fertilisers are applied.

The major processes that increase the rate of soil acidification are:

- The addition and accumulation of organic matter, which creates organic acids; a weak acid.
- The removal from the paddock of plant and animal products that contain high levels of calcium, magnesium and potassium. These three elements are all bases and thus their removal increases acidity. The degree of acidification will depend on how alkaline the product is and how many kilograms of product are removed.
- The leaching of the exchangeable bases (magnesium, potassium and particularly calcium) from the soil caused by high rainfall.
- The leaching of nitrate nitrogen from the root zone.
- The application of acidifying fertilisers, such as those that contain elemental sulphur or that contain nitrogen as ammonium or urea - See Chapter 12.6.2.

7.6.3 Potential problems of acid soils

Problems that can occur in acid soils include:

- Aluminium and manganese toxicity to plants.
- Decreased availability of nitrogen, phosphorus, potassium, sulphur, molybdenum, magnesium, boron and calcium to plants.
- Decreased biological activity of soil microbes and thus reduced recycling of nutrients. For more information refer to Soil Biology Chapter 5.
- Suppression of rhizobia bacteria, which affects legume nodulation.
- Suppression of root growth and the plant's ability to take up water and nutrients.

For more information on soil acidity please refer to link: <http://soilquality.org.au/factsheets/soil-acidity>

7.6.4 Symptoms of soil acidity

The symptoms of soil acidity include:

- Uneven pasture growth.
- Poor nodulation of legumes.
- Stunted root growth and high incidence of root diseases.
- Invasion of acid-tolerant weeds (for example, fog grass, sorrel, geranium).
- Difficulty establishing lucerne, phalaris, and medics.



- Formation of organic mats on the ground surface due to reduced biological activity.

7.6.5 Optimum pH range for pasture plants

Most pasture plants grow best in medium to slightly acid soil ranging from pH (CaCl₂) 4.8 to 5.8 (see Table 7.4), although they can tolerate levels below this.

Table 7.4 The optimum pH range of pastures and crops

| Pasture Species | pH (CaCl ₂) | pH (water) |
|----------------------------|-------------------------------|------------|
| Annual ryegrass | 5.5 | |
| Balansa, Berseen, Persians | 5.2 – 7.5 ¹ | |
| Barleys & Wheat* | 4.3 to 5.5 – 7.5 ¹ | 5.5 to 7.0 |
| Buffel | 5.2 – 7.5 ¹ | |
| Cereal Rye | 4.3 – 7.5 ¹ | |
| Cocksfoot | 4.3 to 6.8 ¹ | 5.0 to 7.5 |
| Consul Love Grass | 3.8 – 7.5 | |
| Cowpeas* | | 5.5 to 7.0 |
| Fescue | 4.3 to 6.4 | 5.0 to 7.0 |
| Kale* | | 5.3 to 7.0 |
| Kikuyu | 4.1 – 7.5 ¹ | 5.5 to 8.0 |
| Lucerne | 4.8 ¹ 5.2 to 7.5 | 5.8 to 8.0 |
| Lupins (Broad leaf) | 4.3 – 7.5 ¹ | |
| Lupins (Narrow leaf) | 4.1 – 7.5 ¹ | |
| Maize* | 4.5 – 7.5 ¹ | 5.5 to 7.0 |
| Medic | 5.3 to 8.0 | 6.0 to 8.5 |
| Millet | 4.5 – 7.5 ¹ | |
| Millet | 4.5 – 7.5 ¹ | |
| Oats | 3.9 – 7.5 ¹ | |
| Peas* | | 6.0 to 7.0 |
| Perennial ryegrass | 4.3 to 6.0 | 5.0 to 6.5 |
| Phalaris | 4.9 ¹ 5.2 to 7.3 | 6.0 to 8.0 |
| Red Clover | 4.4 – 7.5 | |
| Red Clover* | | 6.0 to 7.0 |
| Seradella | 4.2 – 7.5 ¹ | |
| Sorghum, Sudan Grass* USA | 4.4 – 7.5 ¹ | 5.5 to 7.0 |
| Sub clover | 4.8 to 6. | 5.5 to 7.0 |
| Tall Wheat Grass | 4.8 – 7.5 ¹ | |
| Triticale | 4.1 – 7.5 ¹ | |
| Vetch* | | 5.5 to 6.8 |
| White clover | 5.0 to 6.0 | 5.8 to 6.5 |

Source: Adapted from ¹New South Wales Acid Soil Action Program, (2000), *Havlin *et al*, (1999).

7.6.6 Effect of pH on soil nutrients

One of the most significant impacts that acid soils have is the effect that the acidic environment has on the availability of important soil nutrients. As the pH of a soil changes, soil nutrients can become either more or less available for uptake by plants. This change in availability of nutrients can result in pastures showing either a nutrient toxicity or deficiency.



The effect that soil pH has on the availability of soil nutrients is shown for the two soil pH test methods: pH (1:5 water) - Figure 7.12; and pH (1:5 CaCl₂) - Figure 7.13. (Note: There are slight differences between mineral soils and organic soils in the availabilities of the various nutrients).

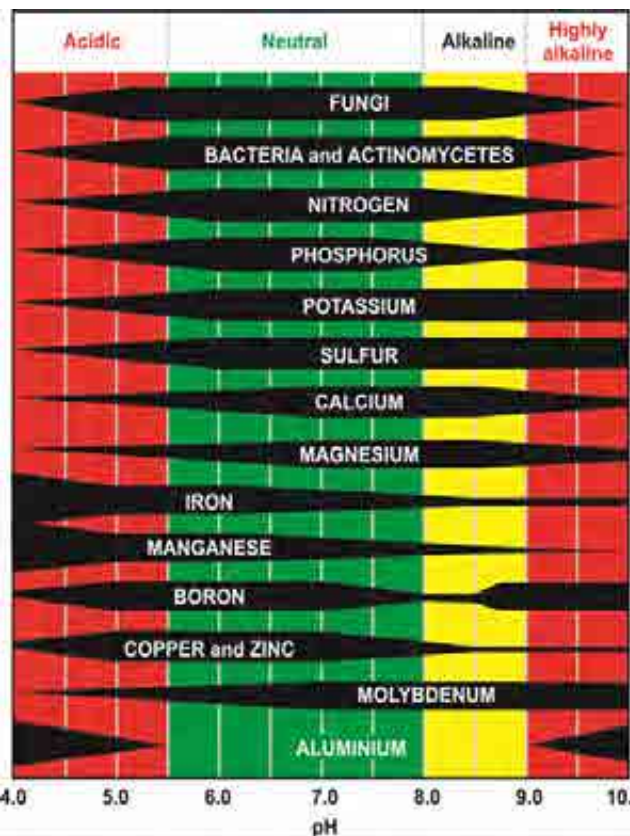


Figure 7.12 Effect of pH (1:5 water) on nutrient availability. *Source:* Incitec Pivot LTD (2008) Agronomy Advantage Manual.

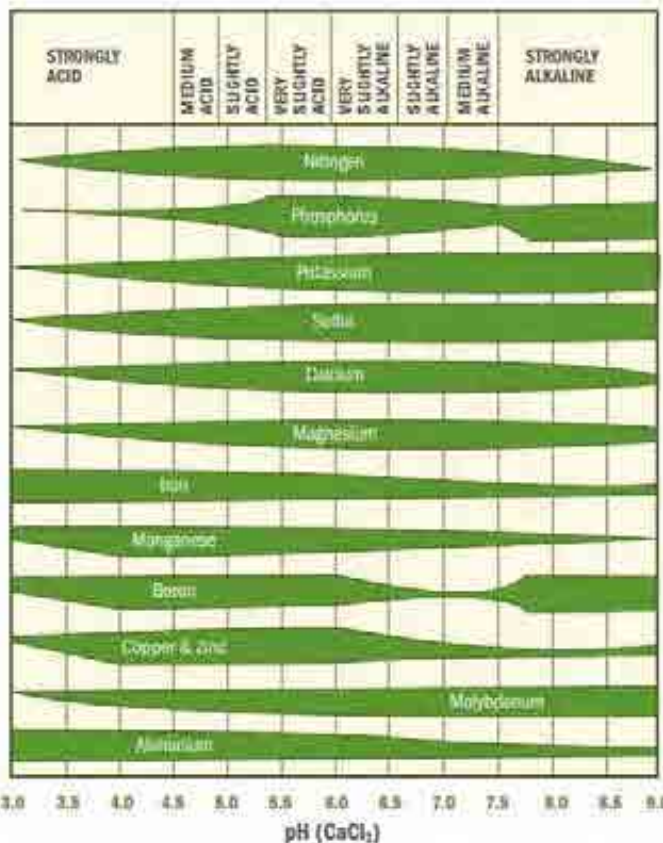


Figure 7.13 Effect of pH (1:5 CaCl₂) on nutrient availability. *Source:* <http://www.sibelco.com.au/LinkClick.aspx?fileticket=VhVvWW7>

The width of the bar represents the relative availability of that particular nutrient at that pH level.

In strongly acidic soils (pH (CaCl₂) less than 4.0), all the major plant nutrients (nitrogen, phosphorus, potassium, sulphur, calcium and magnesium) and the trace element molybdenum may become less available to plants (see Figure 7.13). If the pH (CaCl₂) is greater than 6, some trace elements, such as zinc, copper and boron, become less readily available, which may lead to deficiencies in plants.

Soils that are deficient in molybdenum may show a pasture response when lime is applied because the chemical reactions increase the availability of molybdenum for plant growth, especially legume growth. In many cases, what is seen as a lime response is actually a molybdenum response. For soils low in molybdenum, applying a fertiliser mix that includes molybdenum will cost less than applying lime where the pH is known to be adequate for plant growth. Caution should be exercised with the application of molybdenum as an over application of molybdenum can have an antagonistic effect on copper uptake from pastures. Molybdenum status is best assessed using plant tissue analysis of white clover (or other legume) or by applying a test strip - See Chapter 8.7 for more information on fertiliser test strips.



7.6.6.1 Aluminium and manganese

As soils become more acidic, it is common to see a rise in the plant availability of both aluminium (Al) and manganese (Mn), which can both be toxic to pasture plants and crops (see Figure 7.12). Aluminium toxicity is particularly common in acid soils and restricts root growth and function in sensitive plant species. For more information on critical aluminium levels for various pasture species see Chapter 9.2.9.7.

7.6.7 Effect of pH on biological activity

Living organisms are an important component of the soil. Good organic matter levels, good drainage and appropriate pH levels encourage their presence.

Earthworms are less active in very acidic soils, fungal organisms prefer a wide range of pH, and bacteria prefer slightly acid to neutral soils. Some of the important beneficial organisms (for example, nitrifying bacteria) are inhibited in both very acid and very alkaline soils. On strongly acidic soils and, in particular, those with a pH (CaCl₂) less than 4.5, the activity of the bacteria responsible for the conversion of organic material into plant-available nitrogen is significantly reduced. For more information refer to Soil Biology Chapter 5.

7.6.8 Soil pH across the dairying regions of Australia

For information on soil pH across the dairying regions of Australia see the links below:

- [Australian Soil Resource Information System](http://www.asris.csiro.au) – See Figure 7.14.
- Chapter 6 - Soil types of the dairying areas

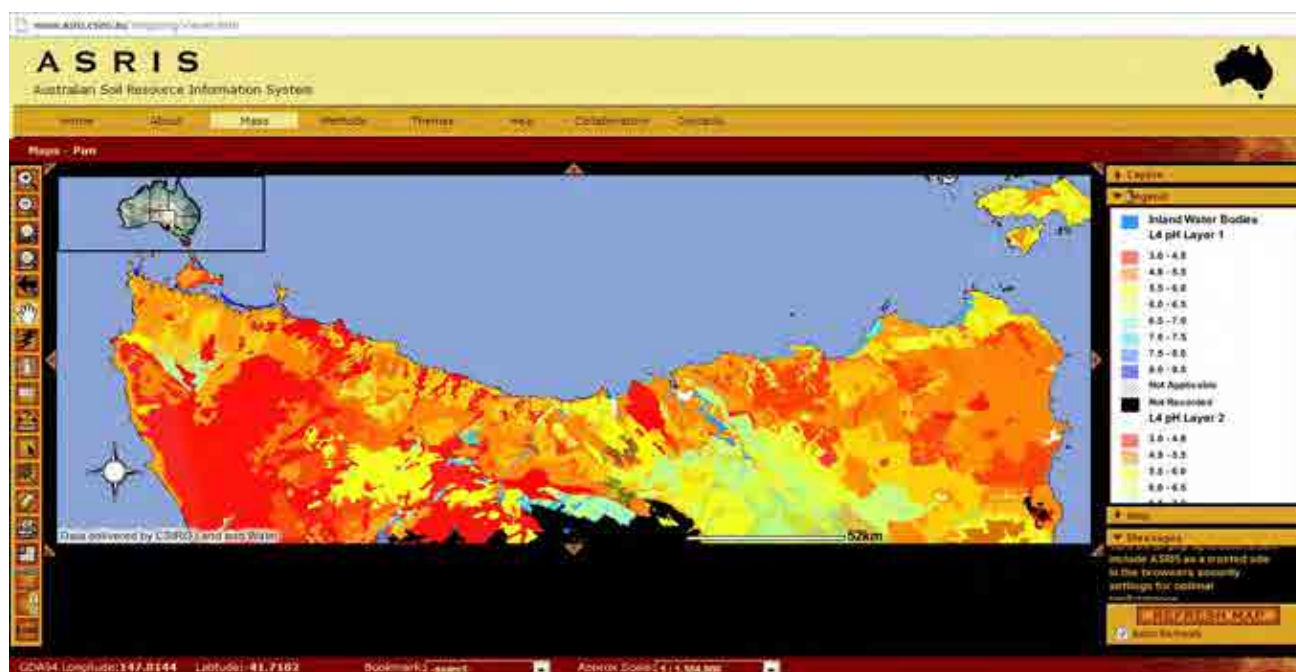


Figure 7.14 A screen shot of a pH map from Northern Tasmania downloaded from the ASRIS website.
Source: <http://www.asris.csiro.au/index.html>



7.6.9 Correcting soil acidity

Soil acidity is corrected by applying agricultural **lime** or **dolomite**. Lime (calcium carbonate) is the most common product applied to dairy pastures to increase the pH and neutralise the effects of soil acidity. **Dolomite** may be used where magnesium is required.

7.6.9.1 How does lime work?

Liming materials consist of calcium and magnesium carbonates. When applied, the carbonates slowly dissolve in the acid soil solutions and consume hydrogen ions and soil pH rises. Consumed exchangeable hydrogen ions are replaced by the calcium and magnesium ions. [Figure 7.15](#) shows a simplified version of these chemical reactions.

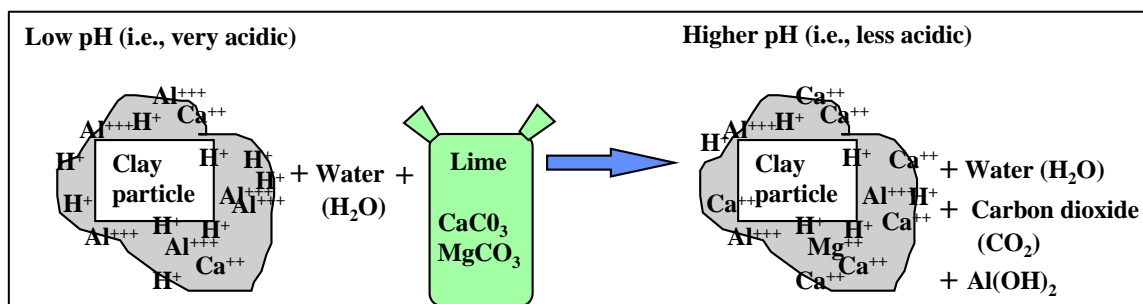


Figure 7.15 How lime works

The amount of lime required to lift a soil's pH to a desired level is determined by how acidic the soil is and by the soil's **pH buffering capacity**. Some soils have a higher pH buffering capacity than others. The pH buffering capacity is the soil's ability to resist a change in its pH level and is largely determined by the soil texture. Soils containing high proportions of clay and organic matter, such as clays and clay loams, have a higher pH buffering capacity than sandy soils. Soils with a high pH buffering capacity acidify at a slower rate than soils with a low pH buffering capacity. As a result, these soils can tolerate acidifying processes, such as product removal and nitrogen fertiliser use, for a greater period before acidity begins to affect plant growth. However, once they do become too acidic, they will require larger quantities of lime to raise the pH level compared to soils with a low pH buffering capacity.

7.6.9.2 How and when to apply lime

Most lime is spread by contractors because of the need for specialised equipment due to the nature of the product and the large quantities applied. Lime is a salt and usually applied prior to sowing a pasture. It is preferred to incorporate the lime into at least the top 10cm to allow greater interaction with soil volume.

7.6.9.3 Lime application at sowing

Lime is relatively insoluble so does not dissolve easily (see [Table 7.1](#)). Thus, it is slow to react. For maximum benefit, it should be worked into the soil when resowing a pasture or sowing a fodder crop. Table 7.5 shows the recommended application rates of lime if applied to an area to be sown.



Table 7.5 Limestone required ([fine and neutralising value \(NV\) > 95](#)) to lift pH (CaCl₂) of the top 10 cm of soil to 5.5.
Source: AgFacts NSW DPI, Soil acidity and liming.

| Soil test ECEC (cmol (+)/kg) | Lime required (t/ha) to lift the pH (CaCl ₂) of the top 10 cm: | | | |
|------------------------------------|--|--------------------|--------------------|--------------------|
| | From 4.0 to 5.2 | From 4.3 to 5.2 | From 4.7 to 5.2 | From 5.2 to 5.5 |
| 1 | 1.6 | 0.8* | 0.3* | 0.2* |
| 2 | 2.4 | 1.2 | 0.5* | 0.4* |
| 3 | 3.5 | 1.7 | 0.7 | 0.5* |
| 4 | 3.9 | 2.1 | 0.9 | 0.6 |
| 5 | 4.7 | 2.5 | 1.1 | 0.7 |
| 6 | 5.5 | 3.0 | 1.2 | 0.8 |
| 7 | 6.3 | 3.3 | 1.4 | 1.0 |
| 8 | 7.1 | 3.8 | 1.6 | 1.1 |
| 9 | 7.9 | 4.2 | 1.8 | 1.2 |
| 10 | 8.7 | 4.6 | 1.9 | 1.3 |
| 15 | 12.5 | 6.7 | 2.8 | 1.9 |

**It is recognised that low rates of lime are impractical to apply, but over-liming can cause nutrient imbalances, particularly in these light soils*

| 0.5 t/ha | 1.0 t/ha | 1.5 t/ha | 2.0 t/ha | 2.5 t/ha | 3 to 4 t/ha | Split applications advised ** |
|----------|----------|----------|----------|----------|-------------|-------------------------------|
| | | | | | | |

*** Do not apply greater than 4 t/ha in a single application, so as to minimise any problems that could arise from over liming.*

In order to use Table 7.5 the amount of lime applied is dependent on both the soil pH and **effective cation exchange capacity (ECEC)**. Soil pH is represented in a logarithmic way; meaning that soils having a pH (CaCl₂) 5.0 are 10 times more acidic than a soil of pH (CaCl₂) 6.0 and a soil with a pH (CaCl₂) 4.0 is 100 times more acidic than a soil of pH (CaCl₂) 6.0. Therefore, proportionately it takes greater amounts of lime to correct a lower soil pH than it does to correct a higher soil pH as reflected in table 7.5.

Soil texture plays an important role in the effectiveness of the lime application, due to its effects on the ability of limestone to move through the profile and the soils buffering capacity. The **effective cation exchange capacity** recognises that as the soil pH drops below pH (CaCl₂) 5.0, aluminium is becoming more soluble and plant available; increasing to possible toxic levels when less than pH (CaCl₂) 4.5. The higher ECEC values would indicate that the soil to be limed has a higher clay or organic matter content and a higher buffering capacity and as a consequence will require more lime to adjust the soil pH.

Two examples using Table 7.5:

1. Your soil has a pH (CaCl₂) of 4.7 in the surface 10 cm and an ECEC of 6 cmol(+)/kg. Your aim is to increase the soil pH (CaCl₂) from 4.7 to 5.2 by incorporating the limestone into the top 10 cm prior to sowing the pasture. Follow the pH column down and the ECEC row across, and where they intersect is the limestone application rate of 1.2 t/ha. This amount in practical terms would be applied at 1.5 t/ha.



2. Your soil has a pH (CaCl₂) of 4.0 in the surface 10 cm and an ECEC of 6 cmol(+)/kg. Your aim is to increase the soil pH (CaCl₂) from 4.0 to 5.2 by incorporating the limestone into the top 10 cm prior to sowing the pasture. Follow the pH column down and the ECEC row across, and where they intersect is the limestone application rate of 5.5 t/ha. This amount in practical terms would be best applied in a split application of 3.0 t/ha in the first year and repeated in a couple of years or at the earliest convenience.

Liming is an expensive input into soil and pasture management, therefore it is crucial that an accurate soil sample is taken from the field which considers preferably both the surface and subsurface acidity.

The pH of the soil and aluminium levels will be the guide to the likely need for lime when resowing pastures. Lime is unlikely to be of benefit for dairying pastures on moderately acid (those above pH (CaCl₂) 5.1), neutral or alkaline soils.

For soils below pH (CaCl₂) 5.1, an application of lime incorporated into the soil top 10 cm by cultivation is recommended, depending on soil pH and sowing method.

Note: Table 7.5 is a rough guide only. For a more accurate estimate of lime application rates, ask your laboratory to do a **pH buffering test** – see Chapter 9.2.4.

7.6.9.4 Lime application as a topdressing

Lime can be applied as a topdressing (in other words, spread over uncultivated soil or existing pasture) if a paddock is to remain in the pasture phase for several years.

In the past, surface-applied lime was not recommended because earlier research indicated that 18 to 24 months might be required before a rise in soil pH was measured. This period of time was often needed to allow movement of the lime into the soil (0.5 to 1 cm each year) and to allow for the chemical reactions to occur.

However, much uncertainty still surrounds the likely responses to surface-applied lime.

Without doubt, most pastures on very acidic soils (less than pH (CaCl₂) 4.3) will respond to surface-applied lime over a period of time. Pastures on soils with very high levels of aluminium or manganese will also respond. Recent experiments illustrate the lime quandary.

A Tasmanian experiment where lime was surface-applied over a range of soil types found that the pH (water) level rose by 0.1 unit for each 1 tonne/ha of lime applied. The more acidic the soil, the greater the pasture response. Even on soils with a pH (water) of 5.8, responses still occurred. Pasture responses varied between 1% to 15% extra annual pasture growth on most plots. If milk solids returned \$2.85/kg and lime cost \$42, then a pasture response of 0.7% per tonne of lime applied is the breakeven point. This trial measured responses of in excess of 1% to 2% per tonne of lime applied.

However, two separate research experiments conducted by DPI at Ellinbank and Hamilton also produced some interesting results:

The research conducted at Ellinbank demonstrated that the rate of downward movement of lime may be much quicker than previously thought in high-rainfall areas and on lighter soil types, than it is in drier areas and on heavier soil types. The pH levels rose significantly between 0 to 5 cm depths and 5 to 10 cm depths (at the higher rates of 10 to 20 t/ha) within 12 months of application of the



lime. Pasture responses to the lime treatments were variable and seasonal and came largely from the higher (above 10 t/ha) treatments. On many of the treatments, there was no immediate response; however, responses may or may not improve over time.

The work done at Hamilton also produced promising results for the effectiveness of surface-applied lime. After 3 successive years of a 5 t/ha application of lime, an increase in pH of up to 2 units was seen in the top 5 cm of the soil profile. In the 5-10 cm range of the soil profile, an increase of 0.5 to 1.0 unit was seen. Some of this response was seen after the first year of treatment, and the soils steadily improved over subsequent years. Another important observation from the Hamilton research was the effect of surface-applied lime on the available aluminium in the soil profile. Exchangeable aluminium levels on the limed treatments were up to 50% to 80% lower after 3 years than on those treatments that received no lime.

On the tropical grass pastures of the Atherton Tablelands region, Far North Queensland, the Krasnozem soils are naturally acidic. This, and the use of nitrogen fertilisers, means that lime is applied at 2.5t/ha every 5 years to maintain a soil pH (1:5 water) of at least 5.0, and preferably 5.2 to 5.4. Where these paddocks are planted to irrigated temperate pastures over winter, lime is applied every 3 years to maintain a soil pH of at least 5.5, and preferably 5.7 to 5.9. Where soil tests indicate magnesium is required, a lime dolomite blend (typically 3% Mg) is applied.

The current advice among many, although not all, advisers is that:

- If the soil is strongly acidic (in other words, below pH (CaCl₂) 4.3), then surface-applied lime (2.5 t/ha) is likely to improve pasture productivity (see Table 7.6).
- In the pH (CaCl₂) range of 4.3 to 4.6, either apply 2.5 t/ha of lime or lay down lime test strips and observe for responses over several years.
- Above pH (CaCl₂) 4.7, lime is unlikely to result in a pasture response in the short term, but a pasture response may occur over the longer term.

Table 7.6 Lime recommendations on existing pasture

| EXISTING pH (CaCl ₂) | EXISTING pH (WATER) | RECOMMENDATION |
|----------------------------------|---------------------|------------------------|
| 4.7 and above | 5.3 and above | No lime |
| 4.3 to 4.6 | 5 to 5.3 | Test strip or 2.5 t/ha |
| Less than 4.3 | Less than 5 | 2.5 t/ha* |

*Another 2.5 t/ha should be applied after 3 years on soils with a pH (CaCl₂) less than 4.3.

Note: Table 7.6 is a rough guide only. For a more accurate estimate of lime application rates, ask your laboratory to do a **pH buffering test** – see Chapter 9.2.4.

When surface-applying lime, a maximum rate of 5 t/ha is recommended for a single application to avoid smothering the plants and to avoid possible animal health problems.

If lime is to be applied to pastures as a topdressing, there is an advantage in using superfine or microfine lime to increase the rate of movement from the surface of the soil to depth.

Check your understanding of lime application rates by working through Exercise 2.



7.6.10 The effective neutralising value of lime and dolomite products

There are many sources of lime and they vary in their ability to change the soil pH and the speed at which this happens. The effectiveness of lime is determined in two ways:

- **Neutralising Value (NV)** – The amount of calcium or magnesium as oxides or carbonates. Neutralising value is expressed as a percentage relative to pure calcium carbonate, which is given a value of 100 per cent (Gazey, 2011).
- **Effective Neutralising Value (ENV)** - Considers the purity (Neutralising Value), as well as particle size or fineness. The finer the product, the greater the surface area for the neutralising chemical reactions to occur.

The key indicators of agricultural lime quality are **neutralising value** and **particle size**, regardless of the lime source.

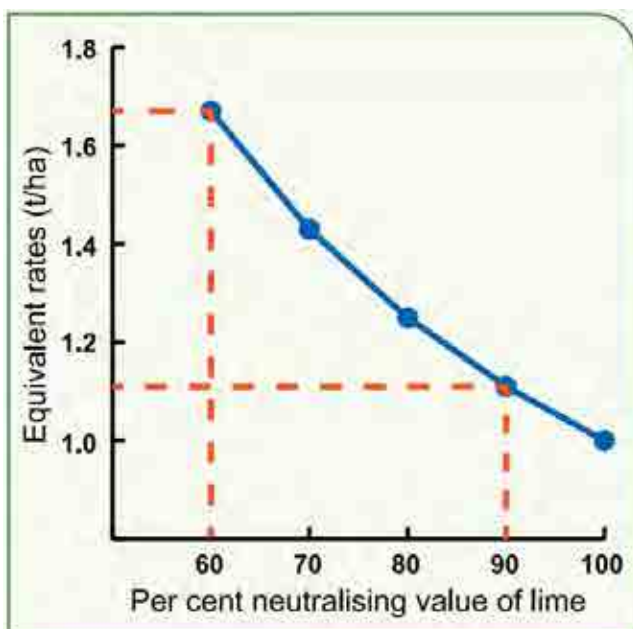


Figure 7.17 Approximately 1.7 t/ha of 60 per cent NV lime is required compared to 1.1 t/ha of 90 per cent NV lime to achieve the same pH change.

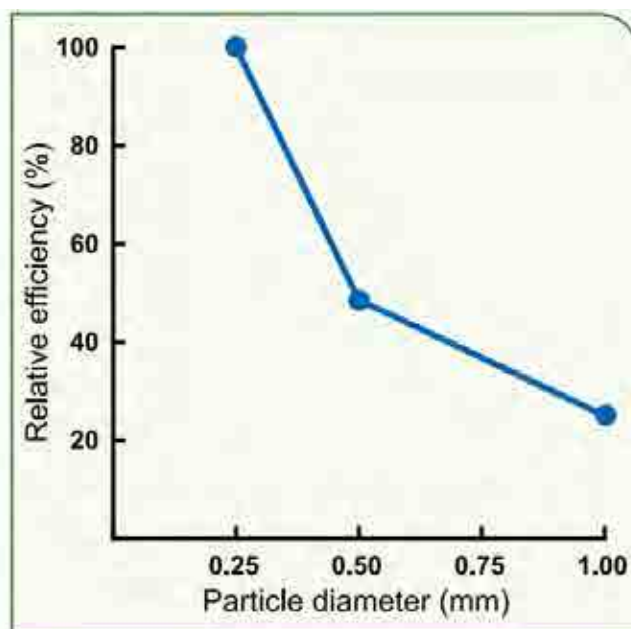


Figure 7.16 Finer particles of agricultural lime were more efficient in changing soil pH at an application rate of 2.5 t/ha (from Cregan *et al.*, 1989).

Source: Gazey, 2011 http://www.agric.wa.gov.au/objtwr/imported_assets/content/lwe/land/acid/liming/bn_2011_lime_quality_audit.pdf


Figure 7.16 shows the rate of lime (t/ha) required to achieve the same pH change using lime products with neutralising values ranging from 60 to 100 per cent. The example shows that only 1.1 t/ha of 90% NV lime is required to achieve the same result as 1.7 t/ha of a 60% NV lime.

Figure 7.17 compares the relative efficiency (%) of agricultural limes with different particles sizes applied at 2.5 t/ha. It shows that lime with a particle size of 0.25 mm is five times more efficient in changing soil pH than lime with a particle size of 1 mm.


Different codes of practice for labelling of agricultural limes apply in each Australian state. For example, Figure 7.18 shows a product information sheet for a Lime WA Inc. accredited supplier. It shows particle sizes, neutralising value of each fraction, and the overall neutralising value of the




bulk product. It also shows the levels of Calcium, Magnesium and Sodium (quoted in pure, not carbonate form).



LIME WA INC.
Accredited Lime Suppliers
Code of Practice
Product Information Sheet


Approved Laboratory 



Aglime of Australia

PO Box 212, Belmont, WA 6984
Tel : (08) 9277 5529 Fax : (08) 9277 5379
Loading : Kim Crossland
0427 632 471

| GENERAL INFORMATION | | | |
|---------------------|------------------------|------------------|--------------------|
| Pit Name | Aglime of Australia | Date of Analysis | February 12th 2011 |
| Location | Cervantes | Laboratory No. | 10A0308-020 |
| Product Description | Limesand | Product Screened | Yes |
| Weigh System | Loadrite Loader Scales | Screen Size (mm) | 1.00 mm |

| CODE OF PRACTICE APPROVED LABORATORY REPORT | | | | |
|---|-------------|---------------|---|---------------|
| | THIS SAMPLE | RANGE FOR PIT | THIS SAMPLE | RANGE FOR PIT |
| Sieve Range (mm) | % Weight | | % Neutralising Value | |
| 0.000 – 0.125 | 2.6 | 2.8 - 9.1 | 92.6 | 91.4 - 94.9 |
| 0.125 – 0.250 | 66.9 | 57.0 - 76.9 | 93.3 | 91.3 - 93.9 |
| 0.250 – 0.500 | 28.9 | 17.2 - 37.0 | 95.2 | 95.0 - 97.0 |
| 0.500 – 1.000 | 1.4 | 0.2 - 1.6 | 89.4 | 85.5 - 98.2 |
| > 1.000 | 0.1 | 0.1 | Insufficient Sample | 86.8 - 91.0 |
| Weighted Average NV | | | 93.7 | 91.7 - 94.5 |
| Bulk NV | 92.9 | 91.7 - 94.5 | This product was sampled by the Department of Agriculture and Food, Western Australia and submitted directly to the ChemCentre for testing as part of the Lime WA Inc. independent audit program.  | |
| Calcium (Ca) (1 M HCl) | 34.8 | 33.1 - 35.8 | | |
| Magnesium (Mg) (1 M HCl) | 1.7 | 1.5 - 1.8 | | |
| Sodium (Na) (1 M HCl) | 0.3 | 0.2 - 0.3 | | |
| Moisture Content | 2.2 | 0.6 - 11.0 | | |

Statement by Supplier : The above analysis, provided by a Code of Practice approved laboratory, is a true representation of the product being supplied from the nominated pit. Pit ranges have been calculated from the last 9 samples analysed.
 Date: _____ Position: _____ Signature: _____

Disclaimer : Lime WA Inc. requires members to provide the above details in accordance with the industry Code of Practice requirements but makes no claims and provides no guarantees on the quality or suitability of the product supplied. Lime WA Inc. is not responsible for any claims and/or liabilities arising from the supply and/or use of the product supplied. However, users are invited to contact the Association on 0419 575 737 in the event of any dissatisfaction with the product description provided by accredited lime suppliers.

Figure 7.18 Example product information sheet. Source: Gazey

2011 http://www.agric.wa.gov.au/objtwr/imported_assets/content/lwe/land/acid/liming/bn_2011_lime_quality_audit.pdf



7.6.11 How to calculate the cost of lime or dolomite

When you compare lime products, make sure that you select the most economical product available in your region.

The value of limes of various types and from various sources can be compared by making the following calculations:

1. Gather quotes from suppliers for the **total cost per tonne** to have various limes applied to the paddock (including the purchase price and the transport and spreading costs).
2. Obtain the **Effective Neutralising Value** for the limes. Most limes on the market have been tested to determine their ENV, and this information should be available from the supplier. This will provide a 'per unit' basis for comparison.
3. Divide the total cost by the **effective neutralising value** of each product:

$$\text{Unit cost} = \text{Total cost per tonne spread} \div \text{Effective neutralising value}$$

Example.

Say that there are two lime products available in your area.

Lime A has an ENV of 95 and costs \$60/t spread.

Lime B has an ENV of 70 and costs \$50/t spread.

Which is more economical?

Lime A: \$60 divided by 95 = \$0.63 per unit of ENV (as received basis).

Lime B: \$50 divided by 70 = \$0.71 per unit of ENV (as received basis).

Lime A is the lower cost lime to use based on its effective neutralising value and the total price.

Knowing these characteristics about lime (including dolomite) allows you to compare the cost-effectiveness of a variety of lime products and purchase the product that will be most cost-effective for your farm. However, you must also take into account other considerations, including the handling requirements of some products. The [lime comparison calculator](http://soilquality.org.au) on the soilquality.org.au website can be used to calculate and compare the cost-effectiveness of agricultural limes. It considers the cost of: lime, transport, spreading; particle size distribution of the lime; and the neutralising value of each particle size range in the lime.

7.6.12 Lime products

By-product and natural limes contain calcium carbonate (CaCO_3), calcium hydroxide (Ca(OH)_2), or calcium oxide (CaO). Dolomitic limes contain magnesium carbonate (MgCO_3) in addition to the CaCO_3 . Pure lime is 100% calcium carbonate (CaCO_3).

Agricultural limestones usually occur in limestone rock deposits with calcium carbonate (CaCO_3) contents ranging from 48% to 97%. Agricultural lime is the most commonly used product for increasing soil pH in pastures and is usually the most cost-effective.

Burnt lime (also called quick lime) is calcium oxide (CaO). It is a faster-acting lime and has the highest neutralising value. This lime is mostly used in horticultural enterprises and is not usually applied to pastures. However, it needs to be used soon after its production because in time it reverts back to lime.



Slaked lime (also called hydrated lime or builder's lime) is calcium hydroxide ($\text{Ca}(\text{OH})_2$) and has a higher neutralising value than agricultural lime but is more expensive and not usually applied to pastures.

Lime kiln dust is the very fine dust (particle size of less than 0.1 mm) produced by kilns used to burn lime. It contains both limestone and burnt lime and is difficult to handle due to its fineness, so a contractor experienced in spreading the product should be used. **Cement kiln dust** has similar properties, plus it can contain significant amounts of potassium (commonly 3% to 5%).

Wet lime is also known as liquid lime. The effectiveness of liquid lime is determined by its NV, not its ENV. There are extra handling costs with wet lime. Wet lime is not usually applied to pastures.

Dolomite is a mixture of calcium carbonate and magnesium carbonate (CaCO_3 and MgCO_3). As the magnesium carbonate content of limestone increases, it is firstly called dolomitic limestone and finally dolomite (pure magnesium carbonate). The Limestone Association of Australia defines dolomite (as a product) as having a minimum magnesium carbonate analysis of 28% and a minimum calcium carbonate analysis of 35%. Dolomite is frequently used in horticulture as a source of magnesium (for example, in orchards) and is sometimes used on pastures.

Dolomite is used as a source of magnesium for magnesium-deficient soils. It can also be used as a source of magnesium for livestock. However, very high rates are required for this purpose (5 t/ha or greater). A Department of Agriculture study at Camperdown showed that 12.5 t/ha needed to be applied to obtain an effect. Experience is that dolomite is generally not effective in reducing [grass tetany](#), and livestock should be treated directly.

7.7 Summary

- Apart from nutrients, many other soil-related factors (for example, slaking, dispersion, sodicity, compaction, salinity, waterlogging and soil acidification) can substantially limit plant growth.
- Soil structure can be improved by increasing organic matter, improving drainage, and using gypsum on some soil types.
- The solution to salinity problems is not a matter of just treating the symptoms but of managing all the factors that raise the water table and influence the well-being of the water catchment.
- Applying lime to acidic soils will increase soil pH.
- Limes vary in their ability to reduce acidity.
- Limes should be applied on the basis of soil test analyses and purchased on the basis of effective neutralising values and cost.

Exercise 3 provides practice in identifying soil-related factors that can limit plant growth.



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Chapter 8

Assessing Soil Nutrients

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8 Assessing Soil Nutrients

8.1 Introduction

Before applying any fertiliser, farmers need to assess which nutrients and how much of each is to be applied to correct deficiencies or to balance what has been removed by the farming system. Many factors must be taken into account before making the final decision. These will be more fully discussed in Chapters 9 through to 15.

However, several tests and observations can be very useful, and even essential, in assisting to make more informed fertiliser decisions. An assessment of pasture nutrient requirements should include a program of [soil testing](#) and [plant tissue analysis](#). Other tools, such as [paddock history](#), [visual paddock indicators](#) and [fertiliser test strips](#), are also useful indicators of nutrient requirements of pastures.

Learning outcomes

At the completion of this chapter, you should be able to:

- Correctly sample a paddock for soil testing.
- Correctly obtain a sample for plant tissue analysis.
- Assess possible nutrient deficiencies in conjunction with the visual appearance of the pasture.
- Set up fertiliser test strips to assist in identifying the fertility status of your pasture.

8.2 Soil testing

Soil testing is very useful for assessing:

- Fertiliser type and rate of nutrients required.
- Lime requirements.
- Gypsum requirements.
- Changes in soil nutrient levels over time.

A recent survey has shown that about 82% of dairy farmers use soil tests to determine the next season's fertiliser application, and 50 % of dairy farmers do this in consultation with independent consultants. A significant proportion (49%) are confident in the advice they receive which still leaves many dairy farmers that are only fairly confident to not confident in the advice, or are still basing their current fertiliser strategy on a soil test carried out 5 to 10 years ago or relying on past practices (Dairy Australia, 2012).

In order to know how much and where the nitrogen, phosphorus, potassium, etc. is in the soil and if it is plant available, you have to take a soil test. Essential plant nutrients in the soil are often in a dynamic state i.e. changing in terms of availability and form; nitrogen being the classic case. There are new soil tests being developed in different regions which allow more specific analysis. In some cases, soil tests are now able to give indications of soil health, in addition to a chemical analysis (See [Chapter 5](#)).

The accuracy of any soil test depends on:

- A truly representative sample being supplied to the laboratory. Many incorrect recommendations associated with soil test results occur due to poor sampling.



- The sample being packaged correctly and transported to an [ASPAC or NATA accredited laboratory](#) for a comprehensive and accurate analysis.
- Correct calibration of the chosen test methods against local or regional field trials to allow reliable interpretation.
- Basing the fertiliser, lime and gypsum recommendations on a broad range of other factors, such as pasture composition, homogeneous soil type, and stocking rate; in other words being site specific.

8.3 Suggested soil sampling guidelines

The standard sampling procedures outlined below are designed to minimise the effects of soil variation and to help you collect a representative sample.

8.3.1 Timing of soil sampling

As soil nutrient availability can vary throughout the year due to changes in temperature and moisture, it is best to:

- sample at the same time each year,
- sample at least 6 weeks prior to planting, and
- avoid sampling within 3 months of liming or 2 months of applying fertiliser.

There is not one particular time of the year to soil sample, as it will vary depending on location, seasonal conditions, the type of crop or pasture being planted, growth flushes, and the nutrient that it is intended to apply.

8.3.2 Selecting areas for sampling

In recent years, dairy farmers have been changing their choice of fertilisers, with an increasing use of organic and potassium fertilisers. Efficient use of fertilisers requires an awareness of environmental and soil conditions. In order to achieve increased nutrient use efficiency, dairy farmers are placing a greater reliance on independent consultants to assist with interpreting soil test results and prepare nutrient budgets. Deciding which field to sample for the nutrient budget should be carefully considered so as to:

- provide a strategy for the management of fields including future rotations, and
- deliver objectives and optimal soil fertility.

A common strategy is to sample a representative paddock from a **farm management zone (FMZ)** – see Chapter 15.3.1.

From these zones, select a number of representative ‘monitor’ paddocks to sample. These monitor paddocks can be sampled regularly over time, following the same transect, to determine if the farm soil fertility is changing. Initially, these areas may need to be sampled every 1 to 2 years while in the development stage of soil fertility. Once the maintenance stage is reached and you are confident that your fertiliser strategies are meeting the maintenance requirements of your farm, the sampling interval could increase to every 2 to 3 years (See [Chapter 1.7](#)). It may then be possible to rotate the areas tested each year so that the soil fertility is monitored on other parts of the farm.

Soil samples can vary greatly in their ability to truly represent the area being tested, even when taken and analysed correctly. For example, a very wide variation in nutrient levels can exist between

paddocks and within paddocks. Figure 8.1 shows the variation of Olsen P (estimated from Colwell P data) within one paddock that was soil tested on a gridline basis, with 20 samples taken randomly around each grid point. Each number in the figure indicates a grid point and the Olsen P around that grid point. As you can see, the Olsen P measurements ranged from 8 to 40 mg/kg.

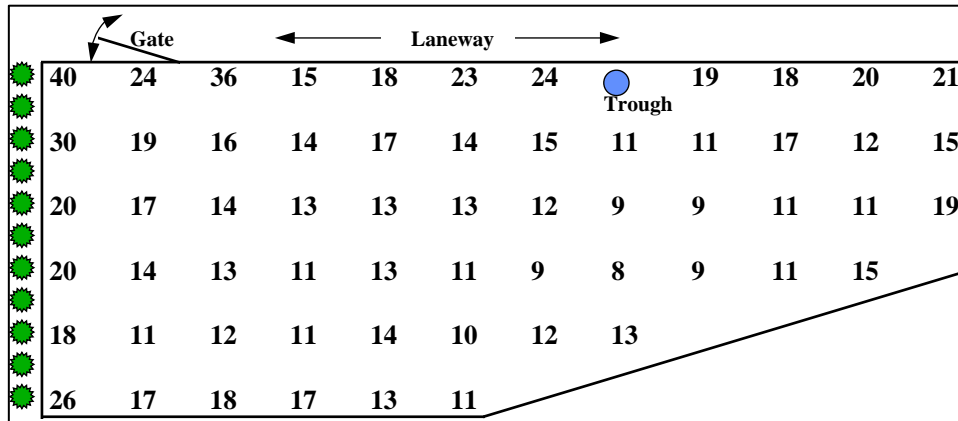


Figure 8.1 Variation of Olsen P (mg/kg) within one paddock.
 Source: State Chemistry Laboratory (Macalister Research Farm)

To minimise variation within paddocks and between times of testing, **transect sampling** is recommended.

Transect sampling means sampling the same path through the paddock each time you do a soil test. Recent experiments have shown that this technique can substantially reduce the variation in the soil test results. Permanently mark the fence posts opposite the end of each path so that future sampling can be carried out along the same line, or use a GPS unit. In irregularly shaped paddocks or sections, a permanent landmark, such as a tree, fence corner or dam, can be used to identify where sampling lines cross - see Figure 8.2.

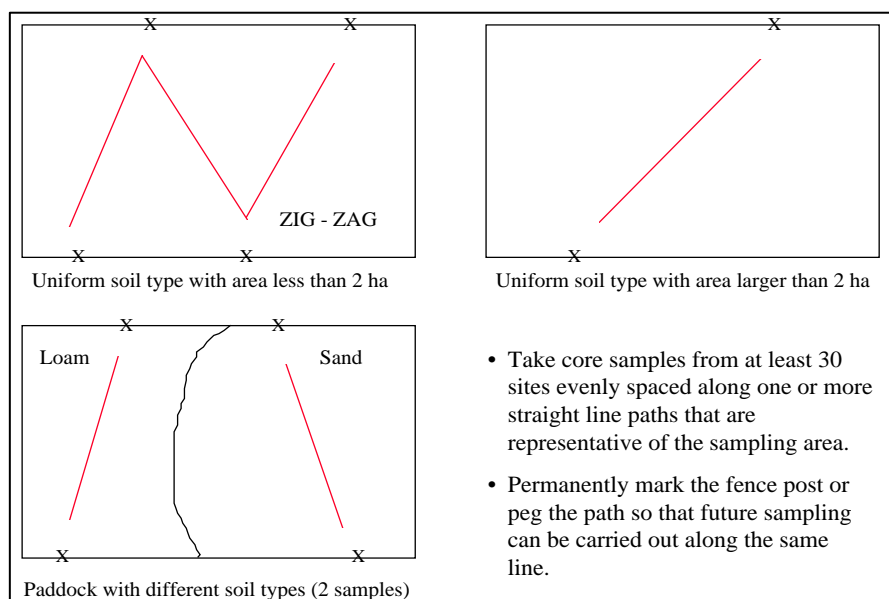


Figure 8.2 Recommended sampling sites for transect sampling



In addition to transect sampling of representative paddocks over time, soil testing is also used to investigate specific problem areas. In these cases, take the sample from the problem area or poor section of the paddock. This is referred to as **poor patch sampling**. It is extremely useful to take a sample from a nearby area that is representative of good pasture so that results can be compared to the 'poor patch' sample. If the soil test results are similar for both the poor area and the good area, then the problem may be related to some other factor, such as a trace element deficiency (which can be tested via a plant tissue analysis; see [Section 8.4](#)), disease or insect pests, lack of suitable pasture species or inadequate drainage or pugging.

8.3.3 Soil sampling depth

Soil nutrient levels vary with depth and usually reduce in concentration as you go deeper. It is critical that soil cores be collected to a standard sampling depth, if results are to be interpreted reliably.

The standard surface soil sample depth for pasture, cereal, oilseed, grain & legume crops is 10 cm, except Tasmania where the standard depth for pasture is 7.5cm and 15cm for field crops.

Optimum soil test values vary with depth due to a concentration of some nutrients such as phosphorus and potassium near the soil surface. Subsurface samples (taken from a depth of 10 to 60 cm below the soil surface, in 10 cm increments) may need to be taken for such problems as:

- Salinity.
- Poor structure.
- Sulphur deficiency.
- Subsoil pH.
- Aluminium toxicity.

Subsurface soils are usually sampled using an auger or hydraulic soil coring machine to remove soil at depth. For phosphorus in particular, it is essential to minimise contamination by the top 10 cm of soil, whilst inserting the auger to collect samples at the deeper profile depths. This is because phosphorus is concentrated in the surface soil where it is applied as fertiliser and dung. After the top 10 cm has been collected, a hole wider than the auger circumference can be dug before collecting the 10-20 cm profile depth with the auger, thereby minimising surface soil contamination. If required, this process can be repeated for subsequent depths.

Correct soil sampling equipment such as hand augers, foot probes, and hydraulic cores, or soil testing services are available from fertiliser companies, private consultants and dedicated soil testing services. Using other sampling tools, such as spades or galvanised pipe is not preferred due to possible contamination or inaccurate sampling methods. In the case of galvanised pipe, the galvanising can affect the soil test results.

8.3.4 Taking core samples

Take cores from **at least 30 sites for surface tests and from at least 15 sites for subsoil tests.**

The samples should be evenly spaced along one or more straight-line or zig-zag paths that are representative of the sampling area. Cores should be taken from spots of average or below-average growth. Bare ground should only be sampled if that constitutes a significant part of the paddock. Remember that you are trying to get an 'average' sample that is representative of the entire area.



Avoid waterlogged or pugged soil, obvious dung or urine patches, stock camps, stock tracks, fertiliser dump sites, recently grazed strips, and silage or hay storage or feedout areas. It is best not to sample within 20 metres of fencelines, gates, troughs or trees. Remember, if 3 or 4 cores in a 30-core sample are from urine patches, it can cause the potassium soil test result to be substantially higher than it should be. Take samples from sacrifice paddocks and those that are soon to be grazed before they are grazed, so you can avoid the urine and dung patches more easily as you can see the extra growth – See Figure 8.3.



Figure 8.3 [Urine and dung patches](#) should be avoided when sampling soils. The prevalence of these is a common indicator of nutrient deficiencies in other areas of the pasture.
Source: University of Georgia, 2011.

When taking cores, avoid growing plant material by inserting the sampler tip between leaves and stems. Remove each core carefully from the sampler, using a clean tool or fingers, and place the core in a clean container such as a plastic bucket. Discard any partial cores and resample near that site.

If the 30 cores weigh more than about 1 kg, thoroughly mix the cores in clean containers and then take a subsample of about 0.5 kg for mailing to the laboratory.

Transfer the cores or the subsample to a clean sample bag and label the bag with the paddock (or area) name and the number of cores taken. Fill in as much detail as possible when completing the paddock information form to ensure that the best possible recommendation can be made. This information is crucial for the person who will interpret your soil test results and formulate a fertiliser strategy for a paddock or area. Labels should be written on paper or cardboard labels with an indelible pen and attached to the outside of the sample bag. Use a second bag to protect the label from being rubbed during transport to the lab. Never put a label in with the sample because it will quickly deteriorate and become unreadable. Your samples are now ready for posting to the laboratory.

Exercises 4, 5, and 6 will help you understand how to choose representative areas to sample and how to take transect samples. [Download Exercises 4 to 6](#)



8.4 Plant tissue testing

Plant tissue testing is the preferred method for diagnosing micronutrient (trace element) toxicities, deficiencies, and imbalances for plants.

Plant tissue testing:

- Checks on fertiliser management recommended from soil testing.
- Checks if nutrients not applied as fertiliser (such as calcium, magnesium, or trace elements) remain adequate.
- Can help to determine nutrient deficiencies in animals, if taken as mixed herbage sample - see [Section 8.4.2](#)).
- Is helpful in diagnosing nutrient levels in pasture or crop diets offered to animals.

Many field experiments have been used to verify the results of laboratory testing of soils and of plant tissue. Research has shown that using soil tests to indicate trace-element deficiencies can be less accurate, especially on acid soils.

The same guidelines apply for plant tissue testing as for soil test sampling when doing simple problem diagnosis:

- Take representative plant samples from the area of interest. In the case of a problem diagnosis, make sure to take samples from both the affected and normal areas.
- Use transects.
- Take the samples in accordance with the physiological growth stage of the plant, when the plants are not stressed and at the same time of each day; generally in the morning between 6 – 10 am.
- Make sure that sufficient quantity of material is collected for testing. The number of tillers or plant parts stipulated has to account for high moisture content when dried in the lab before sampling.
- Do not take samples until about **8 weeks** after the last fertiliser application.

If plant tissue samples are being collected on an ongoing monitoring programme, collecting the sample from the right plant part and at the right time will be more crucial. This is due to the change in nutrient concentrations in plant parts as the season progresses. The results will be useful only if these sampling guidelines are followed carefully.

8.4.1 Testing for plant nutritional deficiency

Plants have different demands for nutrients, even for the same nutrient. If the availability of a nutrient becomes scarce in the soil not all plants display visible symptoms at the same time, i.e. different crop and pasture species have varying sensitivity to nutrient deficiencies. When sampling for plant nutritional deficiencies taking the sample from the legume component of a pasture (e.g. clover or lucerne) provides more accurate results than a sample from the grass component. This is more pronounced in the case of boron and potassium deficiencies. If no legumes are present however, the grass component can be sampled (e.g. ryegrass).

When clover is sampled it is best to select the most dominant species in the paddock. This may be white clover, sub clover, or strawberry clover. A mixture of clover species is not recommended because the various clover species have slightly different adequate levels for each nutrient and will be at different stages of maturity.

Collect the leaves and petioles (stems) from about 60 white clovers or 60 strawberry clovers or 80 to 100 sub clovers (around 2 hands cupped together and filled once with clovers).



Sample the youngest fully grown leaves and their petioles of the same species of clover – see Figure 8.4. Post the samples early in the week so that they are not left to deteriorate in a post office over the weekends, especially during the summer months. Always put samples into paper bags and avoid leaving the sample for too long before posting. Do not leave the sample in a hot tractor cabin, on the ute dashboard, etc.; and refrigerate the sample if there is a delay in sending. Samples can also be oven (preferably not a microwave) or air dried before sending to the laboratory. This is recommended for extended delivery periods, or to avoid the possibility of mould establishing on high moisture plant samples.

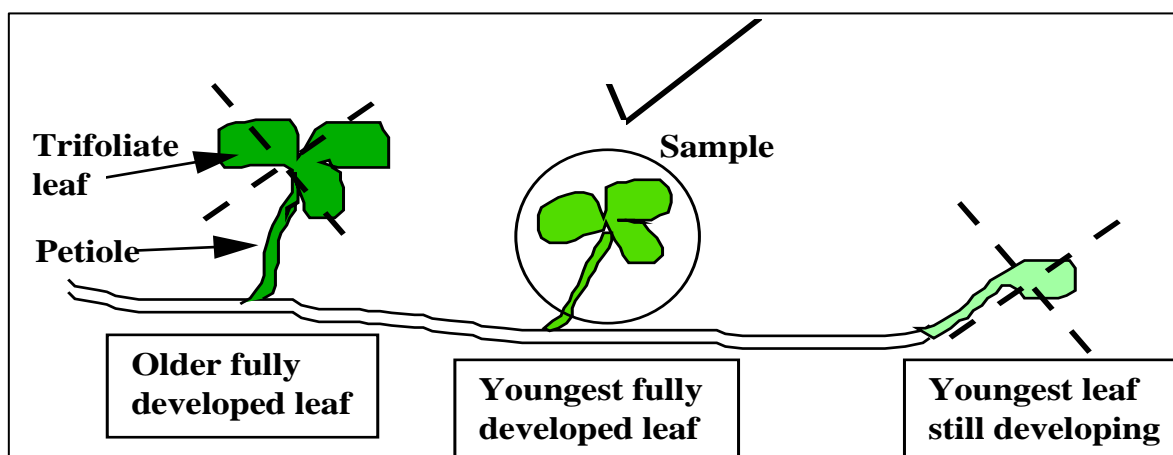


Figure 8.4 Section of clover to sample for plant tissue analysis

When taking tissue samples, it is vital to include as much information as possible. Describing the visual symptoms, noting which leaf is affected (youngest or oldest), and noting whether or not there is an effect on the edge (margin) of the leaf or between the veins are important. You should also outline the **paddock history** in terms of pasture type, soil type and previous nutrient applications.

When taking tissue samples, you should also ensure that the plant symptoms are not the result of other stresses such as, differing soil textures, seasonal changes, root disease, leaf disease, waterlogging, severe frost, insect attack or recent chemical application.

Tissue samples should not be taken when the plant is under a major stress, such as lack of moisture, waterlogging, frost or recent herbicide application.

Another key point is to note the amount of dry matter the plant is producing relative to what is considered adequate. In other words, is the plant growing slowly and producing very little dry matter, or is it producing close to maximum production. This will help the person interpreting the results.

Sampling the correct plant part is also vital, as described above. However, no matter which plant part is taken, ensure you tell the laboratory which plant part you have taken. In most cases, the youngest fully open leaf is the best plant part to take, regardless of the plant type, and the sample should be taken preflowering if possible. If there is a good and bad section in a paddock or farm, take a sample from each area as this is very useful for comparison.

Supplying the species of plant, plant part and stage of growth will allow the person interpreting the results to put the correct nutrient standards in for your sample. Actual adequate levels for any nutrient vary depending on species, plant part and stage of growth, so this information is critical.



For more information on soil, plant and water sampling refer to the link: http://www.incitecpivot.com.au/sampling_instructions.cfm

8.4.2 Testing for animal health problems

When sampling for animal health issues, collect a mixture of the plants that the stock are eating. Include weeds if relevant. Collect at least 20 handfuls across the pasture, using scissors to cut the sample off so as to avoid soil contamination from pulling. This is referred to as a **mixed herbage** sample.

8.5 Soil and plant tissue testing laboratories

A number of laboratories throughout Australia offer a soil and plant testing service. Many laboratories have membership in the **Australasian Soil and Plant Analysis Council (ASPAC)**, but only a limited number have membership of the **National Association of Testing Authorities (NATA)**.

ASPAC conducts regular National Quality Assurance Programs to enhance standards of analysis and to provide standardisation of soil and plant analytical methods across laboratories. Those laboratories that produce analysis results that meet certain criteria are provided a 'Certificate of Proficiency' for each test in which they successfully participated. It is important to remember that ASPAC provides a proficiency certificate for individual tests, not on a whole-of-laboratory basis. Other tests that a laboratory carries out may not have been deemed sufficiently accurate to be worthy of a proficiency certificate. It is recommended that you ask the lab if they are certified for the tests that you require, or check on the ASPAC website (www.aspac-australia.com).

ASPAC offers assistance to improve laboratory procedures. It also encourages laboratories to:

- Use standard units for reporting so that results are comparable between laboratories.
- Regularly check their testing techniques by testing samples with known values.
- Use accredited methods that have been calibrated against field trials under local conditions.

NATA is an association that, among other duties, sets and maintains the high standard for the methodology of laboratory practices and technical advice and accredits laboratories. Laboratories with NATA accreditation are also required to participate in a quality assurance testing program such as ASPAC. More information about NATA is available at www.nata.asn.au.

Using a NATA accredited laboratory, or a laboratory with ASPAC proficiency certificates for the tests required, provides the best assurance of consistent and accurate test results. These laboratories are recommended over those that do not participate in recognised quality assurance programs.

Check the soil test methods offered have been calibrated for crops and pastures in your region or state. Test methods that haven't been calibrated with research and trials are meaningless and should not be used.

Cost of analysis is also an important consideration but only laboratories with quality assurance should be considered when comparing costs.

Using the same quality assured laboratory for future analysis should provide greater consistency, and more comparable results.

Soil test results require interpretation. Check you are receiving quality advice. Fertcare provide quality assurance programs for advisors. For more information on Fertcare Accredited Advisors visit the Fertilizer Australia website: www.fertilizer.org.au.



8.6 Visual symptoms of nutrient deficiencies in pastures

To help determine your fertiliser needs, an important step to take in conjunction with soil testing, is to visually assess the pastures. The main features to look for are overall colour, the presence of weeds and poor pasture species, and if applicable, legume density and leaf size. If symptoms are apparent on individual plants, then pasture production will have been below its maximum potential well before this stage. In fact, visual symptoms will not become apparent until the reduced growth has exceeded 30%. This is referred to as 'hidden hunger'.

8.6.1 Identifying plant disorders from visual symptoms

The visual symptoms plants exhibit in response to nutritional disorders can be a useful guide for identifying the cause of a disorder. Common plant responses include unusual colours or patterns in the leaves, burns, distortion of individual plant parts, stunting or abnormal growth.

Several non-nutritional disorders (Table 8.1) can also produce similar symptoms, so careful observation is needed to ensure the diagnosis is reliable.

Table 8.1 Major causes of visual symptoms in plants

| TYPE OF DISORDER | CAUSES |
|------------------|---|
| Nutritional | Nutrient deficiencies |
| | Nutrient toxicities |
| Non-nutritional | Infectious diseases: fungal, bacterial or viral |
| | Insect damage |
| | Physiological: environmental stresses |
| | Mechanical injury |
| | Chemical injury: pesticide, air pollution, spray burn |

In pasture plants, nutrients move from the roots to other parts of the plant through a network of cells called the vascular system (veins). These cells specialise in moving water, nutrients and metabolic products throughout the plant. The arrangement of veins and the ease with which individual elements move within the plant (in other words, their mobility) have a strong influence on the way symptoms develop.

Symptoms that show patterns that align with the plant's veins usually indicate a nutritional disorder. Non-nutritional disorders usually show no relationship to vein pattern.

8.6.2 Characteristics of nutritional disorder symptoms on leaves

Nutritional disorders produce characteristic symptoms in leaves. These include:

- Symptoms are restricted initially to a single leaf-age class, that is, young, old or intermediate-aged leaves.
- Patterns are symmetrical and closely related to leaf venation.
- Changes in leaf colour and tissue death develop gradually (rarely overnight).
- The boundaries between green and chlorotic (yellow) or necrotic (dead) areas on a symptom leaf tend to be fuzzy or blurred. Strong, definite boundaries are often produced by herbicides or viruses.



- Leaf symptom patterns due to a nutrient deficiency are rarely blocky or angular. Such patterns can be caused by a pathogen or occasionally by nematodes.
- Nutritional problems impair cell function and rarely cause mechanical disruption of the cuticle (outer layer) of the leaf. Thus, damage to the surface of a symptom leaf is not likely to be caused by a nutritional disorder.
- Symptoms develop first in tissues most distant from the major veins of the leaf, such as the interveinal regions and the tips and edges of the leaf blade.

Visible changes in a crop, such as yellowing, small leaves and poor seedset, all begin as a breakdown in cell functioning and tell us that a nutritional disorder exists. For example, the distortion of new tissues or flowers or the death of growing points is typical of boron deficiency. These visual symptoms occur because boron is necessary for the proper regulation of cell division. Similarly, the leaves of nitrogen or magnesium deficient plants are pale because nitrogen and magnesium are components of the green plant pigment, chlorophyll.

Such links between an element's function and a specific abnormality that results when it is deficient are common in plants. For this reason, the nature of the symptom can provide a useful guide to the identity of a nutritional disorder even in unfamiliar crops.

The two most important diagnostic features of a nutritional disorder symptom are:

- Where the symptom is found on the plant (location).
- Its appearance (colour and pattern).

8.6.2.1 Location

Nutritional symptoms generally develop irregularly over a plant but show first in specific organs, such as the leaves, roots, shoots or growing points. Depending on the mobility of the element, leaf symptoms can occur in the upper, middle or lower sections of a plant.

Mobile elements like nitrogen, magnesium or potassium (see Table 8.2) are moved about the plant relatively easily to satisfy local shortages, particularly in new shoots or developing seeds. When one of these mobile elements is deficient, the **older leaves** are the first to be depleted and the first to show symptoms.

Less mobile elements, such as iron, copper, boron or calcium, do not move readily from older to younger tissues; so when these elements are deficient, the symptoms appear in the **newer or upper leaves** or in the flowers or the seed.

Symptoms of nutrient toxicity generally show first in the **oldest leaves**. These leaves have the highest transpiration rates and receive most of the nutrients absorbed by roots as the nutrients move in the transpiration stream.

Table 8.2 The difference in mobility of nutrients within the plant

| MOBILE | VARIABLY MOBILE | IMMOBILE |
|----------------|-----------------|----------------|
| Nitrogen (N) | Sulphur (S) | Calcium (Ca) |
| Phosphorus (P) | Copper (Cu) | Manganese (Mn) |
| Potassium (K) | Zinc (Zn) | Boron (B) |
| Magnesium (Mg) | Molybdenum (Mo) | Iron (Fe) |



8.6.2.2 Pattern

Observe the size and shape of the plant, the overall foliage colour, the colour of symptom leaves and the pattern of chlorotic (pale or yellow) or necrotic (burnt, appears dead) areas in relation to vein pattern. Also note any irregular shape, splitting, cracking or corkiness of affected organs. All of these may help to establish the identity of the disorder.

8.6.3 Deficiency and toxicity

Are the symptoms indicative of a deficiency or a toxicity?

Deficiency symptoms typically occur on a single leaf-age class unless more than one problem exists.

Toxicity symptoms often develop rapidly. When this happens, the affected leaf tissue may change from healthy green to grey-green or dark brown without a transitional yellow phase.

Symptoms that appear on old and new leaves at the same time may indicate a toxicity. For example, when an excess of one element causes a nutrient imbalance, deficiency symptoms may be seen in the young leaves while older leaves may show burn or other symptoms of toxicity. Excess phosphorus, manganese or zinc can cause iron deficiency chlorosis in young leaves as well as symptoms of nutrient excess (toxicity) in the old leaves.

Diagnostic keys (Table 8.3) provide a framework for a visual diagnosis of deficiencies, but there are two major weaknesses:

- A disorder is usually quite advanced before clear visual symptoms appear, and some loss of yield or quality will have occurred. Also, the absence of symptoms in a crop or pasture does not mean that nutrition is adequate. 'Hidden hunger' is the condition in which performance is limited, but no symptoms have been expressed.
- Visual symptoms can be unreliable when more than one element is limiting or when some environmental stress has modified the normal pattern.



Table 8.3 Quick guide to nutrient deficiencies: What to look for. *Source:* Adapted from Weir and Cresswell (1994).

| LOCATION | PATTERN |
|--|---|
| Symptoms first seen in <i>older</i> leaves | <i>Leaf colouration even over whole leaf</i> Nitrogen: Pale-green to yellow leaves. Phosphorus: Leaves dull, lacking lustre, bluish-green or purple colours. Poor growth. |
| | <i>Leaf colouration forms a definite pattern</i> Potassium: Scorching and yellowing, commonly around the edges of leaves, which may become cupped. Magnesium: Patchy yellowing often with a triangle of green remaining at the leaf base. Sometimes brilliant red to orange patterns or scorching. |
| Symptoms first seen in <i>young</i> leaves | <i>Leaf colouration forms a pattern</i> Sulphur: Small, pale, yellow-green leaves with lighter-coloured veins. Iron: Almost total loss of green between veins, leaving faint green 'skeleton' of veins on leaf. Zinc: Severe restriction of leaf size or stem length, or both (hence the terms 'little leaf' or 'rosetting'). Distinct interveinal creamy yellow patches on leaves in many species. Copper: Tip leaves cupped, narrow, distorted or scorched. Defoliation from tip. Chlorosis interveinal or irregular. |
| Symptoms first seen in either <i>old</i> or <i>young</i> leaves | <i>Leaf colouration forms a pattern</i> Manganese: Mottled diffuse pale-green to yellow patches between veins. No restriction of leaf size (unlike zinc). |
| Symptoms usually most prominent in other tissues; seen first in <i>youngest</i> tissues and <i>fruit</i> | Calcium: Breakdown of parts of fruit in some species. Collapse of flower stalk (flax, rapeseed) or leaf petiole (clover). Boron: Internal cracking or breakdown of root or stem tissues. Irregular shaped tissues, corkiness or surface cracking of stems. Irregular flower development or poor seed set. |

Chapter 6 covers all the nutrient disorder symptoms of individual nutrients in more detail.

8.6.4 General paddock symptoms

As soil fertility declines, the grasses and legumes (clovers and Lucerne) become patchy and stunted. Gradually, weeds start to fill the gaps.

Dandelion, rib weed, white daisy, etc. are collectively called 'flat' weeds. They are regularly associated with a reduction in soil fertility, usually potassium deficiency but also phosphorus and molybdenum. This is especially evident in regular silage and hay paddocks or where insufficient fertiliser has been applied in the past.

Onion weed is an indicator of soils that are deficient in phosphorus.

Sorrel and moss are usually associated with low-pH (strongly acidic) soils but can also be acting as a filler species like those mentioned above. That is, coming into a pasture to fill in the areas vacated by the more productive grasses and clovers.

A good indicator of whether a pasture may respond to extra fertiliser is to examine the areas around the dung and urine patches – see Figure 8.3. If there are healthy pasture plants within these areas, but such plants are sparse or less healthy in the areas between the patches, then this pasture is indicating that 'If you feed me (N, P, or K), then I'll grow.'



Soils becoming saline undergo a change of species as the level of salinity increases over time – See Chapter 7.5.5. In temperate regions, the initial changes are a decline in white clover and an increase in strawberry clover. Then buck's horn plantain, toad rush, and windmill grass begin to invade. Yellow buttons, sea barley grass and annual beard grass indicate advanced stages of salinity.

Damage may also be caused by insects, such as lucerne flea and red-legged earth mite, and by various viruses.

8.7 Fertiliser test strips

Fertiliser test strips are useful for determining what nutrients to apply but are less useful for determining the appropriate application rate.

Test strips may be used to check results of soil tests or as a cheap way to test soil fertility. They may be of limited use on high-fertility pastures where there are no obvious nutrient limitations to plant growth. To determine the application rate, it is often more useful to prepare a budget and evaluate the costs of nutrients (discussed in Chapters 14 and Chapter 15).

There are basically two ways to set up test strips:

- small hand-spread strips (20 m x 2 m), or
- longer more commercial tractor/machine-spread strips the length of a paddock.

Whichever system is used, stock need to be kept off the strips for a period of time (at least 4 to 8 weeks, depending on the season) to allow the effects of the fertilisers to be seen.

A 20-m x 2-m test strip is equal to 1/250th of a hectare. Therefore, to apply the equivalent of 250 kg/ha, you need to weigh out 1 kg of the product to be applied. To ensure an even spread over the hand-spread strips, split the required amount of fertiliser in half and go over the plots twice. It can be helpful to apply the selected rate/ha to half of the plots and double the selected rate to the remaining plots in order to establish where the response finishes.

Small hand-spread or 4-wheeler spread strips are easier and less costly to set up and, provided they are around 20 m in length, will cover sufficient good and bad areas of pasture to allow a comparison to be made. Several sets of test strips may be needed around the farm to help in determining the final fertiliser strategy.

8.7.1 Site selection

- Test strips are best sited towards the centre of a paddock or at least 3 metres from a fence line. Run the strips at right angles to the fence line.
- Choose an area in the paddock that is typical of the diagnosed problem or where the change of fertiliser practise is to be and, if possible, a pasture with some clover or other legume present.
- Avoid fence lines, trees, gates, stock troughs, haystacks, old firebreaks, corners of paddocks, stock camps or poorly drained areas.
- Test strips will be of more use if they are put on an area that has not been top-dressed that year. Alternatively, top-dress the strips after the paddock has been top dressed and evaluate the potential for additional response above what is to be gained from the paddock topdressing.



- Run strips up and down a slope, rather than across it. Surface runoff immediately after topdressing can shift fertiliser from one strip to another.

8.7.2 Assessment of the strips

The control (no fertiliser) strip is the most important. Without this, it is impossible to compare treatments to determine whether the fertiliser has had any effect or not.

When comparing the strips consider:

- Pasture height and density.
- Size and colour of clover leaves.
- Botanical composition.
- Evenness of pasture.

The strips should be regularly checked throughout the year and observations recorded, such as regrowth after grazing. The final assessment of the site will be made before the grass seed-heads emerge. If the paddock is going to be grazed, then the test strips will need to be fenced off. To see the effects of the fertiliser, it is important to keep stock off because they will preferentially eat the good strips where there is a response, giving the observer the incorrect answer for responses on the site.

Sometimes it may be preferable to graze the strips off and allow them to grow again to evaluate the regrowth, when the best response is visible.

If nitrogen is applied to any strip, then evaluate it regularly from 2 weeks after topdressing.

The strips can be inspected in the following years to observe carryover effects on pasture production and changes to botanical composition. In longer term trials the accurate marking of strips will be essential. The benefits of some fertilisers may not appear until the clover or legume content of the pasture has increased, so sometimes responses are not evident until the second year. If the strips are to be observed in the second year, make sure that the test site is grazed down similarly to the rest of the paddock in between seasons. Remove the fences to allow better grazing and to reduce the likelihood of stock camping on the plots.

8.7.3 Interpreting the results

If there are clear differences in pasture growth between strips, you will be able to assess which nutrient or nutrients you require to improve pasture production.

A 20% or greater difference in growth rate can be visually detected, whereas a pasture meter can detect about a 10% difference.

If there is poor growth on all strips, it may be due to other factors, such as poor soil structure, soil acidity, plant diseases, pests, waterlogging, salinity or lack of productive pasture species (see [Exercise 1](#)). Usually these factors have all become evident before the test strips were even established.

In areas of reasonable soil fertility, fertiliser test strips may indicate that no fertiliser is needed or be used to evaluate a range of selected fertilisers. In fact, even though a test strip has shown nil response, paddocks may actually respond to fertiliser application. An experiment at DPI Ellinbank compared paddock application versus strip application of superphosphate. Although the test strips indicated that fertiliser was not required, the whole-paddock application did result in an increase in



pasture production and animal gain! The reasons for response in the paddock as against this lack of visible response in the test strip paddocks are probably due to:

- The greater availability of recycled P.
- An interaction between recycled N and K with higher soil P levels.
- Selective grazing of test strips, thereby retarding regrowth due to lower pasture height.

8.8 Summary

- A pasture's nutrient requirements should be assessed using a number of methods, including soil and plant tissue testing, visual paddock indicators, and soil test strips.
- Soil and plant tissue sampling guidelines should be followed carefully to achieve the most accurate results from your tests.
- Plant tissue testing should be used to determine the need for trace elements.
- Visual assessment of pasture condition can be used in conjunction with soil testing to help determine fertiliser needs.
- Fertiliser test strips are useful for determining which fertilisers to apply and can also be of value for determining the appropriate application rate if application rates are accurately calibrated and varied e.g. 1x and 2x application rate.

8.9 References

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Chapter 9

Interpreting Soil and Tissue Tests

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9 Interpreting soil and tissue tests

9.1 Introduction

The interpretation of results from soil and plant tissue tests help farmers and service providers to make more informed, cost-effective fertiliser decisions. Many field experiments have been used to verify soil and plant testing laboratory results.

[Soil tests](#) are a valuable tool for identifying the macronutrient status of paddocks on the farm. They also provide information for soil amendments to address such issues as sodicity and acidity. Although providing very important information, soil and plant tissue tests are only one piece of the jigsaw to determine the final fertiliser recommendations.

[Plant tissue tests](#) are the preferred method for diagnosing the level of micronutrient (trace element) toxicities, deficiencies and nutrient imbalances for plants. Occasionally plants can exhibit a nutrient deficiency which is not detected by a soil analysis. Research has also shown that using soil tests to indicate trace-element deficiencies can be very inaccurate; especially on acid soils.

Soil biological properties are also important to plant growth. A description of the biological properties of soils and how to measure these is discussed in Chapter 5.

Learning outcomes

This chapter will provide information about soil and plant tissue testing, allowing the reader to accurately interpret soil tests and to use the results to assist in making fertiliser decisions.

9.2 Interpreting soil tests

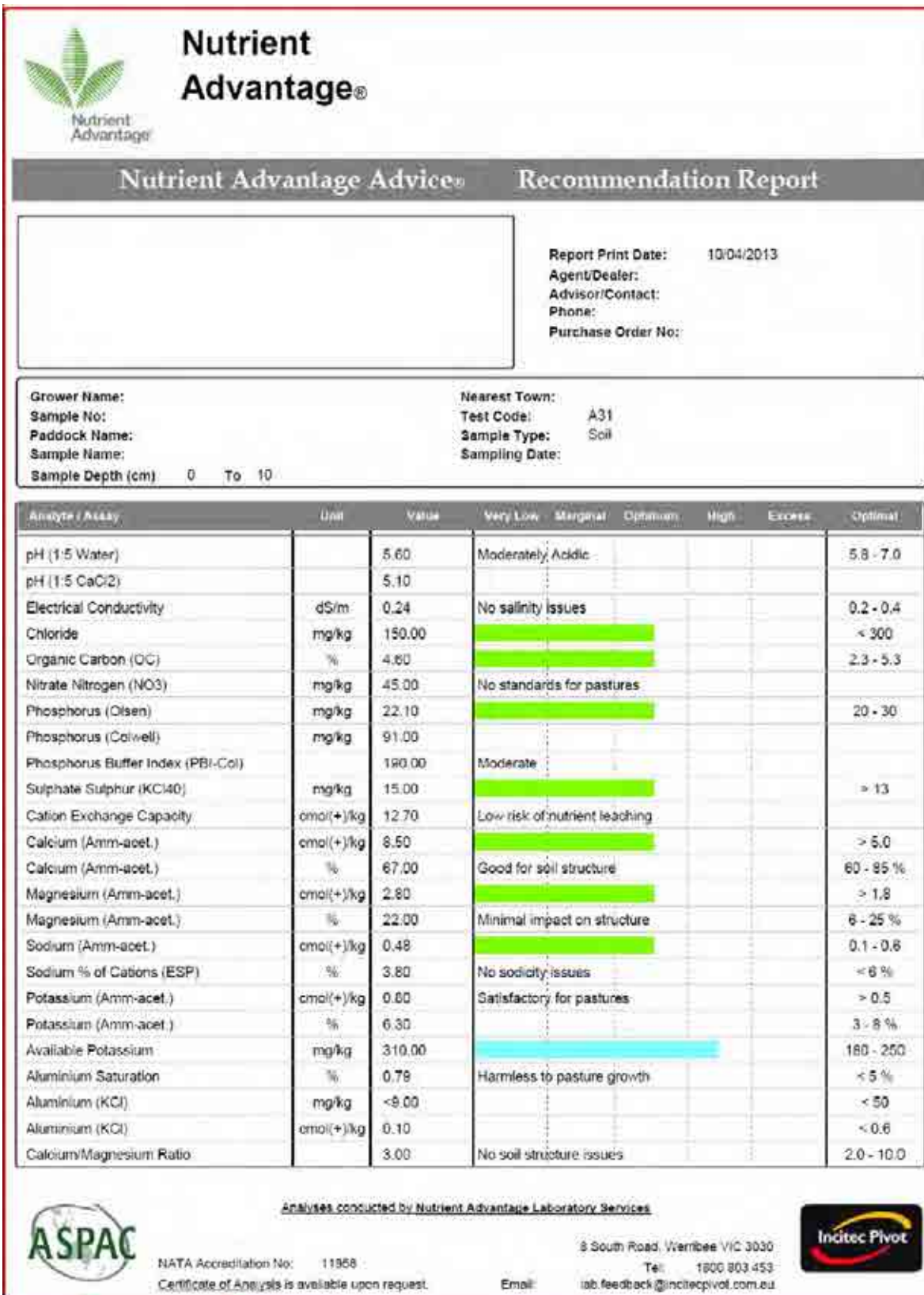
9.2.1 Soil chemical analyses

Many field experiments have been carried out in Australia to calibrate the results of laboratory soil testing with yield responses for specific crops and pastures grown on similar soil types.

A standard soil test report provides information on the following:

- [Soil texture](#)
- [Organic carbon](#)
- [Soil pH](#)
- [Available phosphorus \(P\)](#)
- [Phosphorus buffering index \(PBI\)](#)
- [Available potassium \(K\)](#)
- [Available sulphur \(S\)](#)
- [Nitrogen \(N\)](#)
- [Cation exchange capacity \(CEC\)](#)
- [Exchangeable cations \(Ca, Mg, K, Na and Al\)](#)
- [Calcium/Magnesium Ratio](#)
- [Sodium level \(Na% or Exchangeable Sodium Percent - ESP\)](#)
- [Aluminium level \(Al% or Al_{ex}\)](#)
- [Soil salinity \(Electrical Conductivity - EC\)](#)
- [Comments on the test results](#)
- [Recommendations for fertiliser application \(if requested\)](#)

Refer to the example soil test, recommendations, and comments in Figures 9.1a to 9.1c.





Nutrient Advantage®

Nutrient Advantage Advice - Recommendation Report

| | | | |
|--------------------------|---------|-----------------------|------|
| Grower Name: | | Nearest Town: | |
| Sample No: | | Test Code: | A31 |
| Paddock Name: | | Sample Type: | Soil |
| Sample Name: | | Sampling Date: | |
| Sample Depth (cm) | 0 To 10 | | |

| | | | |
|---------------------------------------|-------------|---|-------|
| Sample Details: | | | |
| Enterprise (Crop): | DAIRY DRYLD | Activity (enterprise): | Dairy |
| Pasture: | Existing | Lucerne: | |
| Proposed Sowing Method: | | Time of Sowing: | |
| Dairy Stocking Rate (cows/ha): | 1.70 | Beef/sheep Stocking Rate (dse/ha): | |
| Other Stock Type: | | Other Stocking Rate (dse/ha): | |
| Cuts per year: | | Yield per Cut (t/ha): | |
| Seed Production Type: | | Fodder Crop Type: | |
| Sample Depth (cm) From: | 0 | To: | 10 |

Recommendations

| Product Recommendation | Application Rate (kg/ha) (Unless Stated) | Timing | Application Method | N kg/ha | P kg/ha | K kg/ha | S kg/ha |
|-------------------------------|--|---|---|-------------|-------------|------------|-------------|
| Pasture Extra | 200.00 | Autumn before the break | Spread but not within 6 days of forecast heavy rain | 0.0 | 25.0 | 0.0 | 24.7 |
| GREEN UREA 14 | 100.00 | Early Winter dependant on feed availability | Spread when soil moisture adequate | 45.0 | 0.0 | 0.0 | 0.0 |
| GrassBoosta | 125.00 | Late Winter dependant on feed availability | Spread when soil moisture adequate | 37.3 | 0.0 | 0.0 | 18.8 |
| Total Nutrient Applied | | | | 83.3 | 25.0 | 0.0 | 43.5 |

This Recommendation has been done by:


| Other Elements in recommendation | Ca kg/ha | Mg kg/ha | Cu kg/ha | Zn kg/ha | Mo gm/ha | Co gm/ha | B kg/ha | Fe kg/ha | Mn kg/ha | Si kg/ha |
|----------------------------------|-------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| Pasture Extra | 31.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| GREEN UREA 14 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| GrassBoosta | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total Nutrient Applied | 31.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| | | | | | |
|----------------|----------------|----------------|----------------|-----------------|--------------|
| Legend: | N : Nitrogen | P : Phosphorus | K : Potassium | S : Sulphur | Ca : Calcium |
| | Mg : Magnesium | Cu : Copper | Zn : Zinc | Mo : Molybdenum | Co : Cobalt |
| | B : Boron | Fe : Iron | Mn : Manganese | Si : Silicon | |



Figure 9.1b Recommendations based on example soil test report





Nutrient Advantage®

Nutrient Advantage Advice Recommendation Report

| | |
|--|--------------------------|
| Grower Name: | Nearest Town: |
| Sample No: | Test Code: A31 |
| Paddock Name: | Sample Type: Soil |
| Sample Name: | Sampling Date: |
| Sample Depth (cm) 0 To 10 | |

Comments

Best practice fertiliser application to pastures can minimise nutrient loss and reduce any impact on the environment. Current best practices for phosphorus fertiliser application are:

- Avoid applying fertiliser when ground cover is less than 70%, or land is overgrazed or affected by drought/wire.
- Prevent run-off (e.g. using waterways and water storage) during application.
- Do not apply fertiliser if heavy rain is forecast within four days.
- Avoid applying fertiliser to waterlogged soils or soils likely to flood soon after application.
- Create fertiliser storage areas away from potential run-off areas.

Guideline Consideration for Nitrogen Use on Pastures

1. Grazing Management (mature pasture) is critical in maintaining a good grass density - graze to a minimum of 1200kgDM/ha (or 5cm in height) - over grazing will cause ryegrass decline, fat grazing will cause shading, tiller death, lower feed quality and density decline. The optimal time for nitrogen application is immediately following a grazing. Ryegrass should be grazed at 2.5-3 leaf stage (spring graze at 2.5 leaf stage) which corresponds with optimal white clover grazing. Phalaris grazing is set at 4-5 leaf stage. Following a nitrogen application stock should be excluded from the paddock for a 3 week period to avoid nitrate poisoning.
2. Pasture Composition plays a part in determining nitrogen responses - generally pastures with a high composition of improved grasses or ryegrass and low to moderate composition of clover (up to 30%) will provide the better pasture response, as will pastures with minimal weeds, disease and insect pest activity.
3. Paddock fertility is very important in supporting a healthy pasture - ensure major nutrients, trace elements and soil ameliorants are addressed to improve dry matter responses to nitrogen applications.
4. Moisture is probably the major limiting factor to nitrogen responses - ensure the soil has adequate soil moisture to sustain production and following a broadcast nitrogen application at least 5mm (light soil) or 10mm (heavy soil) rainfall event or irrigation follows within 2 days of application. Green Urea can be considered if volatilisation is considered to be an issue.
5. Application Rates should be in a range of 30-50kgN/ha.
6. Time of year (season) causes variation in responses to nitrogen. Responses to perennial ryegrass can be as low as 5 kgDM/ha/kgN in the winter and up to 25 kgDM/ha/kgN in the spring. Italian type ryegrasses tend to be more responsive to nitrogen than perennials. Forward thinking in predicting future gaps will allow nitrogen applications to be used to maximum efficiency i.e. Aug 15 calving herd should have nitrogen applied on 1st July assuming leaf emergence every 15 days.

Don't apply nitrogen if soil temperatures are below 5°C as ryegrass has stopped growing

7. Cost of Dry Matter is the key consideration in determining whether nitrogen should be applied or not. Estimates on expected dry matter responses and utilisation coupled with the cost of nitrogen will provide a dry matter cost, this can then be compared to other feed alternative to see the value (or not) in using nitrogen. These costs will vary during the year with winter feed the most expensive.
8. Environment can be negatively impacted by poor nitrogen management. Don't apply close to waterways, or to paddocks that are waterlogged and grasses are not growing.
9. Utilisation - If the additional pasture Dry Matter grown as a result of applying Nitrogen can not be utilised, do not apply Nitrogen.

Follow the points listed above for best practice in nitrogen management

The Phosphorus Buffering Index (PBI) measures the soils capacity to hold phosphorus (P), and how tightly the phosphorus is held by the soil. PBI values can range from a very low value of less than 35 to an extremely high value of greater than 840. The PBI result determined for your soil will impact on the availability of phosphorus. It may also indicate whether your soil is prone to the leaching of phosphorus or the phosphorus being tied up in forms unavailable to the plant. The PBI values will also influence how much phosphorus you will need to apply to build up soil reserves of P.

While potassium levels are adequate for grazing, consider including with nitrogen if hay or silage is to be cut in the spring.

Molybdenum (Mo): Not Treated - Mo is important in the fixation of nitrogen by rhizobium bacteria. Where soil pH(w) < 6.0, Mo may be applied to the soil at 50 to 60 g/ha Mo once every 5 - 8 years. Molybdenum (Mo) and copper (Cu) should be applied with top-dressing fertiliser. Use plant tissue test is best used to determine the need for the Cu & Mo.

Lime could be considered for soils with this pH range, however applying lime would be best left until pastures are renovated so it can be incorporated with cultivation. Avoid the application of lime and molybdenum on the same paddock in the same year. Lime, by increasing the soil pH, can increase the availability of molybdenum, which may pose a risk to stock health.

Discuss the results of these tests with your Area Sales Manager or agent. Where NPK blends are being used to boost winter or spring production, adjustment to these recommendations will be necessary.

Disclaimer: Laboratory analysis and fertiliser recommendations are made in good faith, based on the best technical information available as at the date of this report. Incitec Pivot Limited, its officers, employees, consultants, Agents and Dealers do not accept any liability whatsoever arising from or in connection with the analytical results, interpretations and recommendations provided, and the client takes the analytical results, interpretations and recommendations on these terms. In respect of liability which cannot be excluded by law, Incitec Pivot's liability is restricted to the re-supply of the laboratory analysis or the cost of having the analysis re-supplied.




Figure 9.1c Comments based on example soil test report



Other soil analyses which are available from a range of laboratories are as follows:

- [Soil physical properties](#) (including colour, texture, slaking and dispersion)
- Boron (HWS) e.g. mg/kg
- [Buffer pH](#)
- Carbonate
- Chloride (Cl)
- Exchangeable cations with soluble salt wash (Ca, K, Mg, Na)
- Gypsum
- Total Soil Nitrogen (includes all sources of soil N, including organic matter)
- Total Phosphorus (includes all sources of soil P, including organic matter)
- [Potassium \(K\) Skene](#), Nitric K
- Silicon (BSES, CaCl₂)
- [Sulphur \(S\) \(MCP, CPC\)](#)
- Total Soluble Salts
- Trace elements DTPA (Copper (Cu), Iron (Fe), Manganese (Mn), Zinc (Zn), Zn (HCl))

Soil test results for nutrients are usually expressed as mg/kg (milligrams per kilogram). Cation Exchange Capacity (CEC) is now reported as cmol (+)/kg (centimoles per kilogram) and also reported on a percentage (%) basis.

9.2.2 Soil Physical Properties

Standard soil physical properties measured include:

- [Soil colour](#)
- [Soil texture](#)

Soil colour and texture are taken into account when interpreting some of the other soil chemical analyses and preparing fertiliser recommendations. Other soil physical tests are available to gauge soil structural stability and to diagnose specific problems related to soil management. They are also used to assess a soil's ability to handle a management activity such as mole drainage, cultivation, compaction and irrigation. These tests include:

- [Slaking](#)
- [Dispersion](#)

9.2.2.1 Soil Colour

Soil colour has little direct influence on its chemical, physical or biological attributes but, when considered with other observations, can be very useful. Often soils of darker colour are higher in organic matter than lighter coloured soils. Red colour can be related to *un-hydrated* iron oxides present in well drained soils, whereas yellow or mottled coloured soils may be related to *hydrated* iron oxides which may occur where soils are saturated for long periods and/or poorly drained. The Munsell Soil Colour Charts are internationally accepted as being the standard guide to discern soil colour classification - See [Victorian Resources Online](#).

9.2.2.2 Soil texture description

The texture of a soil is an indication of soil type and its properties, and is always taken into account when interpreting the other results and preparing fertiliser recommendations - See [Chapter 4](#) for more on soil properties. Soil texture is measured separately for Mineral Soils and for Organic Soils (e.g. Peat).

Soil texture shows how we should apply mobile nutrients, such as K, N and to a lesser extent, S. For example, soils with a light texture and low CEC are more susceptible to leaching and should be managed by applying smaller quantities of nutrients more frequently.



Soil texture can be measured in two ways:

- a) **Field method:** Where a small handful of moistened soil is squeezed between the thumb and forefinger to produce a ribbon. The length of the ribbon before breaking and the “feel” of the soil (sandy, silky, etc.) provide an indication of the texture - See [Chapter 4.2.1](#). Table 9.1 describes aspects of soils which can influence soil texture interpretation. To improve consistency of results this test is usually done by experienced laboratory technicians, however the method remains subjective and the results may differ slightly between assessors. Slight variations are of no real concern to the final fertiliser recommendations.
- b) **Mechanical method:** A mechanical sieving process is used to separate and quantify the percentages of sand, silt and clay in a soil. This method is more time consuming and expensive than the field method, however it is used where greater accuracy is required (e.g. research) - See [Chapter 4.2.1](#) for more information on soil texture assessment and classification.

Table 9.1 Aspects of soils which can influence soil texture interpretation

| PARAMETER | INFLUENCE ON SOIL TEXTURE INTERPRETATION |
|----------------|---|
| Clay Type | Clay mineralogy affects tractability. Montmorillonite is very fine and encourages ribboning when using hands to form ribbons. Kaolinite is very coarse and will inhibit ribboning |
| Organic matter | Cohesion of sandy textures and greasiness of clays |
| Oxides | Cementation (Al & Fe) masks fine textures |
| Carbonates | Cohesion in sands and loams, but inhibits ribboning in clays |

9.2.2.3 Aggregate Slaking Test

Slaking refers to the rapid physical breakdown of the larger soil aggregates (2 – 5 mm diameter) into smaller definable soil particles (many <0.25 mm) in rainfall or distilled water (Emerson, 1967, 1991 and McGuinness, 1991). In an irrigated system, it is instructive to use the irrigation water for the Emerson dispersion test in case it has an effect on aggregate stability. See the [slaking animation](#) on the Victorian Resources Online website.

For a laboratory physical soil test, soil is air dried overnight then several aggregates, if not pulverised during transport, are placed in distilled water. The degree of slaking after two hours is recorded and categorised as either; Considerable, Partial or Water Stable.

The interpretation of structural stability depends on the degree of slaking assessed and organic matter content. In Victorian and South Australian soils, a qualitative rating system is used for the interpretation of soil slaking potential (See [Table 9.2](#)).

**Table 9.2** Organic carbon and soil aggregate stability

| Organic carbon rating | Low | Normal | High |
|--------------------------|-------------------------|-------------------------|-------------------------|
| Soil Aggregate Stability | Considerable slaking | Partial slaking | Water stable |
| Management Action | Increase organic matter | Maintain organic matter | Maintain organic matter |

Source: Adapted from Emerson 1967, and Lovejoy and Pyle, (1973).

9.2.2.4 Clay dispersion test

Soil dispersion is a further breakdown of fine aggregates and clay associations. Dispersion is a measure of the potential of natural or remoulded soil aggregates to break down, followed by the small particles spreading out in distilled water (Cass et al 1996a).

The potential for dispersion of both natural and remoulded aggregates is assessed in most labs. The '*natural* soil aggregate dispersion test' provides an estimate of the current potential of soils in their present field condition. The '*remoulded* soil aggregate dispersion test' provides an assessment of the dispersion potential of soils if they are incorrectly managed, for example: soil compaction, continuous cropping, mole draining with unsuitable subsoils – See Chapter 7.2.2.

Natural aggregates of soil are air dried overnight before 3 to 5 aggregates are placed into distilled water. Other soil is dried and ground then remoulded by hand into balls of 4 – 5 mm and placed in distilled water.

The degree of dispersion/cloudiness is recorded after 2 hours and 20 hours for both natural and remoulded soil aggregates – see Figure 9.2. Also at the same 2 hour examination time, the degree of slaking, if it occurs, is also evaluated on the natural aggregates as above.



Figure 9.2 The photographs above show the results of soils placed in dishes of distilled water after a period of time. Figure 9.2a shows small clods of soil which have slaked only, Figure 9.2b shows dispersion only, and Figure 9.2c shows both slaking and dispersion (Retrieved: http://vro.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil_mgmt_slaking. Images by Stuart Boucher).

The degree of soil dispersion is evaluated and rated as shown in [Table 9.3](#). These ratings are added to provide the Dispersion Index which is used to aid in determining the required gypsum application rates.



Table 9.3 Dispersion Index*

| RATING | DISPERSION TEST RATINGS | DISPERSION INDEX | | | |
|----------|---|----------------------------|-------|--------------------------|-------|
| | | Dry natural soil aggregate | | Remoulded soil aggregate | |
| | | 2 hr | 20 hr | 2 hr | 20 hr |
| Nil | No dispersion evident | 0 | 0 | 0 | 0 |
| Slight | 1 out of 3 (or 5) with muddy cloud around the aggregate. | 1 | 1 | 1 | 1 |
| Moderate | Small cloud around each aggregate, with a connection between each aggregate around the side of the vial | 2 | 2 | 2 | 2 |
| Strong | Observable soil aggregates, but most of the base of the vial is covered by a cloud | 3 | 3 | 3 | 3 |
| Complete | Aggregate not visible, total or near total suspension | 4 | 4 | 4 | 4 |

* Soil aggregate dispersion ratings using the Index system developed by Loveday and Pyle (1973)

The 2 and 20 hour dispersion ratings for natural soil aggregates are added to the 2 and 20 hour dispersion ratings for the remoulded soil aggregates to provide the dispersion index. This is used to determine the gypsum requirements of dispersive soils (See Table 9.4).

Table 9.4 Interpretation of dispersion index

| Clay dispersion index | 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 | | | | | | | | | | | | | | | | |
|---------------------------------------|--|--|--|--|--------------------------|--|--|--|--|-------------------------------|--|------------------------|--|------------------------|--|--|--|
| | Established pasture ¹ | No action required – Cultivate with care | | | | | | | | Test strip gypsum at 2.5 t/ha | | | | Apply gypsum at 5 t/ha | | | |
| Cropping and New pasture ² | No action required | | | | Apply gypsum at 2.5 t/ha | | | | | | | Apply gypsum at 5 t/ha | | | | | |

¹Gypsum rates based on surface application with no mechanical incorporation

²Gypsum rates based on mechanical incorporation to 10 cm depth

Source: Adapted from the Incitec Soil Test Interpretation Manual, 1999, p112).

9.2.3 Soil Organic Carbon

Soil organic carbon (SOC) content is used to estimate of the soil organic matter content. Low organic carbon levels in a soil indicates that the soil is low in organic matter and so offers less sites for adsorption of nutrients, and less sorption back into the soil solution than a soil with a high organic carbon. Organic carbon levels will vary according to: the inherent soil type, climate, pasture or crop type; as well as farm management including stocking rate, and grazing management.

The Total Soil Organic Carbon test measures all components of C in the Soil. These can be measured also as Labile and Sequestered C which includes the SOC fractions shown in [Table 9.5](#).

**Table 9.5** Soil organic carbon tests and components

| SOIL ORGANIC CARBON TEST | CARBON COMPONENTS |
|--------------------------|--|
| Total SOC | Crop or pasture residues + Particulate C + Humus + Inert C (or Recalcitrant C or Resistant OM) |
| Labile C | Crop/pasture residue + Particulate C |
| Sequestered C | Humus + Inert C |

The **Walkley and Black (1947) method** of determining SOC does not measure carbon in carbonate or bicarbonate which are not part of the soil organic matter (SOM) but are present in the soil solution or as deposits of carbonate or bicarbonates.

The SOM is difficult to measure directly because of the variations in the contents of its component elements (C, H, O, N, P and S). Therefore, SOM is estimated by multiplying the total SOC (as determined by the Walkley and Black method) by a conversion factor. Conversion factors currently used range from 1.72 to 2.0, but a value of 1.72 is typically used. Since no single conversion factor is appropriate for all soils, it is better to determine and report results in terms of SOC and not SOM values (Peeverill et al.1999).

$$\% \text{ Soil Organic Matter (SOM)} = \% \text{ Soil Organic Carbon (SOC)} \times \text{Conversion factor}$$

Since much attention has focussed on greenhouse gases and carbon sequestration many laboratories have begun to analyse the different forms of carbon in soil organic matter using different analytical methods. These forms include:

- Organic carbon
- Active Carbon
- Labile Carbon
- Recalcitrant Carbon

Guidelines for low, normal and high organic matter percentages (calculated from organic carbon percentages) are listed in Table 9.6. These percentages are based on data analysed using the Walkley and Black (1947) method.

Table 9.6 Organic matter percentage over a range of conditions

| Organic Matter Levels | Crops Low Rainfall (less than 300 mm annually) | Pastures Low Rainfall (less than 400 mm annually) | Crops High Rainfall (400 to 600 mm annually) | Pastures High Rainfall (greater than 400 mm annually) |
|-----------------------|---|--|---|--|
| Low | Below 1.5 | Below 3 | 2.5 | 5 |
| 'Normal' | 1.5 to 2.5 | 3 to 4.5 | 2.5 to 5 | 5 to 10 |
| High | Above 2.5 | Above 4.5 | Above 5 | Above 10 |

Source: Department of Primary Industries Victoria - State Chemistry Laboratory, (1995).

There is currently a National Soil Carbon Research Program whereby sampling and analytical methods are being developed to analyse the different pools of organic carbon. These methods are not commercially available at this time (2013). Guidelines for low, normal, and high organic carbon percentages (using modified Walkley & Black, 1947) are listed in Table 9.7.

**Table 9.7** Victorian organic carbon interpretation guidelines

| Organic Carbon Rating | Crops Low Rainfall less than 475 mm per growing season) | Crops High Rainfall > 475 mm per growing season | Pastures Low Rainfall less than 475 mm | Pastures High Rainfall greater than 475 mm |
|------------------------------|---|---|--|--|
| Low | Below 0.8 | Below 1.3 | Below 1.6 | 2.3 |
| 'Normal' | 0.8 → 1.3 | 1.3 → 2.6 | 1.6 → 2.4 | 2.3 → 5.3 |
| High | Above 1.3 | Above 2.6 | Above 2.4 | Above 5.3 |

Source: Department of Primary Industries Victoria - State Chemistry Laboratory, (1995).

The relationship between soil organic matter, organic carbon and soil physical properties is described in Table 9.8.

Table 9.8 The relationship of soil organic matter and organic carbon to soil physical properties

| Organic matter % (g/100 g) | Organic carbon % (g/100 g) | Rating | Interpretation |
|--------------------------------------|--------------------------------------|---------------|---|
| <0.70 | <0.40 | Extremely low | Subsoils or severely eroded/degraded surface soils |
| 0.70 – 1.00 | 0.40 – 0.60 | Very low | Very poor structural condition, very low structural stability |
| 1.00 – 1.70 | 0.60 – 1.00 | Low | Poor to moderate structural condition, low to moderate structural stability |
| 1.70 – 3.00 | 1.00 – 1.80 | Moderate | Average structural condition, Average structural stability |
| 3.00 – 5.15 | 1.80 – 3.00 | High | Good structural condition, high structural stability |
| >5.15 | >3.00 | Very high | Good structural condition, high structural stability and soils probably water repellent |

Source: Adapted from Hazelton and Murphy, (2007).

Refer to Chapter 5 for further information about organic matter and organic carbon.

9.2.4 Soil pH

Soil acidity and alkalinity are indicated by soil pH tests. Two laboratory methods are currently used to measure pH: the water method and the calcium chloride (CaCl₂) method. Both tests use a 1:5 ratio of soil:water or soil:CaCl₂. The results are usually reported in one of the following formats:

- If the water method is used, the results are reported as pH_w, pH (water), pH (H₂O) or pH 1:5 water.
- If the calcium chloride method is used, the results are reported as pH_{Ca}, pH (CaCl₂) or pH 1:5 CaCl₂.

The water method has been the test most commonly used in Australia for over 50 years and more readily reflects current soil conditions for plants than does the calcium chloride method. However, the water method is more subject to seasonal variations. The pH (water) value may vary by as much as 0.6 units over the year.

The calcium chloride test is more useful for long-term monitoring of pH and is the one most agronomists tend to use when making management decisions regarding pH and for lime recommendations.



In the pH (CaCl₂) range 4 – 5, the mean difference between pH (CaCl₂) and pH (Water) is linearly and highly correlated at 0.84 units, the former being lower than the pH (water) value. However, the pH (CaCl₂) value can range from 0.2 to 1.0 unit lower than the pH (water) value.

The pH readings from the two testing methods will be much closer (0.2 – 0.3) if the soil contains high levels of salt. This is typical of soils that have a salinity problem or may be seen after a recent application of a fertiliser high in salt, such as muriate of potash. Most of the major soil testing laboratories will present pH results for both testing methods. It is important to be aware of which pH testing method has been used when interpreting a soil test and when discussing management options with an adviser or agronomist.

As soils become more acidic, it is common to see a rise in the plant availability of both aluminium (Al) and manganese (Mn), which can both be toxic to pasture plants and crops. Aluminium toxicity restricts root growth in sensitive plant species. Refer to Chapter 7.6 for further information about the availability of soil nutrients at different pH levels.

Soil acidity is corrected by applying agricultural lime or dolomite. Agricultural lime (calcium carbonate) is usually applied to dairy pastures to increase the pH and neutralise the effects of soil acidity. A clay soil will require more lime to raise the pH than a sandy soil, and the soil property that determines how much lime is required to raise soil pH by one unit is called 'pH buffer capacity'. Commercial laboratories have a '**buffer pH**' soil test that allows lime recommendations to be made for target soil pH of 5.5, 6.0 or 6.5. A good-quality lime (high neutralising value, fine particle size, low water content) will have the best effect on raising pH.

Different species have different pH tolerance levels for optimum growth (See [Table 9.9](#)) but little information can stipulate how much production may be lost in white clover grown at pH 5.6 versus 5.8. That is, where is the economic optimum compared to optimum growth potential? These are the ranges for optimum growth but many species will grow reasonably well at lower pH levels, e.g. Kikuyu at pH (water) 4.5. See Chapter 7.6.8 for details on liming and how to correct soil acidity.

**Table 9.9** The optimum pH range of pastures and crops

| Pasture Species | pH (CaCl ₂) | pH (water) |
|----------------------------|-------------------------------|------------|
| Annual ryegrass | 5.5 | |
| Balansa, Berseen, Persians | 5.2 – 7.5 ¹ | |
| Barleys & Wheat* | 4.3 to 5.5 – 7.5 ¹ | 5.5 to 7.0 |
| Buffel | 5.2 – 7.5 ¹ | |
| Cereal Rye | 4.3 – 7.5 ¹ | |
| Cocksfoot | 4.3 to 6.8 ¹ | 5.0 to 7.5 |
| Consul Love Grass | 3.8 – 7.5 | |
| Cowpeas* | | 5.5 to 7.0 |
| Fescue | 4.3 to 6.4 | 5.0 to 7.0 |
| Kale* | | 5.3 to 7.0 |
| Kikuyu | 4.1 – 7.5 ¹ | 5.5 to 8.0 |
| Lucerne | 4.8 ¹ 5.2 to 7.5 | 5.8 to 8.0 |
| Lupins (Broad leaf) | 4.3 – 7.5 ¹ | |
| Lupins (Narrow leaf) | 4.1 – 7.5 ¹ | |
| Maize* | 4.5 – 7.5 ¹ | 5.5 to 7.0 |
| Medic | 5.3 to 8.0 | 6.0 to 8.5 |
| Millet | 4.5 – 7.5 ¹ | |
| Millet | 4.5 – 7.5 ¹ | |
| Oats | 3.9 – 7.5 ¹ | |
| Peas* | | 6.0 to 7.0 |
| Perennial ryegrass | 4.3 to 6.0 | 5.0 to 6.5 |
| Phalaris | 4.9 ¹ 5.2 to 7.3 | 6.0 to 8.0 |
| Red Clover | 4.4 – 7.5 | |
| Red Clover* | | 6.0 to 7.0 |
| Seradella | 4.2 – 7.5 ¹ | |
| Sorghum, Sudan Grass* USA | 4.4 – 7.5 ¹ | 5.5 to 7.0 |
| Sub clover | 4.8 to 6. | 5.5 to 7.0 |
| Tall Wheat Grass | 4.8 – 7.5 ¹ | |
| Triticale | 4.1 – 7.5 ¹ | |
| Vetch* | | 5.5 to 6.8 |
| White clover | 5.0 to 6.0 | 5.8 to 6.5 |

Source: Adapted from ¹[New South Wales Acid Soil Action Program, \(2000\)](#), *Havlin *et al*, (1999).

9.2.5 Available Phosphorus

Available phosphorus (P) is the amount of phosphorus in milligrams per kilogram (mg/kg), or parts per million (ppm) extracted from the soil. Various chemical test methods are used to determine the amount of phosphorus from the three sources of P in the soil which include; the soil solution, labile phosphorus, and non-labile phosphorus.

Phosphorus tests include:

- [Olsen P](#)
- [Colwell P](#)
- [Bray 1 P](#)
- [BSES P](#)



It is important to use a soil test suitable for your region and situation. Soil testing methods are only meaningful where there has been research conducted to establish yield response curves for that specific soil test method, soil type and plant species (See Figure 15.1 for an example of a yield response curve). For this reason soil test methods tend to be specific to regions where robust yield response curves have been developed for particular soil tests. For example, Queensland dairy farmers would typically take soil samples from 0 – 10 cm and use a Colwell P test, while Tasmanian dairy farmers would take samples from 0 - 7.5cm and use an Olsen P test - See Chapter 8.3 for more information on soil sampling guidelines.

9.2.5.1 Which test to use for available phosphorus

The Olsen P (Olsen *et al*, 1954) and the Colwell P (Colwell *et al*, 1963) tests measure plant-available P, and are used to indicate whether or not additional phosphorus is required for plant growth. The Olsen P and the Colwell P tests have been extensively calibrated against pasture production over a range of soils and climates in Australia and New Zealand. Due to past research, pasture yield response curves for the Olsen P test method are well established in Victoria and Tasmania whereas pasture yield responses to the Colwell P test method are better established in all other Australian States.

Olsen P test

Olsen's method (1954) uses an extracting solution, sodium bicarbonate (NaHCO_3), in the ratio of 1:20 soil:solution and the sample is then turned end for end for 30 minutes (Rayment and Higginson, 1992). This provides a measure of the more readily plant-available P from the soil solution and mineralised P from organic matter.

Soil test P values derived using the Olsen procedure are not affected by the capacity of the soil to sorb P and therefore the [Phosphorus Buffering Index](#) (PBI) is not required to interpret the soil test results. However, the PBI is used to determine the amount of capital P fertiliser required to raise the soil Olsen P or Colwell P by one unit (1 mg/kg) – See Chapter 15.8.1.

The test has been extensively calibrated against pasture production (including the 'Phosphorus for Dairy Farms Project' and other trials) over a range of soils and climates in Australia and New Zealand. Olsen P has been the most commonly used P test in Victoria, Tasmania and NZ.

Colwell P Test

The Colwell P test (1963) is a modification of the Olsen procedure and also uses sodium bicarbonate (NaHCO_3) as an extractant but in a ratio of soil:extractant solution of 1:100, and the sample is turned end for end for 16 hours (Rayment and Higginson, 1992). Colwell P not only gives a measure of the readily available P, but also some of the less available labile or adsorbed P in the sample, hence producing higher values than Olsen P tests. Soil test values obtained using the Colwell P procedure are strongly affected by the capacity of soil to sorb P. The capacity of different soil types to sorb P is ranked using the PBI.

**When Colwell P is used, the PBI needs to be measured also
for correct interpretation of soil test results**

In the past Colwell P has been estimated by converting the Olsen P value to Colwell P, or vice versa, by use of a conversion ratio. However, there was far too much variation (1:1 up to 5:1) for the conversion to be reliable.

Colwell P is most commonly used in NSW, SA, QLD and WA, and in cropping areas of Victoria where soils tend to be neutral to alkaline. Colwell P provides a wider range in soil test P values for



sandy soils than the Olsen method making it a better method for providing fertiliser advice on these soils.

Bray 1 P Test

The Bray 1 test uses Ammonium Fluoride and dilute Hydrochloric Acid as the extractant solution, mixed in a 1.4:10 soil:solution ratio and vigorously mixed for 1 minute (Rayment and Higginson, 1992). The Bray 1 is not suitable for calcareous soils as the small amounts of calcium carbonate neutralises the acidity and precipitates fluoride. Bray 1 soil test results are usually very similar to those obtained with the Colwell procedure, although the relationship is influenced by the type of fertiliser previously applied to the soil.

The Bray 1 test has several advantages when compared with the Colwell test. The acidic extractant dissolves very little organic matter by comparison with that of the alkaline bicarbonate extractant. Consequently, interferences due to extracted organic matter are of no consequence in the Bray 1 procedure (Allen and Jeffery, 1990). The Bray 1 test is used in the more temperate areas on acid soils such as along the northern coastal areas of NSW and central and southern NSW (Department of Primary Industries New South Wales, 2004).

BSES P Test

The BSES P test (Kerr and von Stieglitz, 1938) was developed by the Bureau of Sugar Experimental Stations for the sugarcane industry. The test uses dilute sulphuric acid as the extractant, mixed in a soil:solution ratio of 1:200 and mixed for 16 hours. The BSES P test measures both the labile (plant available) and non-labile (slowly released) P pools. The non-labile pool will not release enough P within an annual crop cycle to sustain yields however it may partially replenish available P reserves over a period of years ([Guppy, Bell, and Moody 2012](#)).

The suitability of the BSES extractable P for predicting fertiliser response is thought to be more important where large root/fungal networks exist, especially as the crop matures. These root/fungal networks are primarily located in the subsoil where soil moisture is greatest thus subsoil testing and soil volume may improve the usefulness of BSES-P in predicting P fertiliser response. This test has been used for pastures (and other crops) in acid soils, and sometimes used in combination with Colwell P as an indication of P 'in reserves' for the long term.

Phosphorus Buffering Index

The Phosphorus Buffering Index (PBI) is used widely to formulate the recommended rate of phosphorus fertiliser to apply in the next growing season. It is also used in conjunction with the [Colwell P test](#) to determine if Soil P levels are adequate. The PBI test (Burkitt *et al*, 2002) measures the P-sorbing capacity of a soil. P-sorption is the process by which soluble P becomes adsorbed to clay minerals and/or precipitated in soil. P-sorption also determines the partitioning of P between the solid and solution phases of the soil (See Chapter 3.4.2.2 for information on the P cycle and forms of P).

9.2.5.2 P Soil test interpretation

Soil test interpretation is based on the results of trials and research which have been used to calibrate soil test values to yield response. The soil test guidelines below (Tables 9.10 to 9.12) show the expected pasture performance for different levels of available P for each Australian dairy region. Take care to select the correct table and soil test guidelines for your region.



The production response curve for most plant nutrients tends to 'flatten out' towards maximum yield potential (i.e. 95% - 98%). This means that the yield response to higher soil test levels diminishes to a point where further applications of fertiliser become uneconomical.

Table 9.10 also explains what action is required to maintain a 95% - 98% maximum potential pasture yield. For example, if a soil sample from a Victorian dairy farm has an Olsen P test level of 20 mg/kg, maintenance applications of fertiliser would be required to maintain yields at 98% of the maximum potential yield. See Chapter 15.7 for more information on how to calculate maintenance applications of fertiliser. The tables 9.10 to 9.12 are based on calibrated results from the 'Better Fertiliser Decisions Project'. The response relationships are based on a large amount of data collated from an extensive national review of soil test – pasture response experiments conducted over the past 50 years (Gourley *et al* 2007). Note that the Olsen P levels used in Tasmania are higher than those used in the Victoria due to higher P fertility levels associated with a shallower sampling depth of 0 – 7.5 cm (compared to 0 – 10 cm in all other Australian states).

Table 9.10 Phosphorus soil test guidelines for 0 -10 cm samples for dairy systems aiming for 95 - 98% potential yield at "Adequate" soil test result - For use in **Victoria, QLD, NSW and South Australia**.

| Pasture performance compared to potential yield* | <90% | 90% - 95% | 95% - 98% | 98% - 99% | 100% |
|--|--|--|---|---|---|
| | Deficient large capital fertiliser required | Marginal moderate capital fertiliser required | Adequate maintenance fertiliser required | High low fertiliser maintenance required | High Trial data shows no fertiliser response |
| Victoria | Olsen P (mg/kg) | | | | |
| All soils | <9 | 9 - 14 | 14 - 20 | 20 - 27 | >27 |
| QLD, NSW, SA | Colwell P (mg/kg) | | | | |
| PBI 0-15 (Very sandy) | <15 | 15 - 23 | 23 - 30 | 30 - 41 | >41 |
| PBI 15-35 (Sand, Sandy loams) | <17 | 17 - 26 | 26 - 34 | 34 - 47 | >47 |
| PBI 35-70 (Sandy/Silty loams) | <19 | 19 - 30 | 30 - 39 | 39 - 53 | >53 |
| PBI 70-140 (Sandy/Silty clay loams) | <22 | 22 - 35 | 35 - 45 | 45 - 61 | >61 |
| PBI 140-280 (Clay loams) | <26 | 26 - 42 | 42 - 54 | 54 - 74 | >74 |
| PBI 280-840 (Clay loams & Clay) | <37 | 37 - 58 | 58 - 75 | 75 - 102 | >102 |
| PBI >840 (Volcanic clays, Peat) | <50 | 50 - 90 | 90 - 120 | 120 - 150 | >150 |

Source: Adapted from Department of Primary Industries Victoria, (2011)



Table 9.11 Phosphorus soil test guidelines for optimum pasture production on **Tasmanian dairy farms** using 0 - 7.5 cm soil samples

| | Very low | Low | Optimum | High | Very High |
|-----------|-----------------|---------|---------|---------|-----------|
| Tasmania | Olsen P (mg/kg) | | | | |
| All soils | <10 | 10 - 20 | 20 - 30 | 30 - 60 | >60 |

Source: Adapted from [University of Tasmania and the Tasmanian Institute of Agriculture, ND](#).

Table 9.12 Phosphorus soil test guidelines for **Western Australia** dairy systems aiming for 95% potential yield and 0 -10 cm soil samples

| Western Australia | | Phosphorus Status at 95% of maximum production | | |
|----------------------------|-----------|--|--------|------|
| | | Low | Medium | High |
| Capacity of soil to sorb P | PBI | Critical Colwell Soil Test (mg/kg) | | |
| Exceedingly low | <5 | <7 | 7-10 | >10 |
| Exceptionally low | 5 - 10 | <10 | 10-15 | >15 |
| Extremely low | 10 - 15 | <15 | 15-20 | >20 |
| Very very low | 15 - 35 | <20 | 20-25 | >25 |
| Very low | 35 - 70 | <25 | 25-29 | >29 |
| Low | 70 - 140 | <29 | 29-34 | >34 |
| Moderate | 140 - 280 | <34 | 34-40 | >40 |
| High | 280 - 840 | <40 | 40-55 | >55 |

Source: Adapted from [Bolland et al. 2010](#)

9.2.5.3 Capital P Applications

The PBI test allows for a more accurate phosphorus fertiliser decisions based on a farm's soil type. Firstly, the PBI is useful when looking to boost soil fertility with capital fertiliser applications to desired or targeted levels. These are referred to as Capital P applications. As different soils have different phosphorus buffering capacities, they require different amounts of phosphorus to raise their plant available P level. See Chapter 15.8.1 for more information on how to calculate capital P applications.

9.2.5.4 Maintenance P Applications

The intent of maintenance P applications is to keep the soil nutrient status at a steady level of high productivity. For full details on how to work out maintenance P applications see Chapter 15.7.

9.2.6 Available Potassium

The amount of potassium (in mg/kg, or parts per million) available for plant growth is measured by one of three methods: the Colwell K (1963) soil test; Skene K (1956) soil test; or it is estimated by multiplying the exchangeable potassium test result by 391 (See 'Exchangeable potassium' in [Section 9.2.9.5](#)). For the same soil sample, all three soil test K procedures provide very similar soil test K values, except in alkaline soils or recently limed soils.

The appropriate level of available potassium for good pasture growth depends on soil type. Clay soils have a higher nutrient holding capacity and need higher levels of available K than do sandy soils. Refer to [Table 9.13](#) for the Colwell K soil test guidelines for all states except Western Australia, and take care to use the correct guidelines for your dairy region. Refer to "[plant tissue testing for potassium on sandy soils](#)" for information relevant to WA.



9.2.6.1 Tests for available Potassium

There are several analytical methods for determining soil K but all measure the true plant available K in the soil. These tests measure either “exchangeable K” or “extractable K”.

Exchangeable K is usually determined by replacing the K^+ ions on the exchange sites with other cations such as NH_4^+ , Ba_2^+ or Na^+ . **Extractable K** tests generally use stronger extractants, which aims to measure the exchangeable K along with some non-exchangeable K, which would contribute to plant-available K during the growing season.

The concentration of potassium is usually measured by use of an Ammonium Acetate extract after a 30 minute shake in a 1:10 soil:solution ratio. The ammonium ions displace the adsorbed potassium ions from the clay complex into the soil solution after which the potassium concentration is measured by a spectrometer. Another technique using Barium Chloride as the extractant produces very similar results to the Ammonium Acetate method.

The **Skene K** soil test (Skene, 1956) has been used in Victoria for many years and also in some areas of Queensland (at double the soil:solution ratio). The **Colwell K** test (1963) has been widely used in South Australia, Tasmania, Western Australia and New South Wales. Both tests are well correlated to the concentration of potassium using the ammonium acetate extractant except in alkaline or recently limed soils. Also, calcareous soils are generally high in K, so care needs to be taken when interpreting K tests results. Both the Skene and Colwell K tests measure similar K values in any given soil and a conversion factor used on the exchangeable K value all produce similar K availability results. That is, Skene K (mg/kg) = Colwell K (mg/kg) = extractable potassium (amm. Acetate cmol (+)/kg X 391).

Research into yield responses to K have not been as extensive as for P, however the more commonly used K tests have a greater degree of field calibration. Because of the K buffering capacity of soils and many other influences on K concentration in the soil, K levels can vary throughout the year, and substantially from year to year. It is therefore important to monitor K regularly, and in most regions soil testing is used to monitor K levels. Test strips can also be used to detect responses to potassium fertiliser (See Chapter 8.7 for information on how to set up a fertiliser test strip). Soil testing for K is less reliable on sandy soils in higher rainfall zones, so under these situations [plant tissue testing for K](#) is recommended. Plant tissue testing is also recommended for peat soils in which fewer trials have been done to correlate yield responses on these soil types.

The optimum plant available K levels are dependent on soil texture. Clay soils have a higher nutrient holding capacity and need higher levels of available K than do sandy soils. See [Table 9.13](#) for the soil test guidelines for Colwell K on various soil types.



Table 9.13 Soil test guidelines for Colwell K

| Pasture performance compared to potential yield* | <90% | 90% - 95% | 95% - 98% | 98% - 99% | 100% |
|--|----------------------------------|---|---|--|--|
| | *(after fertiliser is applied) | Deficient large capital fertiliser required | Marginal moderate capital fertiliser required | Adequate maintenance fertiliser required | High low fertiliser maintenance required |
| Victoria, QLD, NSW, SA (0-10cm) | Colwell K (mg/kg) | | | | |
| Sand | <70 | 70 - 120 | 120 - 170 | 170 - 230 | >230 |
| Sandy/Silty loam | <80 | 80 - 130 | 130 - 190 | 190 - 250 | >250 |
| Sandy/Silty clay loam | <90 | 90 - 130 | 130 - 190 | 190 - 260 | >260 |
| Clay loam and Clay | <100 | 100 - 150 | 150 - 220 | 220 - 280 | >280 |
| Peat**† | <200 | 200 - 270 | 270 - 350 | 350 - 400 | >400 |
| Victoria, QLD, NSW, SA (0-10cm) | Exchangeable K (meq/100g) | | | | |
| Sand | <0.18 | 0.18 - 0.31 | 0.31 - 0.44 | 0.44 - 0.6 | >0.6 |
| Sandy/Silty loam | <0.20 | 0.20 - 0.33 | 0.33 - 0.49 | 0.49 - 0.64 | >0.64 |
| Sandy/Silty clay loam | <0.23 | 0.23 - 0.33 | 0.33 - 0.53 | 0.53 - 0.66 | >0.66 |
| Clay loam and Clay | <0.26 | 0.26 - 0.39 | 0.39 - 0.56 | 0.56 - 0.72 | >0.72 |
| Peat**† | <0.51 | 0.51 - 0.69 | 0.69 - 0.90 | 0.90 - 1.02 | >1.02 |
| Tasmania**†† (0 - 7.5cm) | Colwell K (mg/kg) | | | | |
| Sand | <70 | 70 - 120 | 121 - 170 | 171 - 230 | >230 |
| Sandy loam | <90 | 90 - 150 | 151 - 220 | 221 - 290 | >290 |
| Sandy clay loam | <100 | 100 - 150 | 151 - 220 | 221 - 300 | >300 |
| Clay loam and Clay | <115 | 116 - 170 | 171 - 250 | 251 - 320 | >320 |

Sources: Adapted from Department of Primary Industries Victoria, (2005), *J. Gallienne, Pers. Com. May 2013.

†Plant tissue testing is recommended for peat soils because fewer trials have been done to correlate yield responses on these soil types. ††Derived from Gourley *et al* (2007) Making better fertiliser decisions for grazed pastures in Australia. Victorian Government, Department of Primary Industries, Melbourne (multiplied by 1.15 for depth adjustment).

Plant tissue testing for potassium on sandy soils

Plant tissue testing is recommended on sandy soils in higher rainfall zones, such as in areas of Western Australia. This is due to potassium being easily leached from the pasture root zone, but typically no deeper than 20 cm. Dairy production in south-western Australia differs greatly from dairy production in eastern Australia. Most annual dairy pastures in this region are rain-fed ryegrass and clovers on sandy soils.

Clover is very sensitive to K deficiency which reduces pasture dry matter production and seed production. As a result clover rapidly disappears from K deficient pastures. In contrast, ryegrass rarely shows yield responses to applied fertiliser K regardless of the soil test K value, except when high yielding silage and hay crops are harvested and fed to cows in other paddocks (M. Bolland, Pers. Com. April 2013).



9.2.7 Available Sulphur

This is the amount of sulphur (mg/kg or ppm) available for plant growth as measured by CPC S, MCP or the KCl 40 S (sometimes referred to as Blair S or Blair KCl 40) test methods.

The **CPC S test**, which contains charcoal, estimates the water soluble and exchangeable sulphate sulphur using calcium orthophosphate ($\text{Ca}(\text{H}_2\text{PO}_4)_2$), sometimes referred to as calcium hydrogen phosphate test. The **MCP test** uses a similar extractant as for CPC but without charcoal. The KCl 40 S test uses heated potassium chloride extract to measure the readily available pools of both inorganic and organic S.

Although data from field-calibrated trials is limited, it is suggested that the **KCl 40** test be used as it should vary less with time of sampling and soil type compared to the CPC test. It is also a quicker and cheaper test and has been adopted in most soil testing laboratories. Other tests for S are the Total S and Organic S tests both of which provide little information on the amount of plant-available S.

The major laboratories now use the Blair KCl 40 test because it provides an improved indicator of sulphur status. Although the adequate ranges are similar, the KCl 40 test is more accurate because it takes into account some of the sulphur that will become available from the breakdown of organic matter. This is relevant for dairy pastures because over time large organic matter levels accumulate in the topsoil of dairy pastures. Pasture plants take up S from soil as sulphate-S. As a consequence of soil organism activity, much sulphate-S is released (mineralised) from soil organic matter. This sulphate-S is either taken up by plants or leached.

If the sulphur level is high to very high there could be a number of causes: it is possible that gypsum may have been recently applied; the soil may be saline; or the soil may be a potential acid sulphate soil. See [Table 9.14](#) for the CPC and KCl 40 soil test guidelines.

Sulphur on sandy soils in high rainfall areas

Sulphur deficiency is generally confined to high rainfall (greater than 800 mm annual average) pastures on sandy soils in wet years, as a result of leaching of sulphate sulphur below the root zone. In these circumstances soil testing cannot be used to confidently determine fertiliser sulphur requirements for the next growing season.

In south-western Australia, intensively rotationally grazed ryegrass dominant dairy pastures need to be treated with fertiliser N and fertiliser S after each grazing to prevent both elements decreasing pasture DM yields. A ratio of 3-4 N and 1 S is required, achieved by applying half urea (46% N) and half ammonium sulphate (21% N and 24% S) after each grazing. Tissue testing can be used to assess and improve sulphur management (M. Bolland, Pers. Com. April 2013).



Table 9.14 Soil test guidelines for available Sulphur

| Pasture performance compared to potential yield* | | | | | |
|--|---|---|--|--|--|
| | <90% | 90% - 95% | 95% - 98% | 98% - 99% | 100% |
| *(after fertiliser is applied) | Deficient large capital fertiliser required | Marginal moderate capital fertiliser required | Adequate maintenance fertiliser required | High low fertiliser maintenance required | High Trial data shows no fertiliser response |
| VIC, QLD, NSW, SA (0-10cm) | Sulphur (KCl-40) (mg/kg) | | | | |
| All soils | <4.5 | 4.5 - 7.5 | 7.5 - 10.5 | 10.5 - 14 | >14 |
| | Sulphur (CPC S) (mg/kg) | | | | |
| All soils | <1.5 | 1.5 - 3 | 3 - 4 | 4 - 6 | >6 |
| Tasmania^{††} (0-7.5cm) | Sulphur (KCl-40) (mg/kg) | | | | |
| All soils | | <8 | 8 - 16 | 16 - 32 | >32 |

Sources: Adapted from Department of Primary Industries Victoria, (2007)

^{††}Derived from Gourley *et al* (2007) Making better fertiliser decisions for grazed pastures in Australia. Department of Primary Industries Victoria (multiplied by 1.15 for depth adjustment).

9.2.8 Available Nitrogen

Pastures

It is difficult to measure the amount of nitrogen (N) available for plant growth in soils because the form and availability of nitrogen in the soil can change quickly, particularly in grazed dairy pastures. Therefore by the time the soil samples are received and analysed by the laboratory the amount of mineral N in the sample may have changed. Even if the amount of mineral N is correctly analysed by the laboratory by the time the soil test results are returned to the farmer changes may have already occurred in the N content of the soil.

Nitrogen fertiliser applications for pastures are better calculated by using a pasture production target, rotation length during the growing season, or obvious symptoms of N deficiency. Soil nitrogen, and the practical application of nitrogen fertilisers in pastures, is covered in Chapter 12.

Crops

In some cropping regions plant available N can accumulate in the soil profile and becomes a valuable source of N for the subsequent crop. In Queensland and Northern New South Wales extraction of nitrate N with KCl has been found to be useful to determine its contribution to plant-available N (Russell 1968; Hibberd *et al.* 1986; Holford & Doyle 1992; Strong 1990 as cited in Peverill *et al.* 1999). Soil nitrogen is to be interpreted in consideration of other factors including: soil water content at planting, in-crop rainfall, yield target, and the likely crop response. These factors are accounted for in calculating N fertiliser requirements – For more information refer to the following link: http://www.daff.qld.gov.au/26_18112.htm.

In contrast to this, crop response to applied N in Western Australia is poorly correlated to nitrate concentration in the surface 10 cm (M.G. Mason unpublished data, cited in Peverill *et al.* 1999). In western and southern Australia surrogate tests of the soil's capacity to increase mineral N supply, such as total N or C contents, are used (Pyane & Ladd 1994; Bowden & Diggle 1995, cited in Peverill *et al.* 1999). Soil testing and interpretation of soil nitrogen for field crops is regionally specific



and is a specialised area, and as such is not covered in this manual. See ‘*Soil Analysis: an Interpretation Manual*’ (Peverill et al. 1999) for more information.

9.2.9 Cation Exchange Capacity (CEC)

Cation Exchange Capacity is a measure of the soil’s capacity to hold and exchange cations (positively charged ions). CEC provides a buffering effect to changes in available nutrients, pH, calcium levels and soil structural changes. As a result, CEC is a major influence on soil structure stability, availability of nutrients for plant growth, soil pH and the soil’s reaction to nutrient application and soil ameliorants.

9.2.9.1 Measuring CEC

CEC is usually measured by displacing the exchangeable cations (Na, K, Mg and K) with another strongly adsorbed cation, followed by determining how much of the strongly adsorbed cation is retained by the soil. The details of the methods used and their pros and cons are discussed in Rayment and Higginson (1992) and Rengasamy and Churchman (1999).

The soil CEC is now measured in terms of centimoles of positive charge per kilogram [(cmol (+))/kg] of soil and is numerically equivalent to the previously used unit of milli-equivalents per 100 grams (meq/100 g) as follows:

$$1 \text{ cmol (+)/kg} = 1 \text{ meq/100 g.}$$

After the cations (calcium, magnesium, potassium, sodium and sometimes aluminium) have been measured, they are totalled and this is referred to as the sum of cations. A sum of cations above 15 meq/100 g (15 cmol (+)/kg) means that a soil has a good ability to retain nutrients for plants. Their proportional relationship to one another is calculated as a percentage of the total for some of the cations.

On some soil tests, aluminium levels will be assessed by the CaCl₂ (Calcium Chloride) or KCl (Potassium Chloride) methods, which are reported in milligrams per kilogram (mg/kg) or parts per million (ppm). When this happens, exchangeable aluminium is not included in the cation exchange capacity test.

9.2.9.2 Interpreting CEC levels

Soil tests will report on exchangeable calcium, exchangeable magnesium, exchangeable sodium, exchangeable potassium, and exchangeable aluminium.

For many years the use of the ‘Balanced’ Ca, Mg, and K ratios, as prescribed by the basic cation saturation ratio (BCSR) concept, has been used by some private soil-testing laboratories for the interpretation of soil analytical data. However, a recent review by Kopittke and Menzies (2007) of data from numerous studies (particularly those of Albrecht and Bear who are proponents of the BCSR concept) would suggest that within the ranges commonly found in soils, the chemical, physical, and biological fertility of a soil is generally not influenced by the ratios of Ca, Mg, and K. However, some ratios have been used to indicate the potential for animal health issues and are also important to soil structure.

The five most abundant cations in soils are Ca²⁺, Mg²⁺, K⁺, Na⁺ and, in strongly acidic soils, Al³⁺ (Table 9.15). Other cations are present but not in amounts that contribute significantly to the cation complement.

**Table 9.15** Levels of exchangeable cations (cmol (+)/kg)

| CATION | VERY LOW | LOW | MODERATE | HIGH | VERY HIGH |
|--------|----------|-----------|-----------|---------|-----------|
| Ca | 0 – 2 | 2 – 5 | 5 – 10 | 10 - 20 | >20 |
| Mg | 0 – 0.3 | 0.3 – 1.0 | 1 - 3 | 3 - 8 | >8 |
| K | 0 – 0.2 | 0.2 – 0.3 | 0.3 – 0.7 | 0.7 – 2 | >2 |
| Na | 0 – 0.1 | 0.1 – 0.3 | 0.3 – 0.7 | 0.7 – 2 | >2 |

Source: Metson, (1961)

CEC is a good indicator of soil texture and organic matter content. The CEC of clay minerals is usually in the range of 10 to 150 cmol (+)/kg, while that of organic matter may range from 200 to 400 cmol (+)/kg. The CEC of sand and sandy soils is usually below 10 cmol (+)/kg. So, the type and amount of clay and organic matter content of a soil can greatly influence its CEC.

A high CEC soil means that the soil has high resistance to changes in soil chemistry that are caused by land use. Where soils are highly weathered and the organic matter level is low, their CEC is also low. Where there has been less weathering and organic matter content is higher, CEC can also be quite high. Clay soils with a high CEC can retain large amounts of cations against leaching. Sandy soils with a low CEC retain smaller quantities of cations, and this has important implications when planning a fertiliser program. In soils with a low CEC, consideration should be given to splitting applications of K and S fertilisers. Table 9.16 below relates soil texture to the CEC.

Table 9.16 Soil texture, CEC rating and the Cation Exchange Capacity.

| TEXTURE [†] | CEC RATING ^{††} | CEC (cmol (+)/kg) |
|-------------------------|--------------------------|-------------------|
| Sand | Very low | <6* |
| Sandy loam to Silt loam | Low | 6 – 12 |
| Silt loam to Clay loam | Moderate | 12 - 25 |
| Clay loam to Clay | High | 25 - 40 |
| Clay | Very high | >40 |

Source: Adapted from [†]University of New South Wales, (2007), and ^{††}Metson, (1961).

* Soils with CEC <3 are usually very low in fertility and susceptible to soil acidification.

As CEC increases, the soil also tends to become more structurally resilient. The sum of exchangeable calcium, magnesium, potassium and sodium in soil, provides a rough index of the shrink-swell potential (resilience) of soil. A resilient soil is a soil with the ability to develop a desirable structure by natural processes after destructive forces (e.g. soil compaction from animal hooves) have been removed (University of New South Wales, 2007).

Soil that is capable of naturally enhancing the development of shrinkage cracks through the process of shrinking when dry and swelling when wet, will aid the formation of stable vertical cracks into the soil. These cracks facilitate root growth and incorporation of organic matter and water into the subsoil. In addition, the activity of soil fauna such as ants and earthworms will be assisted. Table 9.17 provides an indication of the shrink-swell of soils with increasing CEC values.



Table 9.17 Levels of exchangeable cations (cmol (+)/kg)

| SHRINK-SWELL POTENTIAL | VERY POOR | POOR | MODERATE | GOOD |
|-------------------------------|------------------|-------------|-----------------|-------------|
| CEC (cmol (+)/kg) | <10 | 10-20 | 20-30 | 30-40 |

Source: Adapted from University of New South Wales, (2007)

The desired ranges, relationships or limits for the various cations are discussed in Sections 9.2.9.3 to 9.2.9.7. Also discussed is how CEC is most useful for determining soil structural problems and high aluminium levels in the soil.

9.2.9.3 Exchangeable calcium

Exchangeable calcium should make up the largest amount of the cations in the soil. Deficiency of calcium for plant growth is not common in Australian soils, however many soils have inadequate concentrations for a healthy soil structure (Hamza, 2008). High levels of exchangeable Ca increases flocculation and can improve soil structure in clay soils. The level of exchangeable Ca in the soil reflects the following:

- Interacting effects of the total amount and the solubility of Ca sources
- CEC
- Competition from Al, Mg or Na
- Ca-removing processes

In general, neutral and alkaline soils possess higher concentrations of exchangeable Ca relative to acid soils. Ca saturation is correlated with soil pH and inversely related to Al saturation. In this case soil amendments such as gypsum and lime are required to increase the saturation percentage. Acid soils with low CEC in high rainfall environments are most likely to be low in Ca (Hamza, 2008).

The ratio of exchangeable calcium to exchangeable magnesium provides some guide to a soil's structure and any potential problems that might be influencing soil drainage, root development and subsequent plant growth. The ratio is usually written as the **calcium/magnesium ratio** on a soil test.

Well-structured soils have a calcium/magnesium ratio greater than 2:1. In other words, the amount of calcium cations is more than two times greater than the amount of magnesium cations.

The stability of heavier soil types (clays and clay loams) is possibly reduced where the calcium/magnesium ratio is less than 1:1. In other words, the amount of magnesium ions exceeds the amount of calcium ions. This is not as important for lighter soils (sands and loams). However, if the exchangeable sodium is greater than 6% of the CEC, then soil structure may be affected and addition of gypsum may be required. A calcium-to-magnesium ratio of more than 10:1 indicates a potential magnesium deficiency in pasture species (this can be confirmed with a plant tissue analysis).

9.2.9.4 Exchangeable magnesium

Exchangeable magnesium should make up the next largest amount of the cations. The ratio of magnesium to potassium should be greater than 1.5:1. In other words, the amount of magnesium should be more than one and a half times greater than the amount of potassium. A magnesium/potassium ratio of less than 1.5:1 indicates an increased chance of grass tetany; however there are many other factors that can influence the occurrence of [grass tetany](#).



If the exchangeable magnesium is more than 20% of the cations, it may cause a potassium deficiency. Conversely, if the exchangeable potassium is more than 10% of the cations, it may cause a magnesium deficiency. See '[Exchangeable calcium](#)' for the recommended ratio between magnesium and calcium.

9.2.9.5 Exchangeable potassium

Exchangeable potassium should make up the third largest amount of the cations. The value of potassium in relationship to magnesium plus calcium should be less than 0.07. A result of 0.07 or higher indicates a greater danger of [grass tetany](#); a result less than 0.07 indicates minimal danger of grass tetany. (Note that animal symptoms or blood tests are the most accurate indicators for grass tetany.) To determine the relationship, use the following formula containing the exchangeable values for:

$$K \div (Ca + Mg)$$

For example, if a soil test showed potassium as 0.47 cmol (+)/kg, calcium as 5.60 cmol (+)/kg, and magnesium as 1.4 cmol (+)/kg, then the calculation would be:

$$0.47 \div (5.6 + 1.4) = 0.067$$

This level is just under the grass tetany danger level of 0.07 or greater.

9.2.9.6 Exchangeable sodium

Exchangeable sodium should be the fourth largest amount of the cations. Often referred to as the **Exchangeable Sodium Percent (ESP)**, the desirable level is less than 6%. Although not needed for plant growth, Na is needed by animals. However, a high CEC Na value can cause crusting/dispersion in sodic clay soil with low organic carbon (OC) (see Chapter 7.2.2), and this is made worse with high Mg ratios. This often occurs where sodium cations make up 6% or more of the cation exchange capacity – see also [Section 9.2.9.3](#).

9.2.9.7 Exchangeable aluminium

Exchangeable aluminium (Al_{ex}) should be the lowest amount of the cations but is not needed by plants. The desirable amount is less than 1% and is toxic to the roots of many plant species, especially lucerne.

Exchangeable aluminium is used to indicate the need for lime for aluminium-sensitive species such as: lucerne and white clovers; and to a lesser extent, sub clovers. High aluminium levels can be toxic to plants, but aluminium generally falls to harmless levels once the pH ($CaCl_2$) exceeds 5.0 – See Table 9.18 for critical acidity and aluminium levels for crops and pastures.

**Table 9.18** Critical acidity and aluminium levels for crops and pastures

| | VERY SENSITIVE PLANTS | SENSITIVE PLANTS | TOLERANT PLANTS | VERY TOLERANT PLANTS | |
|--|---|--------------------------------------|--|--------------------------------------|---------|
| Examples of plants | Barrel Medic, Canola, Lucerne | Wheat, sensitive Phalaris, Barley | Wheat, Phalaris, Sub clover, Cocksfoot, Perennial ryegrass | Lupins, Triticale, Oats, Serradella | |
| pH (CaCl₂) below which yield declines | 4.3 – 4.7 depending on soil group | 4.1 – 4.5 depending on soil group | 4.0 – 4.3 depending on soil group | 4.0 – 4.2 depending on soil group | |
| Extractable Al in CaCl₂ solution above which yield declines | 0.1 - 0.4 ppm | 0.4 - 0.8 ppm | 0.8 -1.6 ppm | 1.6 - 2.7 ppm | |
| Exchangeable Al as a percentage of CEC | EC ¹ <0.07 (Infertile soils low CEC) | 9 - 16 | 16 - 21 | 21 - 32 | 32 - 43 |
| | EC 0.07- 0.23 (Most fertile soils, low CEC) | 8 - 12 | 8 - 12 | 12 - 21 | 21 – 30 |
| | EC>0.23 (Fertile bands, saline soils) | 0.5 - 2 | 2 - 6 | 6 – 10 | 10 - 16 |

¹EC Electrical conductivity 1:5 dS/m.

Source: Adapted from Geeves *et al* (1990), Fenton *et al* (1993), Fenton and Helyar (2007), cited in 'Interpreting Soil Tests: Pam Hazelton and Brian Murphy NSW DNR 2007' Retrieved:

<http://www.bellingerlandcare.org.au/documents/InterSoilTestResults.pdf>

Lucerne establishment and persistence are particularly susceptible to high exchangeable aluminium in both the topsoil and the subsoil. The desirable aluminium levels in the topsoil for lucerne establishment, as measured by the three methods, are as follows:

- Less than 1%, if measured as part of the cation exchange capacity.
- Less than 2 mg/kg (or ppm), if measured by the CaCl₂ method.
- Less than 50 mg/kg (or ppm), if measured by the KCl method.

Subsoils should also be soil tested if lucerne is to be grown. Lucerne is a deep-rooted plant, and it should not be sown if the level of aluminium in the subsoil, as measured by the KCl method, is above 50 mg/kg.

Table 9.19 explains management options and the likely response to lime applications for a range of crops, pH levels, and Exchangeable Aluminium (Al_{ex}) levels.

**Table 9.19** Likely responses to lime application over a range of pH and Exchangeable Aluminium (Al_{ex}) levels.

| SOIL PH ($CaCl_2$) | EXCHANGEABLE ALUMINIUM | MANAGEMENT |
|-------------------------|---------------------------|--|
| > 5.4 | 0 – 5% | There are no problems from soil acidity and there is net movement of lime effect down the soil profile |
| < 5.3 | 0 – 5% | There is a chance of molybdenum deficiency (Check local advice) |
| < 5.1 | 0 – 5% | The effectiveness of rhizobia that inoculate acid sensitive legumes e.g. Lucerne, faba beans, is reduced. Liming will increase rhizobia effectiveness and production of their crops and pastures |
| < 4.8 | >5% | Pastures and crops that are sensitive to soil acidity (Table 9.9) will give an economic response to lime.* If pH is less than 4.6 the speed of nitrification process will increase with liming regardless of Al_{ex} . |
| < 4.8 | >10% | Crops that are sensitive to soil acidity will show an economic response to lime. Sensitive and tolerant pastures will also show a response but its economics may be marginal. |
| < 4.8 | >15% | Crops that are tolerant will give an economic response. The response of sensitive and tolerant pasture will increase with higher aluminium, but its economics may be marginal. |
| < 4.8 | >20% | Highly tolerant crops and pastures will give a small response |

*Economic response will depend on cost of applied lime and level of response.

Source: Fenton (1999).

9.2.10 Salinity

Soil salinity refers to the accumulation of water soluble salts comprised mainly of sodium; but also potassium, calcium and magnesium; and may include chlorides, sulphates or carbonates.

Salinity levels are usually determined by measuring the **electrical conductivity** of soil/water suspensions. Traditionally, the electrical conductivity of saturated extracts was used (EC_e) but the tests are time consuming and difficult to determine.

Now, electrical conductivity is determined more rapidly and more easily on a mixture of 1 part soil to 5 parts distilled water. This test is called the EC 1:5 method, and the unit of measurement is deciSiemens per metre (dS/m). The soil and water are continuously mixed for one hour before the electrical conductivity is tested.

The EC 1:5 (dS/m) values are converted to the appropriate value of EC_e (dS/m) value based on the estimated water holding capacities of the soil, which is based on its soil texture. Multiplication factors are dependent on soil type as shown in Table 9.20.

Example:

A clay loam soil has an EC 1:5 test of 0.4 dS/m. The multiplication factor for clay loam is 8.6.
 $EC_e \text{ value} = 0.4 \text{ dS/m} \times 8.6 = 3.44 \text{ dS/m}$.

It is important to check the results of the soil test to see which method was used to report the EC value.

Table 9.20 Conversion factor of various soil types for EC 1:5 to EC_e



| SOIL TEXTURE GROUP | MULTIPLICATION FACTOR |
|---|-----------------------|
| Sand, loamy sand, clayey sand | 23 |
| Sandy loam, fine sandy loam, light sandy clay loam | 14 |
| Loam, very fine sandy loam, silty loam, sandy clay loam | 9.5 |
| Clay loam, silty clay loam, very fine sandy clay loam, sandy clay, silty clay, light clay | 8.6 |
| Light medium clay | 8.6 |
| Medium clay | 7.5 |
| Heavy clay | 5.8 |
| Peat | 4.9 |

Source: Adapted from Slavich and Petterson, (1993)

Soil scientists use deciSiemen per metre (dS/m) as the standard scientific unit of EC but other numerically equivalent units are also used:

- 1 dS/m = 1 mS/cm = 1 mmho/cm
- dS/m is deciSiemen per metre; mS/cm is milliSiemen per centimetre; mmho/cm is millimoho per centimetre
- 1 dS/m = 1000 microSiemen per centimetre (μ S/cm or EC units)

Data on the salt tolerance of plants is usually based on a different test, the electrical conductivity of a saturated extract. This is called the EC_e method and is also measured in deciSiemens per metre. A plant growing in saline conditions will make adjustments to cope with the increase in salt levels in the soil solution. The ability of the plant to continue this adjustment is a measure of its tolerance to salinity. See Chapter 7.5 for more information on salinity, salt tolerance of plants, and salinity management:

- [Soil classification and salinity measurement](#)
- [What does salinity look like?](#)
- [Plant tolerances to salty conditions](#)
- [How can we best manage salinity?](#)



9.3 Interpreting plant tissue tests

Plant tissue testing is the preferred method for diagnosing trace element toxicities, deficiencies, and imbalances for plants. Tissue tests, also known as plant or leaf analysis, determine the chemical analysis of the nutrients present in plant tissue. Tissue tests are also used to confirm that plants are accessing the nutrients that have been applied and to confirm a diagnosis made by other means. Both the major nutrients and the micronutrients (trace elements) are covered in plant tissue tests (see the example in [Figure 9.3a](#)).

Plant tissue testing is also very useful to corroborate animal nutritional or deficiency problems such as copper (Cu), cobalt (Co) and selenium (Se). Both plant nutrient and animal health problems can be diagnosed by comparing results from healthy and unhealthy samples. However, the rapid growth and quick maturity of annual crops combined with daily management (e.g. irrigation, fertiliser), and the effects of grazing on pasture plants, can make assessments of subclinical deficiencies or toxicities difficult.

Tissue testing is carried out by comparing samples with standard results recorded in various publications (see [references](#) at the end of this section). However, where animal health is a concern, blood testing is often more useful and it is more cost effective to treat the animals directly.

Clover samples are generally used to diagnose trace element deficiencies in dairy pastures where clover is prevalent, however lucerne or ryegrass samples can also be used. Plant tests are also used to confirm that plants are accessing the nutrients that have been applied, and to confirm a diagnosis made by other means.

Interpretation of the results of a plant tissue test is complex and depends on a number of factors. It is therefore recommended that interpreting the results of plant tissue tests should be done by a trained professional. This is because actual adequate levels for any nutrient varies depending on species, plant part, time of year, and stage of growth.

When using plant tissue tests to determine nutrient levels in plants, it is vital to take the sample correctly and to provide as much information as possible to aid interpretation. Supplying relevant information will help the person interpreting the results to correctly calculate the level of nutrients in your sample. If possible, tissue samples of identical plant parts and age should be taken from 'good' and 'poor' areas to allow a direct comparison of tissue nutrient levels. See [Chapter 8.4](#) for details on sampling for tissue tests.

Results from laboratories will be analysed by trained professionals who will take into account the information you have provided and will interpret the results. The results are usually shown with a number and an interpretation of this (for example, deficient, adequate, high). Based on this interpretation, you can then make decisions about nutrients required in your fertiliser program.

More information about interpretation of tissue test results can be found in *Plant Analysis: An Interpretation Manual* (Reuter and Robinson, 1986) and *Plant Nutrient Disorders 4: Pastures and Field Crops* (Weir and Cresswell, 1994).

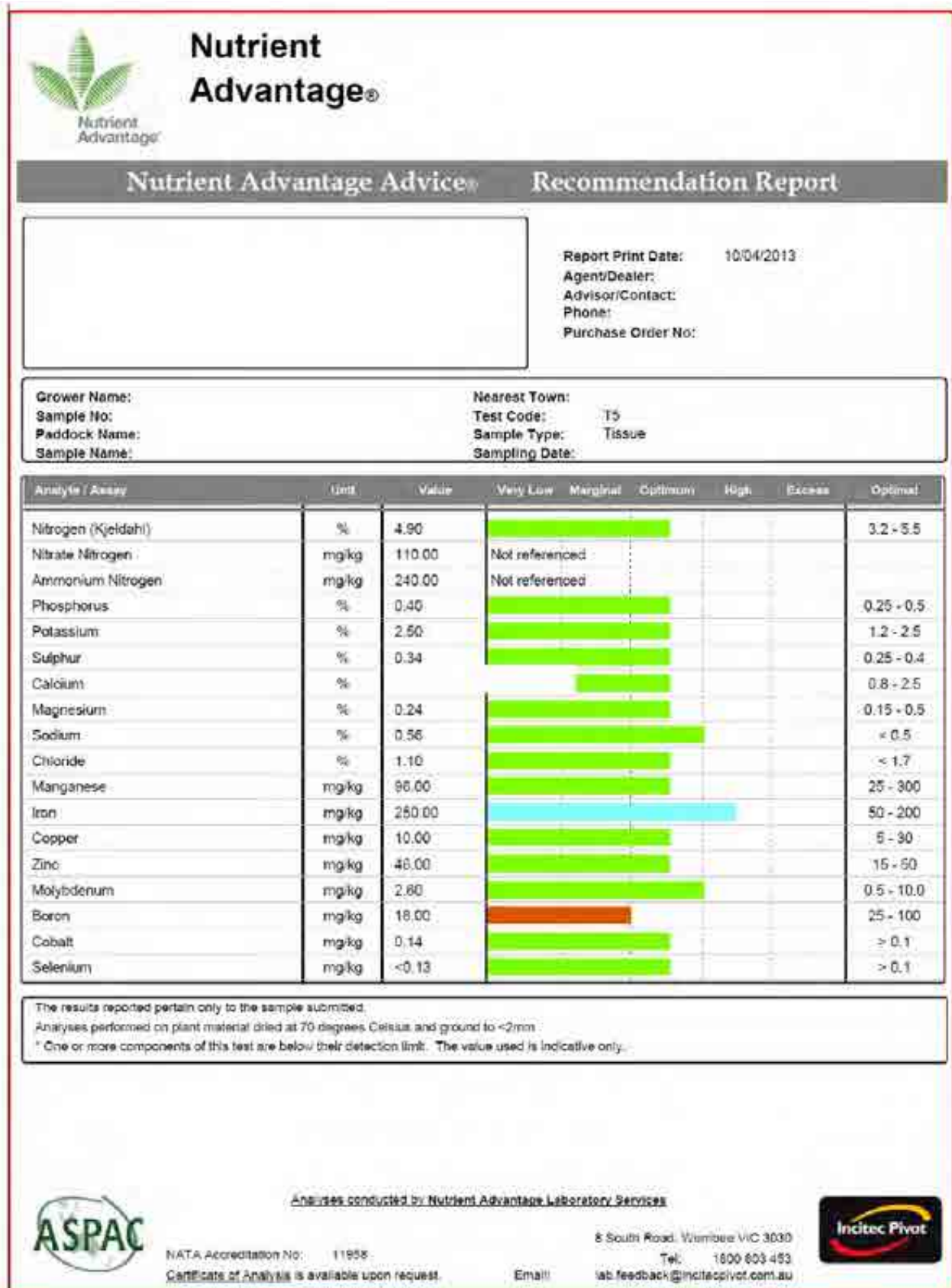


Figure 9.3a An example plant tissue test





Nutrient Advantage®

Nutrient Advantage Advice
Recommendation Report

| | |
|----------------------|----------------------------|
| Grower Name: | Nearest Town: |
| Sample No: | Test Code: T5 |
| Paddock Name: | Sample Type: Tissue |
| Sample Name: | Sampling Date: |

Comments

NITROGEN:
Nitrogen (N) status satisfactory at time of sampling and yield is unlikely to be affected.

PHOSPHORUS:
Phosphorus (P) nutrition appears adequate.

POTASSIUM:
Sufficient potassium (K) nutrition - monitor with soil test.

SULPHUR:
Sufficient sulphur (S) nutrition indicated at the time of sampling.

CALCIUM:
This level should be adequate for maximum pasture and animal production.

MAGNESIUM:
This level should be adequate for maximum pasture and animal production.

SODIUM:
Production losses due to high sodium (Na) may exist at this site. The cause of which should be explored. **Burning of the leaf tip and yellowing or scorching of the margins are the most common symptoms.**

CHLORIDE:
Satisfactory chloride (Cl) levels at time of sampling.

MANGANESE:
Sufficient at time of sampling.

IRON:
Iron (Fe) status higher than normal at time of sampling, which may indicate soil contamination of the tissue sampled.

COPPER:
Sufficient at time of sampling.

ZINC:
Sufficient at time of sampling.

MOLYBDENUM:
This level should be adequate for maximum pasture. As copper (Cu) and molybdenum (Mo) are antagonistic, the high molybdenum levels in the sample indicate that scrutiny of copper levels is required.

BORON:
Tentative guide only.

COBALT:
This cobalt (Co) level should be adequate for maximum pasture and animal production.

Disclaimer: Laboratory analyses and fertiliser recommendations are made in good faith, based on the best technical information available as of the date of this report. Incitec Pivot Limited, its officers, employees, consultants, Agents and Dealers do not accept any liability whatsoever arising from or in connection with the analytical results, interpretations and recommendations provided, and the user taking the analytical results, interpretations and recommendations as their basis, in respect of liability which cannot be excluded by law. Incitec Pivot's liability is restricted to the integrity of the laboratory analysis or the cost of having the analysis re-sampled.



Figure 9.3b Explanation of an example plant tissue test



9.4 Summary

- Soil and tissue tests provide valuable information about soil properties (mostly chemical properties) that affect plant growth.
- After soil and tissue test results come back from the lab, it is important to determine what they actually mean and act upon the advice.
- The interpretation of results from soil and tissue tests will help to make more informed, cost-effective fertiliser decisions.



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Chapter 10

Keeping nutrients on farm

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10 Keeping nutrients on farm

10.1 Introduction

In this section;

[Importance](#)

[Management principles](#)

10.1.1 Importance

Keeping nutrients on dairy farms is important for several reasons including:

[Cost of production](#)

[Environmental impacts](#)

[Sustainable use](#)

[Community responses](#).

Nutrients drive dairy production, so excess nutrients lost from a farm are literally ‘money down the drain’ and a lost opportunity for higher yields. Compounding the loss, the nutrients may then have a negative impact on the off-farm environment. Keeping nutrients on the farm makes financial and environmental sense.

‘Only a quarter of the nutrients brought onto a dairy farm leave it in product’

Considering the bigger picture of nutrient use in agriculture, there are questions about the sustainability of current nutrient applications and management. Will farmers in the future have the same access to nutrients as those of today? Keeping nutrients on farm will help ensure they do.

Along with the question of sustainable use, the possibility of adverse environmental impacts also attracts the interest of community groups. Hence, both have the potential to result in regulations on fertiliser use and / or consumer action to demand improved management.

Studies of dairy farms across Australia in the ‘Accounting for Nutrients’ project, have shown that;

- There is large variation in the nutrient status of soils on dairy farms, between farms and within and between paddocks on individual farms.
- On average, there are excess nutrients available, implying low efficiency in converting nutrients to milk and potentially, subsequent losses to the environment – which confirms the results of other research.
- There is a wide variation in nutrient efficiencies between farms, indicating that improvements are feasible in many situations.

For more information on Accounting for Nutrients, see: <http://www.accounting4nutrients.com.au/>

10.1.1.1 Cost of production

Some paddocks on dairy farms may be under-fertilised, but many are not. The Accounting for Nutrients project revealed that of the 37 conventional dairy farms studied around Australia:

- 20% of pasture paddocks had more than three times the required level of phosphorus (Olsen P of 20 mg/kg). Phosphorus levels in paddocks close to the dairy were often two to three times those 2km from the dairy and four times higher than those 4km away.
- All dairy farms are likely to have surplus nitrogen due to conversion inefficiencies, high concentrations in urine, and poor storage in soils. Nitrogen is lost with water run-off, leaching, or to the atmosphere. Nitrogen surpluses rise in proportion to milk production.



- The average soil test levels for sulphur were twice the recommended level for pasture (KCI-40 of 10 mg/kg).
- The average soil test levels for potassium were twice the recommended level for pasture (Colwell K of 140 mg/kg) and three times the level in 20% of cases.

Phosphorus and sulphur levels were substantially lower on organically farmed properties, but not below levels required for productive pastures. If no further phosphorus or sulphur was applied to the high level conventional paddocks for several years, it is unlikely that pasture productivity would suffer. Soil potassium levels were similar between conventional and organic dairy farms (Department of Primary Industries Victoria (n.d.)a).

There are clear opportunities for many dairy farmers to reduce fertiliser applications to high nutrient level paddocks; thereby reducing costs without compromising production, and hence resulting in higher net profit. The value of lost nutrient inputs will increase as do fertiliser costs.

For some case studies, highlighting the savings to be made, see:

<http://www.dairyingfortomorrow.com/index.php?id=16>

<http://www.dairyaustralia.com.au/Levy-investment/Case-studies/Cutting-fertiliser-costs.aspx>

Detrimental influences on the cost of production can also come about due to animal health and productivity impacts due to excessive nutrient intake. High potassium levels can contribute to metabolic disorders such as grass tetany and milk fever, while high nitrate content in pastures can trigger nitrate poisoning (see [Chapter 12.6.1](#) for more information). Excessive calcium and magnesium have also been associated with poor stock health.

10.1.1.2 Environmental impacts

Many excess nutrients are removed in water – either in surface flows or groundwater.

In surface waters, nutrients can stimulate the growth of algae, some of which can be poisonous like types of nitrogen-fixing 'blue-green algae'. Surges in the growth of aquatic plants and algae can also leave an unwanted legacy. As they die, they are decomposed by microorganisms such as bacteria, which use up the available oxygen in the water – and lead to fish deaths as a consequence (Carpenter *et al*, 1998). The availability of excess nutrients can also change the ecology of a water body, leading to the replacement of aquatic plants or macro-algae by micro-algae (Harris, 2002).

In groundwater, high concentrations of nutrients, particularly nitrogen, can lead to human health risks. Excess levels of nitrate have been associated with 'blue baby syndrome', although the relationship is not clear. When introduced to waterways, pathogens from dairy cows can also pose a public health risk and, in some situations, a risk to young stock. As pathogens often follow similar pathways to those of excess nutrients, some practices that reduce nutrient losses will also help reduce the risk of water contamination by dairy pathogens. Nitrogen leaching may also increase the acidity of soil, necessitating treatment with lime.



Minimise trade-offs

Agronomic optimal nutrient concentrations are often greater than safe environmental limits but, as the following graph indicates, it is possible to obtain optimal production without challenging aspects of the environment. In this case, soil phosphorus levels for optimal pasture production are below the level at which there is a significant increase in the risk of phosphorus being lost in sub-surface drainage. The key message is to consider the impact of nutrient levels on the environment as well as on production and to avoid exceeding agronomic requirements to minimise impacts on the environment.

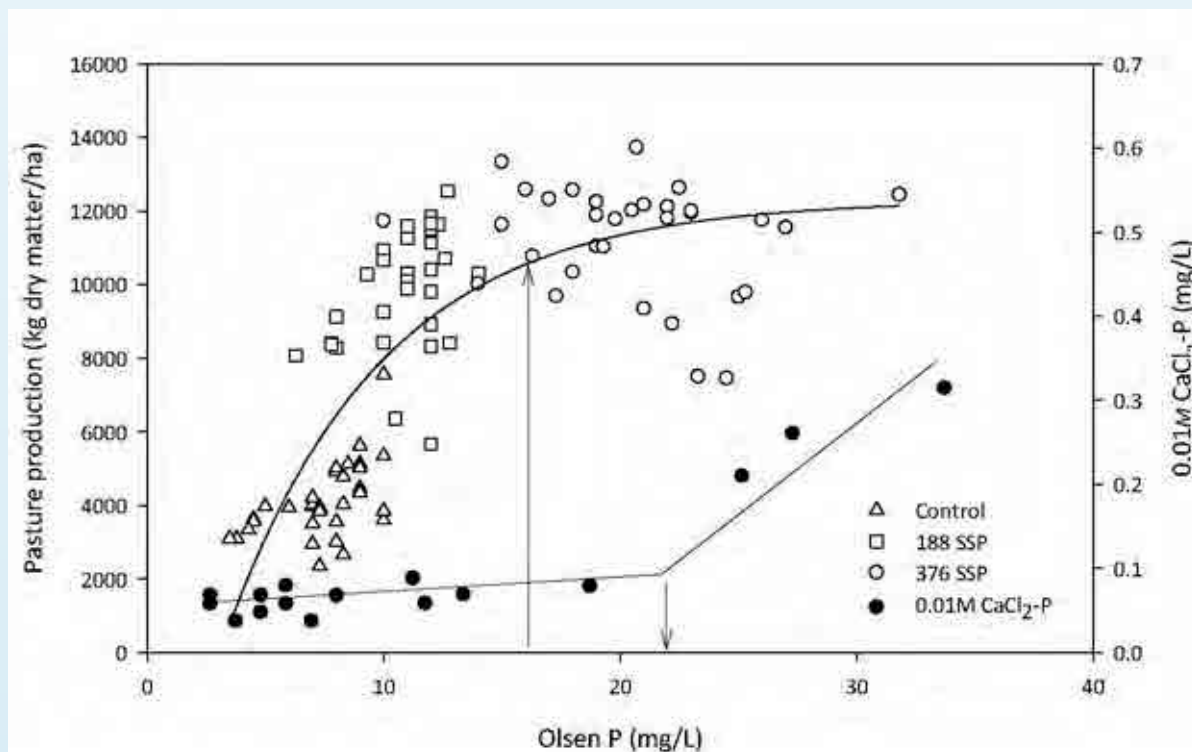


Figure 10.1 Agricultural optimum (up arrow) versus environmental impact (down arrow) for P loss in subsurface drainage (as estimated by 0.01M CaCl₂-P). Data are from plots receiving different rates of superphosphate (SSP; kg ha⁻¹ yr⁻¹) at Canterbury, NZ (McDowell, 2012).

Not all areas are of equal risk of losing nutrients to the environment. Some sites, referred to as 'Critical Source Areas' or 'Hot Spots', are more liable to pose a risk. These areas are typically wet and have high nutrient levels. Identifying and managing critical source areas are important ways to keep nutrients on farms. See [Section 10.3.3](#) for more information.

Gaseous losses (e.g. nitrous oxide from soils, methane from cows and effluent and ammonia from ammonium-based fertilisers) are increasingly important in a carbon economy that is designed to reduce greenhouse gas emissions.

10.1.1.3 Sustainable use

Nutrients are a critical factor driving dairy production. Global populations and their requirements for food are increasing yet, in some cases, questions are being raised about how much access producers will have to nutrients in the future. In that scenario, nutrients will be increasingly important and valuable.



- The Global Phosphorus Research Initiative is one example of a response to concerns that reliable, good quality phosphorous resources are fast diminishing. Global TraPs aims to engage differing viewpoints in better understanding the current and future availability of phosphorous for optimal use; see <http://phosphorusfutures.net/> and <http://www.globaltraps.ch/about-us.html>
- Concerns have also been raised about the sustainability of increasing the amounts of reactive nitrogen within the environment; see <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1247398/>

As a generalisation, Australian soils tend to be very old and low in nutrients, making nutrient inputs an important contributor to high levels of productivity. Modern farming systems tend to import nutrients, such as feeds and fertilisers, to boost production, with relatively little recycling. Many nutrients are shipped out in produce, ultimately entering urban waste treatment systems and then oceans, or lost to the off-farm environment (Cribb, 2006; and Gourley & Weaver, 2012).

10.1.1.4 Community responses

Communities around the world, through organisations and consumer reactions, have pressured governments and food producers in response to environmental and sustainability issues, as outlined previously. The responses range from local to multi-national in scale and include:

- Regulations on nutrient applications – e.g. capping fertiliser application rates or stocking rates, limiting the types of fertiliser to be applied, or requiring nutrient management plans or budgets and capping the ‘loss’ component.
- Public campaigns – e.g. detracting from the credentials and image of the dairy industry to invite regulations, consumer backlash, or additional barriers to trade.

Some regulations are now evident in Australia, with controls on fertiliser use being introduced to protect the Great Barrier Reef (Qld) and Peel Harvey Inlet (WA). For more information, see Gourley & Weaver (2012). There are also ‘softer’ options occurring, involving combinations of research, extension, incentives and regulation, affecting both fertiliser and milk supply-chains. Wise use of nutrients, and demonstration of that management, will be required to reduce the risk of increased regulation of farming activities.

10.1.2 Management principles

Research has shown there are areas on dairy farms with an oversupply of nutrients. There are opportunities for dairy farmers to improve the efficiency at which nutrients are converted to produce, to redistribute nutrients on-farm and to curtail off-farm losses.

The key management principles for dairy farmers to follow are to:

- [Understand nutrients](#) – know about nutrient cycles; where nutrients come from, the transformations they undergo and the pathways they follow.
- [Plan to retain nutrients on-farm](#) – apply the understanding of nutrients to plan for optimal productive efficiency and to contain losses; and check to see the plan is followed and succeeding.
- [Optimise production](#) – get as much production from applied nutrients as possible by focusing on the ‘4Rs’ (the right sources of nutrients, in the right place, at the right rate and right time), and recycle and redistribute nutrients within that framework; especially in the more resilient areas of a farm.
- [Minimise losses](#) – take special care to avoid direct losses and to lock-up or re-use excess nutrients; especially in areas more prone to environmental loss (critical source areas).

These principles, along with the key strategies to address them, are discussed in the following sections.



10.2 Understand nutrients in the environment

The keys to understanding nutrients are:

[Know the sources of nutrients.](#)

[Understand nutrient stores and transformations.](#)

[Know how nutrients are lost.](#)

As summarised in the following diagram, nutrient stores, transformations and pathways are complex, especially for nitrogen. For more information on the nitrogen cycle, see [Chapter 12.1.1](#) and the Nitrogen Cycle Animation:

http://vro.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_nitrogen-cycle

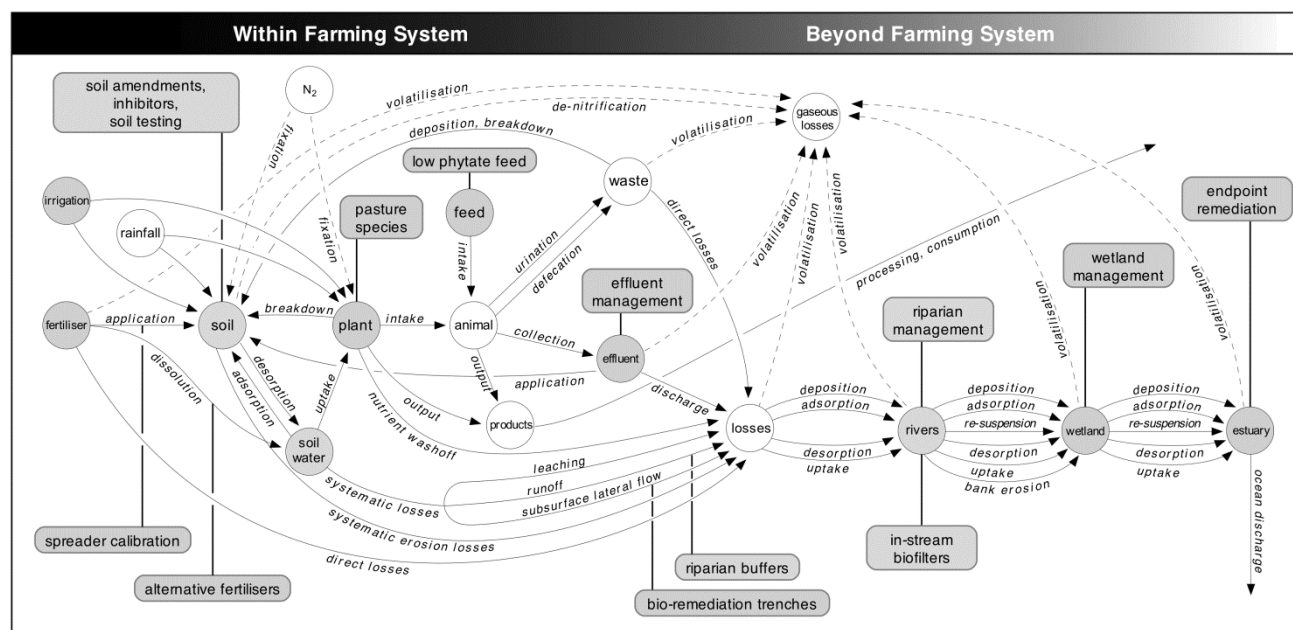


Figure 10.2 Phosphorus and nitrogen stores, transformations and pathways - nitrogen specific pathways shown by dashed lines (Gourley & Weaver, 2012).

10.2.1 Know the sources of nutrients

Nutrients on dairy farms come from inputs, such as [feeds and fertilisers](#), [redistribution or recycling](#), and, in the case of nitrogen, from nitrogen fixation by legumes.

10.2.1.1 Feeds, fertilisers and fixation

The relative importance of feeds and fertilisers in nutrient budgets shifts with different farming systems:

- If imported feed is less than 20% of the feed budget, then fertiliser is usually the main source of nitrogen, phosphorus, potassium and sulphur.
- If purchased feeds are more than 40% of the feed budget, then they tend to be the main source of nutrients.
- On low-input farms, with little imported feed or fertiliser application, nitrogen fixation can be the biggest source of nitrogen (Department of Primary Industries Victoria (n.d.)b.)

Fertilisers are usually the main source of phosphorus and highly water soluble forms, like superphosphate and Di-Ammonium Phosphate (DAP), are most commonly used in fertilisers. Water soluble phosphorus may be taken up immediately by plants and it may be readily transported by water, but this is dependent on the soil's ability to adsorb phosphorus (measured by its Phosphorus Buffering Index (PBI) – see [Section 10.2.3.3](#)).



The nutrient concentrations in feeds should be tested as they vary within and between different types. Forages and by-products are especially variable, compared to grains and pellets.

Annual fodder crops can 'harvest' surplus nutrients but they may require additional different nutrients and cultivation may increase the risk of losses through leaching or erosion.

10.2.1.2 Redistribution

Nutrients may be redistributed on-farm by stock in urine and dung, by recycling treated effluent and through harvesting and feeding out home-grown feeds such as silage or hay.

The Accounting for Nutrients project showed that cows on conventional farms spend approximately three-quarters of their time in paddocks (especially those close to dairies), 6% in laneways, 9% in yards and 2% in milking sheds. Changing where they spend their time can change where they redistribute nutrients, although cows tend to excrete more in response to certain stimuli, such as entering yards or crossing a creek (Davies-Colley *et al*, 2004).

Urine patches are sites of high nutrient concentration, especially nitrogen and potassium, which can increase pasture yield and the concentration of nitrogen and potassium in the forage. There is, however, an increased risk of ammonia loss and nitrate leaching from these patches.

Dung is another source of nutrients that can be redistributed over the farm via stock or collected and spread as fertiliser.

Recycling treated effluent onto paddocks can effectively re-use and relocate nutrients. Risks occur when effluent is applied to saturated soils resulting in nutrient-rich run-off, and when the same area continuously receives effluent resulting in high soil nutrient levels. An application of 100mm of effluent can equate to 34 kg of phosphorus and 210 kg of nitrogen (Rivers & Dougherty, 2009).

10.2.2 Understand nutrient stores and transformations

To optimise the productive value of nutrients and assess their risk to the environment, it is important to understand how different nutrients cycle through the soil, plants and environment – e.g. whether they are lost, transformed, or stored. In general, phosphorus, potassium and sulphur may be stored, but nitrogen isn't. This section covers:

[Transformations](#)

[Stores](#).

10.2.2.1 Transformations

Nutrients cycle through the environment. That is, they move through the soil, plants, animals and atmosphere; between inorganic and organic forms; and through soluble, insoluble and sometimes gaseous forms. For more information on nutrient cycles, see [Chapter 3.3](#)

The observed concentrations of nutrients in waterways may vary with 'in-stream processes' such as dilution by high flow rates or deposition in slow-flowing water; or through processes such as adsorption to, or desorption from sediments, and uptake by algae or plants.

Nitrogen is not generally stored in the environment and can be readily lost as water-soluble nitrate through runoff or leaching, or in gaseous forms such as nitrous oxide through denitrification or ammonia through volatilisation. This is one reason why the efficiency with which applied N is converted to produce is relatively low. Nitrogen may also be 'immobilised' or stored as organic nitrogen through incorporation in plants, soil organic matter, fungi and bacteria. Detailed analysis of 11 dairy farms found 50% of the nitrogen lost was via leaching and 48% via volatilisation; with 2% by denitrification (Gourley *et al*, 2011).



As the following graphs show, total nitrogen inputs are related directly to milk production – and to nitrogen surpluses. It cannot be concluded that all surplus N will be uniformly lost to the environment, as an array of factors will influence that including temperature, pH, moisture levels and the amount of organic matter present. However, increasing surpluses do increase the risk of nutrient losses to the environment.

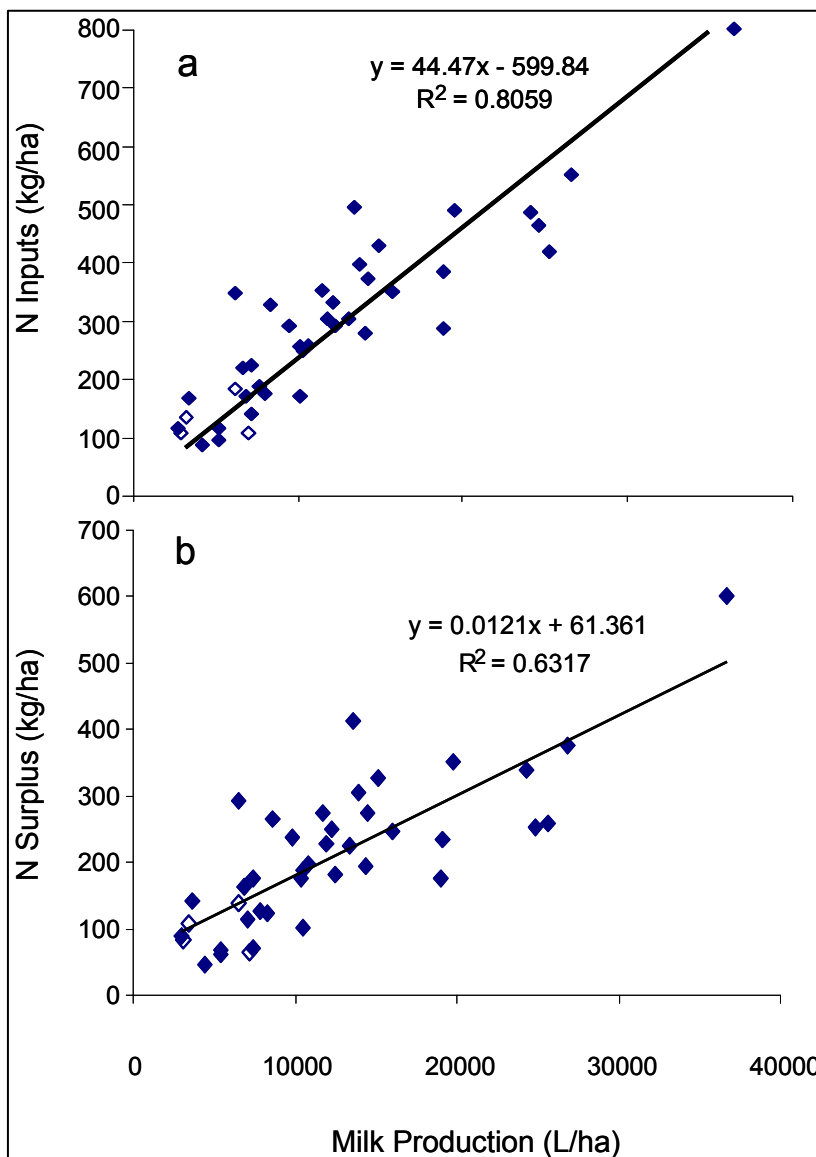


Figure 10.3 Relationship of N inputs to production and surpluses for 41 contrasting dairy farms across Australia - unshaded symbols represent organic dairy farms. (Gourley & Weaver, 2012)

The Accounting for Nutrients project found wide variations in nutrient conversion efficiencies. Conversion efficiencies relate to the proportion of nutrient entering the farm that is converted into saleable product such as milk or meat, or in other words, nutrient outputs divided by nutrient inputs. These wide variations as listed below, suggest that many farmers have scope for improvement:

- Nitrogen surpluses on Australian dairy farms ranged from 47 – 601 kg N/ha/yr and Nitrogen Use Efficiency ranged between 14%-50%.
- Nitrogen surpluses averaged 12 grams of N per litre of milk which is similar to those found overseas in Europe, the US and New Zealand.



- Phosphorus Use Efficiencies averaged 29%, but were very variable, with some exceeding 100% if inputs failed to match losses in product (Gourley & Weaver, 2012 and Gourley *et al*, 2012).

10.2.2.2 Stores

Phosphorus is stored in the soil with higher concentrations in the surface layer of soil, but it may be present in forms which are inaccessible to plants. Soils differ in their ability to hold phosphorus (as measured by their Phosphorus Buffering Index – see [Section 10.2.3.3](#)) and are also affected by their acidity. In acidic soils, phosphorus may become locked up by aluminium and iron, while calcium or magnesium phosphates may form in neutral or alkaline soils.

10.2.3 Know how nutrients are lost

Nutrients are removed from dairy farms via:

- [Produce](#) – milk, hay and livestock,
- [Atmosphere](#) – as gases or as particulate matter (e.g. wind-blown soil),
- [Water and erosion](#) – in surface water or ground-water, and through water erosion from paddocks or stream banks.

Taking action to reduce losses of a certain form can result in increased losses of another form – termed ‘pathway swapping’ – see [Section 10.2.3.3](#). For example, nitrogen may be lost as nitrate, ammonia or nitrous oxides. Restricting one pathway may open another, although the losses may occur at a different rate. Managers may have to set priorities.

10.2.3.1 Produce

Livestock sales usually only account for a small amount of the nutrients exported from a dairy farm in produce. Hay can be a larger source, and it is usually high in potassium and nitrogen. In terms of produce leaving the farm, milk is the largest nutrient exporter on a dairy farm.

10.2.3.2 Atmosphere

Around half the nitrogen present in urine and faeces occurs as ammonia; a form which may be readily lost to the atmosphere. Manure, and effluent treatment, can also result in the release of nitric oxide and nitrous oxide, a potent ‘greenhouse gas’ (Birchall *et al*, 2008). Wet soils can also be sources of nitrous oxides.

Methane, another greenhouse gas, is produced in the rumen of cows and from the biological treatment of effluent. In terms of greenhouse impact from established dairy farms, the two main contributors are methane from the rumen and nitrous oxide from urine and nitrogenous fertilisers.

Wind erosion is not usually a big issue on dairy farms, although dust from yards and feedpads may be; and would carry nutrients with it.

10.2.3.3 Water and water erosion

Water-borne nutrients may be transported via surface water run-off or sub-surface flows (leaching). Spaces between soil particles such as macro-pores, earthworm holes and decayed roots, provide ‘preferred pathways’ for sub-surface flows, but water will also move through the soil matrix itself. Water may also erode soil particles, removing them and the nutrients within. Erosion may occur in paddocks, along tracks or from stream banks.

Understanding these pathways requires consideration of:

- Run-off and drainage
- Nutrient concentrations
- Connectivity



- Effluent ponds
- Pugged soils
- Sealed surfaces
- Surface cover
- Wetlands
- Riparian buffers
- Stream-bank erosion

Run-off and drainage from rainfall or irrigation are key drivers of water-borne nutrient losses. Nutrient movement is proportional to water movement. Episodic events (storms) can be a major force, with studies finding 30% and 69% of annual losses occurring in a single storm (Holz, 1997 and Nash & Halliwell, 1999).

The amount of water moving and the rate at which it moves is affected by many factors besides climate, such as soil type, slope, landform, surface cover and sub-surface geology. Different combinations of factors result in different pathways being important – and in variable losses across farms. Some parts of a farm will lose nutrients more readily than others. Areas of higher potential loss are referred to as ‘**Critical Source Areas**’ or ‘**Hot spots**’.

Nutrient concentrations are also important. The application of fertilisers, defecation by grazing stock and recycling effluent in paddocks, all immediately increase the concentration of nutrients. Run-off or infiltration soon after will consequently have high concentrations. However, the concentrations measured in paddocks decrease rapidly with time. Phosphorus from most fertilisers has a ‘half-life’ (the time for concentrations to halve) of less than 10 days (Nash & Halliwell, 1999) and for N it is less than 2 days (Barlow et al, 2007).

Nutrient concentrations due to effluent recycling will be influenced by the ‘depth’ or volume of effluent and the rate and frequency of application.

Trade-offs: pathway swapping.

Applying nitrogenous fertilisers after rain will reduce the risk of N loss as water-borne nitrate. However, to reduce losses of N as gaseous ammonia from volatilisation, it is recommended that fertilisers be applied within a day before expected rainfall or irrigation (Barlow et al, 2007). Reducing atmospheric losses can require a trade-off; increasing the risk of water-borne losses.

The concentration of phosphorus in surface run-off is proportional to the concentration of phosphorus in the surface layers of soil with which it is in contact – and inversely related to the Phosphorus Buffering Index (PBI) of the soil. That is, soils that are high in available phosphorus and have little capacity to hold additional (or ‘buffer’) phosphorus (low PBI), are most likely to result in high concentrations of phosphorus in surface run-off, as shown in the following graph. The risk of losses occurring increases as soil phosphorus concentrations increase and soil is saturated with phosphorus (Dougherty *et al*, 2010; Weaver & Wong, 2011; Bolland & Russell, 2010).

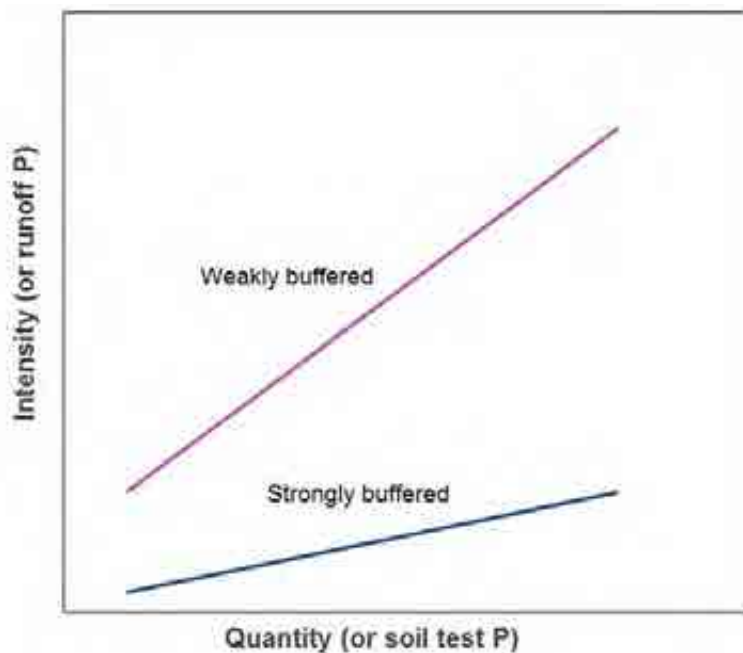


Figure 10.4 Runoff P concentrations (Dougherty *et al*, 2010)

Critical concentrations of phosphorus for maximum pasture production also vary with the Phosphorus Buffering Index of soils, as demonstrated by the following table.

Table 10.1 Critical P levels (DPIV, 2011)

| PHOSPHORUS BUFFERING INDEX (Soil type) | CRITICAL COLWELL SOIL TEST P (mg/kg) | |
|---|---|-----------|
| | Pasture performance compared with potential | |
| | 90% - 95% | 95% - 98% |
| PBI 0-15 (Very sandy) | 15 - 23 | 23 - 30 |
| PBI 15-35 (Sand, Sandy loams) | 17 - 26 | 26 - 34 |
| PBI 35-70 (Sandy/Silty loams) | 19 - 30 | 30 - 39 |
| PBI 70-140 (Sandy/Silty clay loams) | 22 - 35 | 35 - 45 |
| PBI 140-280 (Clay loams) | 26 - 42 | 42 - 54 |
| PBI 280-840 (Clay loams & Clay) | 37 - 58 | 58 - 75 |
| PBI >840 (Volcanic clays & Peat) | 50 - 90 | 90 - 120 |

With regard to environmental impacts, ‘**connectivity**’ is another important factor. If nutrient-carrying water flows from a critical source area directly to a water body, then more nutrients will enter that water body, than if the ‘connection’ was via considerable overland flow where sedimentation would remove nutrients. However, connectivity is not just a factor of physical location. Soils that are saturated will have stronger connectivity with adjacent sites than will dry soils that hold water with little run-off. Artificial drainage can increase connectivity and larger storms will have more connectivity than small ones.

Inadequate or poorly maintained **effluent ponds** can be sources of direct loss of water-borne nutrients to the environment. Problems can include insufficient free-board to handle input surges or insufficient storage capacity to hold effluent when conditions dictate against it being recycled in paddocks (e.g. saturated soils not suitable for irrigation).



Pugged (saturated and compacted) soils have low infiltration rates and hence high run-off. They are also sites of increased nitrogen loss through denitrification and can be liable to erode. If they occur in low-lying areas, where water and nutrients from adjacent paddocks accumulate, they can be critical source areas for nutrients. Draining such areas will transport nutrients as well as water – making management of the drainage water crucial if environmental risks are to be managed.

Sites of heavy stock use which are **compacted or sealed** (e.g. laneways near milking sheds, yards, feedpads, troughs and gates) have high concentrations of nutrients and run-off rates. Although loaded with nutrients from manure and urine, they are often only a small area of a dairy farm, hence their total contribution to losses may not be as significant as appearances may suggest. Their 'connectivity' with vulnerable environments will be another factor in assessing their risk. For more information see; Monaghan & Smith (2012), Lucci *et al* (2012) and Dougherty & Hossain (in-print).

Cultivated paddocks or those with little **surface cover** such as emerging fodder crops, are potential sites for soil erosion, subject to features like slope, length of run, rainfall or irrigation intensity and soil type.

Wetlands can be very effective in 'mopping up' excess nutrients and preventing them from leaving a farm, but there are a number of caveats about that. Wetlands can be considered as sinks which work well until they are full or saturated, at which time they can then become sources of nutrient. Constructed wetlands are made in a way to permit their periodic cleaning out to avoid that problem. The other main challenge for wetlands is their ability to take flood waters. If floods (when most nutrient movement occurs) simply flow straight over a wetland or run through it very quickly, then they have minimal impact on reducing peak loss events.

Riparian buffers ('filter strips' adjacent to waterways) play a similar role to wetlands and face the same performance issues.

If the riparian areas include vegetated stream banks, then that can help stabilise the banks and reduce **stream-bank erosion** – which can be significant in some soil types. Stream flow-rate is another key factor in stream-bank erosion. Although it is driven by flows and run-off in upstream areas, slowing the flow of water as it leaves farms is one way to help reduce flow-rates in streams; and, in suitable circumstances, reduce stream-bank erosion – see [Section 10.5.2](#).



10.3 Plan to retain nutrients

The keys to nutrient planning are:

- [Analyse farm nutrient status.](#)
- [Determine production potentials.](#)
- [Assess risks and identify critical source areas.](#)
- [Document a plan.](#)
- [Monitor and evaluate.](#)

These steps align with the annual nutrient planning cycle as follows:

| NUTRIENT PLANNING | ANNUAL CYCLE | NUTRIENT PLANNING | ANNUAL CYCLE |
|---|--------------|--------------------|--------------|
| Analyse | Step 1. | Document a plan | Steps 4 & 5. |
| Production potential | Step 2. | Monitor & evaluate | Step 7. |
| Assess risks | Step 3. | | |
| Step 6 (Implement) is covered in the following sections 10.4 & 10.5 | | | |

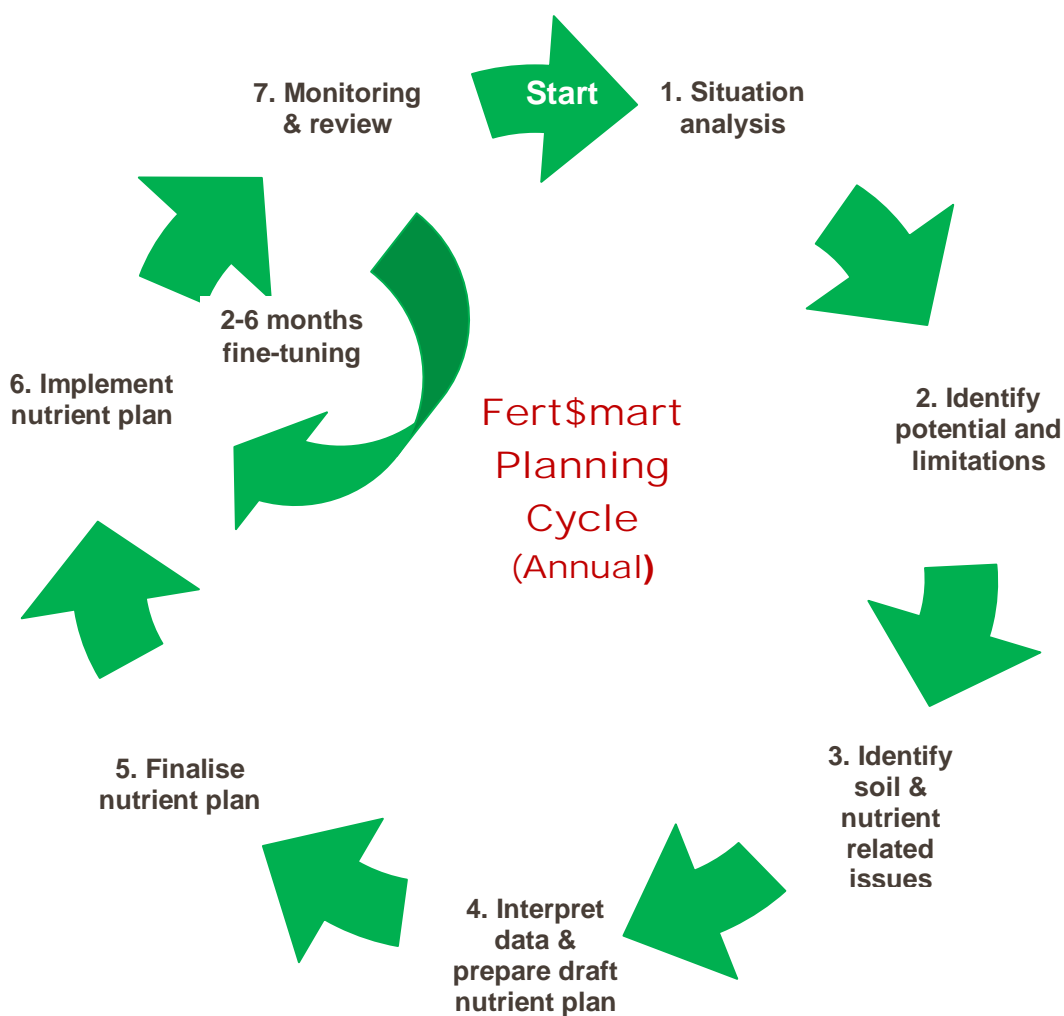


Figure 10.5 Annual nutrient planning cycle.



10.3.1 Analyse farm nutrient status

Important tools to understand a farm's nutrient status are:

- [Soil test and nutrient maps](#)
- [Nutrient budgets.](#)

10.3.1.1 Soil test and nutrient maps

Farm management zones (areas with similar physical features and management) should be soil tested regularly (see [Chapter 15.3.1](#) for more detail). The results should be considered as part of a time series to note any trends.

It is useful if soil nutrient status can be mapped to identify paddocks with high nutrient levels and those with low levels. Maps make it easy to see the paddocks that are potential 'critical source areas' for nutrient loss and where less fertiliser could be applied. Nutrient maps also visually assist in readily identifying where ameliorants such as lime are needed; or where there are opportunities to redistribute excess nutrients, for example in low nutrient status paddocks in which effluent could be recycled.

10.3.1.2 Nutrient budgets

Nutrient budgets (see [Chapter 15.5](#) for more information) provide additional perspectives on nutrient status. They provide insight into the efficiency with which nutrients are converted to produce and highlight potential risks and opportunities for improvement, such as striving to better match inputs against losses. As indicated in the following table, as farm productivity rises due to additional inputs (such as imported feeds) so too may the nutrient surplus.

Table 10.2 Potassium and phosphorus budgets. (Gourley *et al*, 2007).

| Potassium and phosphorus inputs in feed, outputs in milk, and difference, for three stocking rates (2, 3 or 4 cows/ha) in a wet (1998-99) and dry (2000-01) season in Victoria. | | | | | | |
|--|-----------|-----------|-----------|-----------|-----------|-----------|
| | 1998-99 | | | 2000-01 | | |
| | 2 cows/ha | 3 cows/ha | 4 cows/ha | 2 cows/ha | 3 cows/ha | 4 cows/ha |
| <i>Potassium (kg/ha)</i> | | | | | | |
| Feed | 28 | 52 | 74 | 39 | 107 | 184 |
| Milk | 19 | 29 | 36 | 20 | 30 | 36 |
| Difference | +9 | +23 | +38 | +19 | +77 | +148 |
| <i>Phosphorus (kg/ha)</i> | | | | | | |
| Feed | 7 | 15 | 23 | 9 | 22 | 38 |
| Milk | 10 | 15 | 19 | 10 | 16 | 21 |
| Difference | -3 | 0 | +4 | -1 | +6 | +17 |

For more information on nutrient budgets, see Gourley *et al*, 2007.

10.3.2 Determine production potentials

Unlocking the productive potential of a farm involves:

- [Nutrient targets](#)
- [Soil limitations](#)
- [Redistribution options](#)

10.3.2.1 Nutrient targets

Nutrient budgets combined with feed budgets are a first step to ensuring adequate nutrition for pastures and livestock. Setting nutrient targets for soils – to optimise production yet minimise risks of environmental loss – is another important step. Areas where nutrient targets have already been



achieved for phosphorus may be prioritised as locations in which P applications may be reduced or halted.

10.3.2.2 Soil limitations

In some situations, plants are not able to make use of the nutrients that are present due to other limiting factors. As examples, soil pH may not be suitable and the nutrients may be bound to other elements or the soil may be saturated and plant roots unable to function due to a lack of oxygen, curtailing nutrient uptake. In such situations, simply adding more nutrients will do little to improve productivity but much to increase the risk of nutrient loss, whereas rebalancing the pH or improving soil structure will unlock existing potential.

10.3.2.3 Redistribution options

Options for redistributing nutrients should also be assessed from a cost:benefit perspective. Nutrient budgets for farm management zones and farm nutrient maps may identify some options (e.g. cutting hay in high nutrient (especially potassium) paddocks for feeding out in low nutrient paddocks, applying effluent to low nutrient areas, or changing grazing pressures between paddocks), but management factors and costs must be considered to determine which options are realistic.

10.3.3 Assess risks and critical source areas

Assessing risks involves identifying hazards then considering the likelihood of them occurring and the potential consequences or effects, should the hazard eventuate.

Risk = Likelihood X Consequence.

For dairy farms, water-borne nutrients often pose the major risk to the local off-farm environment. As such, water movement either above or below the surface, is a key driver and a big influence on risk. Identifying critical source areas is an important step in assessing the risk of nutrients being lost from a farm.

Dairy farmers are used to managing nutrients as a fundamental input to controlling economic and productivity risks. For efficiency and sustainability reasons, farmers will increasingly have to also assess the environmental risks of nutrient inputs.

10.3.3.1 Hazards

'Cracking the Nutrient Code' (FIFA, 2001) was developed by Fertilizer Australia and presents a framework for assessing hazards, likelihoods and consequences at a farm scale, including practices checklists. It includes questions to help assess the likelihood and consequences of risks concerning nutrient stores or imbalances and losses, grouped as:

- **Load** – excess nutrients, e.g. exceeding optimal soil concentrations.
- **Mine** – depleting nutrient stores, e.g. downward trending soil nutrient concentrations that are below optimal levels.
- **Run** – losing nutrients in surface run-off, e.g. steep, high rainfall country which is high in nutrients.
- **Leach** – losing nutrients in sub-surface water movement; e.g. shallow water tables in permeable soils.
- **Blow** – losing nutrients to the atmosphere, e.g. wind erosion of dry, exposed soils.

When considering hazards associated with water-borne nutrients it is often useful to also consider the hazards associated with water-borne dairy pathogens. Pathogens can travel via similar pathways to nutrients and some management innovations to contain nutrient losses will also reduce the risk of pathogens entering waterways.



10.3.3.2 Likelihood

The dairy industry has developed several tools to help assess risks.

The **Farm Nutrient Loss Index** (FNLI) considers management practices, climate and the physical characteristics of different farm management zones likely to be at risk of losing nutrients to the environment. The tool can provide detail to help apply the Fertilizer Australia framework and identify potential 'critical source areas' on individual farms. It can remove some subjectivity from an assessment. Coupled with the Dairy Self Assessment Tool (**Dairy SAT**) – a best practices checklist – the FNLI provides some quantitative input to qualitative assessments such as '**Cracking the Nutrient Code**'.

For more information on the FNLI and DairySAT see the 'tools and guidelines' at:

www.dairyingfortomorrow.com.au.

For more information on Cracking the Nutrient Code, see:

http://www.fifa.asn.au/default.asp?V_DOC_ID=840

It is essential that risk assessments consider:

- those areas of a farm likely to pose most risk (critical source areas),
- management practices likely to be a hazard, and
- the location of individual farms in their catchment context (e.g. degrees of connectivity).

'**Understanding Dairy Catchments**' is a tool to help assess risks for dairying in a catchment context. It helps users understand the critical links between the management of different areas and the likelihood of negative impacts for a catchment. For more information see:

<http://www.dairyingfortomorrow.com.au/index.php?id=55>.

10.3.3.3 Potential consequences

The significance of an impact on the environment can be considered in light of the value of the environmental asset in question and the vulnerability of the asset. In this context, environmental assets are things like lakes, rivers, estuaries and wetlands, and the plants and animals they support.

The Commonwealth Government's Environment Protection and Biodiversity Conservation Act and associated website (<http://www.environment.gov.au/epbc/>) provide a good place to begin to assess the significance of an asset. It includes lists of threatened flora and fauna including migratory birds, ecological communities and critical habitats. Internationally important wetlands listed under the Ramsar Convention are also recorded along with information on nationally important wetlands. Similar lists and protection measures may also be relevant from a State or regional level.

The vulnerability of the asset to an impact is affected by the asset itself – e.g. whether the asset is able to recover from an impact or if it will suffer permanent, irreversible change – and the impact; e.g. its severity and extent, and whether it is a sudden impact or a cumulative one in response to gradual changes. Characteristics of the local environment (or 'receiving waters') will help determine some of those aspects. For example, a high energy coast with strong flushing coastal currents (an 'open' system) will usually be more resilient than a shallow, low energy terminal lake into which streams drain (a 'closed' system). The social characteristics of local communities may also be relevant, with some communities being highly aware and concerned regarding the environment.

When considering nutrients, concentrations are often important in assessing immediate threats but loads (the amount of nutrient in the water-body over time) and budgets are important in understanding how concentrations may change over time, and if systems are on the verge of being overloaded or saturated. Once saturated, wetland ecosystems may become much more sensitive to small additional loads of nutrients which may trigger major, irreversible changes in the environment.



When assessing potential consequences, it is useful to know whether short term nutrient concentrations or long term loads pose the greatest threat to the environment (Kleinman et al, 2011). Catchment management officers may be able to help work this out and provide directions to programs with support for on-farm change.

10.3.4 Document a plan

The nutrient management plan, (including the recycling of effluent, redistribution of nutrients between paddocks and rebalancing soil chemistry) should fit within a whole farm management plan. In regard to fertilisers, its focus will be on determining which fertilisers to use, where, when and in what amount (see the '[4Rs](#)' Framework - the right sources of nutrients, in the right place, at the right rate and right time).

Considerations in a whole-farm context include:

- **Nutrient balance.** Inputs need to replace outputs in produce plus unavoidable losses. For phosphorus, inputs must also provide for the buffering capacity (PBI) of the soil (Weaver & Wong, 2011).
- **Critical levels.** Inputs should achieve critical soil concentrations to optimise production but not exceed them or any known critical levels that increase the risk of loss to the environment.

For more information see [Chapter 16](#).

10.3.5 Monitor and evaluate

Keeping an eye on how the nutrient management plan is being implemented and the impact it is having on production, soil nutrient levels and profit will be an on-going exercise. Observations from that monitoring, and any trends, will help fine-tune the plan for the future (See [Chapter 1.7](#)).

As part of the evaluation it is also worthwhile estimating the savings being generated from improved nutrient management. The simplest measure may be a reduction in fertiliser costs or a reduction in the application of specific nutrients (e.g. phosphorus applications may not be required). Revisiting whole-farm or management zone nutrient budgets may be another way to consider the reductions in nutrient loss due to improved management.



10.4 Optimise production

The keys to optimising production, in terms of converting nutrients into milk, are:

[Get top value from low risk areas](#)

[Recycle nutrients](#)

[Optimise irrigation efficiency](#)

[Consider stock as a management tool](#)

10.4.1 Get top value from low-risk areas

A good way to ensure nutrients are not lost to the environment is to use them in production – converting them to produce. For example, if higher rates of nitrogen are being applied, then higher rates of stocking are needed to make use of extra pasture growth. Optimising production from areas that are more resilient and a lower-risk in terms of nutrient loss is one way to profitably manage risk at a farm scale. That is, strive for peak production in resilient areas, and reduce the pressure on critical source areas.

10.4.2 Recycle nutrients

Effluent can be a valuable source of water and nutrients when treated as an irrigation supply and/or applied in the [4Rs](#) framework. Recycling effluent can reduce risks to the environment and optimise production without additional fertiliser inputs.

Infrastructure is a key to optimising the productive value of effluent. There must be adequate storage capacity for the effluent, the ability to get treated effluent to where it will be useful and an appropriate irrigation or spreading system. Separating solids and liquids can make effluent recycling an easier proposition.

10.4.3 Optimise irrigation efficiency

Excess (lost) water inevitably means lost nutrients on a dairy farm. Optimising water use efficiency to minimise water loss will drive measures of production (yields of dry matter / mega litre) while containing nutrient loss. The approach should be the same when irrigating water and recycled effluent. An irrigation and drainage management plan is a useful tool to help design appropriate infrastructure and to develop a plan for scheduling irrigation, including irrigating with recycled effluent.

10.4.4 Consider stock as a management tool

Options to redistribute nutrients through grazing patterns and feed transfers are discussed in [Section 10.2.1.2](#), and can be an effective aide to optimal productivity. Another practice to reduce nutrient losses and optimise production is by managing grazing pressure to avoid wet-soil pugging by the use of on-off grazing; keeping pastures productive for longer and avoiding higher risks of nutrient loss from compacted, saturated soils.



10.5 Minimise losses

The keys to minimising nutrient losses are:

[Avoid direct losses](#)

[Reduce and reuse run-off](#)

[Lock-up excess nutrients](#)

10.5.1 Avoid direct loss from fertilisers, effluent and livestock

Direct losses are losses of nutrients from the farm system through a pathway with direct off-farm connectivity, e.g. by spreading fertiliser over flowing surface water. These can be almost immediate and come from inadequately managed:

- [fertiliser applications](#),
- [effluent](#) or
- [livestock](#).

10.5.1.1 Avoid direct loss from fertilisers

Some potential fertiliser losses are easy to avoid:

- No applications direct to surface waters such as drains, creeks and dams – maintaining a buffer between fertilised pastures and surface waters or drains.
- No applications to ‘hot spots’ – avoiding critical source areas with strong connectivity; such as pugged paddocks adjacent streams or bare soils, laneways and yards.
- Minimise irrigation run-off – ensuring there is no run-off after applying fertilisers, or not applying fertilisers to a buffer strip at the end of irrigation bays.

Others require some planning:

- No applications of nitrogen within 5 days of an anticipated run-off event.
- Minimise ammonia volatilisation from urea applied during the warmer months by irrigating fertiliser into the soil, but avoid run-off. Where irrigation is not possible, losses can be reduced significantly by applying urea 2-3 days before grazing (Warning: lumps of urea ingested by animals can cause ammonia toxicity). See [Chapter 12.3](#) for further information regarding minimising nitrogen losses.
- No applications of phosphorus within 7 days of an anticipated run-off event or when soils are freely draining after heavy rains.

To reduce nutrient losses from fertilisers it is necessary to consider the ‘4Rs’ framework of:

- [Right source](#),
- [Right place](#),
- [Right rate](#), and
- [Right time](#).

Right source

Stable, slow release, forms of fertiliser pose least risk to the environment, but may not be cost effective or necessary in many situations. Using fertilisers of low solubility can reduce losses by 0-20% depending on the circumstances (McDowell & Nash, 2012). See [Chapter 11](#) and [Chapter 12](#) for information on how to select the right source of fertiliser for different situations and conditions.

Right place

Special attention is needed for critical source areas and to avoid direct applications to water-ways. Following the [Fertcare program guidelines](#) for application will address those concerns. Select areas with low nutrient levels for added applications. In cultivation paddocks, ensure pre-plant fertilisers are incorporated and covered by loose soil.



Right rate

A common goal is to meet the needs of plants by ensuring nutrients, particularly N, K and S, are available at rates to match plant uptake. Nutrient types and rates should be targeted for different areas of the farm based on soil test results, critical levels for plant growth and nutrient budgets. Some 'rules of thumb' are summarised below and can be seen in full at:

<http://www.nitrogen.unimelb.edu.au/> :

- Apply N at 30-50 kg/ha per application to meet plant growth requirements, at intervals of at least 21 – 28 days respectively during periods of active plant growth.
- Where annual N applications exceed 250 kg N/ha/yr, soil testing and applying lime may be required if fertilising at higher rates in high production paddocks.
- Don't apply P if soil test levels are above those where a pasture response is likely. The critical level will vary with the phosphorus buffering capacity (PBI) of the soil and the desired level of production from the paddock – Refer Figure 5.

Ensuring spreading equipment is [Accu-spread](#) accredited will result in an even distribution of fertilisers within the targeted application zone.

Right time

Timing applications to meet plant needs is a priority, for example as needed for Nitrogen. However, consideration must also be given to optimising uptake and minimising losses. Timing activities (e.g. not applying fertilisers when heavy rainfall and run-off is imminent) is a management option to reduce nutrient losses. Seven-day forecasts from the Bureau of Meteorology can be useful guides to help determine the risk of significant run-off occurring. Losses that may be controlled by management are sometimes termed 'incidental losses'. Avoiding run-off from irrigation is another example.

Applying nitrogen on a cool, dry surface, a day prior to adequate 'watering in' rain but not before heavy, run-off inducing rainfall is one way to optimise production and minimise losses through volatilisation and run-off.

10.5.1.2 Avoid direct loss from effluent

Effluent from milking sheds, feedpads and yards should be effectively captured and stored for treatment. Designing, and maintaining, correctly sized pre-treatment systems, ponds and sumps to cope with peak loads (e.g. capturing a 'first flush' in storms but diverting cleaner subsequent water) is the first step. Similarly, laneways (especially those subject to heavy traffic and/or draining direct to a water-body) should be constructed and maintained with adequate shape and crown to disperse nutrient-rich run-off in a low-risk manner. Constructing drainage diversion humps or 'whoa boys' that direct sloping laneway run-off to grassed areas is one way to achieve this.

The rule of thumb that recycled water should be applied as thinly as possible over as large an area as possible is as relevant to recycled dairy effluent as it is to other recycled wastewaters, although opportunities on dairy farms may be limited and require additional irrigation infrastructure. It is particularly important to avoid applying recycled effluent to saturated soils where run-off will occur. Having adequate storage capacity and irrigation capacity are fundamental for that. A soil-water budget can help in planning an appropriate system. If losses remain a risk, then additional treatment may be an option to reduce nutrient loads (e.g. high rate algal ponds, where nutrients from effluent help grow algae which are harvested for use as fertiliser or stock-feed, have been trialled to reduce phosphorus levels) (McDowell et al, 2004).



Effluent irrigation systems may be prone to blockages, which can in turn lead to stoppages or overflows, which result in run-off. Having fail-safe tools like breakdown alerts and automatic shut-downs can help manage that risk (Hanly, 2012).

Refer to [Chapter 13](#) for further information about using dairy effluent.

10.5.1.3 Avoid direct loss from stock

Keeping stock out of watercourses is a fundamental approach to keep nutrients and pathogens out of waterways. Fencing, creek crossings and alternative watering points are prerequisites. 'Hot spots' like troughs and gates should also be carefully sited.

Pugged areas with strong connectivity to water are a potential 'critical source area' and should not be grazed, to avoid direct losses. For more information on assessing pugging and planning recovery, see [GippsDairy \(2011\)](#). Changed grazing management (e.g. on-off grazing) or feedpads may be necessary.

10.5.2 Reduce and reuse run-off

Water movement is a key driver of risk, so reducing run-off and deep-drainage will help reduce the loss of nutrients from dairy farms. Irrigation should be managed to minimise overwatering and waterlogging and should consider the water holding capacity of the soil type. Irrigation systems that result in good distribution uniformity (low pressure systems) and scheduling based on plant water usage and accurate soil moisture monitoring equipment can assist in this regard.

It is necessary, however, to consider individual farms and sub-catchments in their own right, as general rules do not always apply. For example, while boggy areas on farms may have been drained to increase production, there can be merit from a nutrient management perspective in some locations in slowing the flow of water and reducing run-off. Taking a whole-farm, or even sub-catchment, view can help to identify opportunities to retain water and nutrients in a useful manner (e.g. to maximise water use efficiency as measured by pasture production / mm of rainfall) and to slow the rate of flow in local streams and hence reduce stream-bank erosion.

This may be as simple as retaining thick grass buffers adjacent to water lines, especially small streams in paddocks. At the other extreme, it could be constructing an artificial wetland to take water from low-lying areas or for water drained from boggy areas. Care should be taken with natural wetlands, but there may be opportunities to reduce stock access or reinstate wetland vegetation and increase their capacity as a nutrient sink, without harming their ecology.

An option for flood irrigation is to not fertilise the end of bays, providing a buffer as recommended for waterways, and to avoid run-off. Re-use dams may also be installed, increasing the efficiency of water use and recycling nutrients.

Avoiding water movement that results in erosion will also reduce the loss of nutrients from farms. Permanent pastures and adopting conservation tillage during pasture renovation or the growing of fodder crops will help maintain groundcover (e.g. retaining residues or sowing cover crops), surface roughness and infiltration. Careful periodic deep cultivation can also be beneficial, incorporating nutrient rich top-soil within the deeper soil profile and closing off macro-pores through which P may be lost (McDowell *et al*, 2004). Diversion or contour banks can also slow water movement on sloping grounds.

Rehabilitating any eroding areas (including streambanks in some situations) and ensuring there is good ground-cover will retain soil and reduce the loss of nutrients. As with buffering waterways, it can be relatively easy and very beneficial to work on small order streams within paddocks.



10.5.3 Lock-up excess nutrients

Applying soil ameliorants to 'lock-up' nutrients may be an option for some situations; especially when focused on critical source areas - and when it makes the saved nutrients available for plant uptake.

For example, in Western Australia, bauxite has been applied when available as an economically feasible way to retain phosphorus in sandy, at-risk soils. Research is also showing that nitrification inhibitors can work in the field; although practical, well-tested applications have not been available for conventional Australian dairy farms (Eckard *et al*, 2008) but work is ongoing in this area. The N-inhibitors work by reducing the rate at which ammonium from the main sources, fertilisers and urine, is converted to nitrate and nitrous oxide. The process gives plants more time to take up both ammonium and nitrate ions, meaning more fertiliser is available to, and is used by, pastures; increasing productivity and reducing environmental losses (Cameron *et al*).



10.6 Summary

In this section:

[Significance](#)

[Best practice checklist.](#)

10.6.1 Significance

Losing nutrients from a dairy farm is:

- wasting increasingly expensive inputs, effectively increasing the cost of production per litre of milk, and
- increasing the risk of adverse environmental impacts.

The waste of important nutrient resources and the risk of adverse impacts may trigger community responses which result in increased regulation of farming activities and/or market reactions and trade barriers.

Keeping nutrients on farm can improve gross margins and enable dairy farmers to proudly promote their sound environmental ethics.

10.6.2 Best practice checklist

In this section:

[Management principles and strategies](#)

[Management practices.](#)

10.6.2.1 Management principles and strategies

The key strategies to retain nutrients on dairy farms, and optimise production and profit, are:

Understand nutrients in the environment

- Know the source of nutrients
- Understand nutrient stores and transformations
- Know how nutrients are lost

Plan to retain nutrients on-farm

- Analyse farm nutrient status
- Determine production potentials
- Assess risks and identify critical source areas
- Document a plan
- Monitor and evaluate

Optimise production

- Get top value from low-risk areas
- Recycle nutrients
- Optimise irrigation efficiency
- Consider stock as a management tool

Minimise losses

- Avoid direct losses
- Reduce and re-use run-off
- Lock-up excess nutrients



10.6.2.2 Management practices

Examples of how those principles may be applied, with reference to practices recorded in DairySAT, are:

[Print table>>>](#)

| | Understand nutrients | Plan to retain nutrients | Optimise production | Minimise loss |
|-------------|---|---|--|---|
| Soils | <ul style="list-style-type: none"> Understand the types of erosion occurring and their causes. | <ul style="list-style-type: none"> A plan is in place to minimise erosion. | <ul style="list-style-type: none"> Management minimises compaction and pugging. Irrigation is managed to minimise overwatering and waterlogging. Management avoids soil acidification. | <ul style="list-style-type: none"> Management minimises erosion. |
| Fertilisers | <ul style="list-style-type: none"> Understand why soil sampling is needed. | <ul style="list-style-type: none"> Correctly taken soil samples are regularly collected from representative areas. A farm nutrient management plan guides fertiliser applications. Soil constraints are considered when determining nutrient requirements. | <ul style="list-style-type: none"> Calibrated or Accuspread-accredited fertiliser spreaders are used. Effluent is used as a fertiliser with rates determined by soil nutrient (and water) requirements. | <ul style="list-style-type: none"> Buffers are used to protect waterways and drains from fertilisers. Additional nutrients are not applied to critical source areas. Fertiliser applications are timed to avoid run-off. |
| Effluent | <ul style="list-style-type: none"> | <ul style="list-style-type: none"> Ponds have been integrated into the farm plan. Ponds are correctly sized and managed. Manure stockpiles are sited away from sensitive areas and are banded. Feedpads are designed for appropriate effluent, | <ul style="list-style-type: none"> Effluent is retained on-farm and reused for productive gains. Effluent composition is tested and is suitably distributed to match application rates with soil, pasture and crop requirements. | <ul style="list-style-type: none"> Ponds are emptied regularly. Ponds are desludged when required. Sump/traps have sufficient capacity and spare pumps are on hand. Buffers are used to protect waterways and drains from effluent. |



| | | manure and waste feed management. | | |
|------------------|-----------------------------|---|--|--|
| | Understand nutrients | Plan to retain nutrients | Optimise production | Minimise loss |
| Irrigation | • | <ul style="list-style-type: none"> Seasonal water use is measured. | <ul style="list-style-type: none"> Irrigation scheduling is based on plant water use or soil moisture. | <ul style="list-style-type: none"> Management avoids run-off and deep drainage. |
| Greenhouse gases | • | <ul style="list-style-type: none"> Nitrogenous fertiliser sources are selected to minimise nitrogen losses. Effluent is tested for nitrogen levels. | <ul style="list-style-type: none"> Nitrogen is applied when pastures are actively growing and can use the N. Nitrogen fertiliser application rates are kept below 50 kgN/ha per application. Effluent application is timed to avoid wet conditions and maximise plant uptake. On/off grazing or stand-off areas are used to minimise pugging of wet soils. | <ul style="list-style-type: none"> Nitrogen is not applied to water-logged soils, before irrigation/heavy rains and for at least 2-5 days after irrigation/heavy rains. Nitrification inhibitor sprays are applied once or twice in wetter months. |
| Waterways | • | <ul style="list-style-type: none"> Farm plan seeks to improve native biodiversity and environments; e.g. through grazing management. | <ul style="list-style-type: none"> Stock are provided with alternative (non-riparian) watering points. | <ul style="list-style-type: none"> Riparian and wetland areas are fenced for stock control. Bare riparian areas are revegetated. |



10.7 References

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Chapter 11

Introducing Fertilisers

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11 Introducing Fertilisers

11.1 Introduction

In this Chapter:

[What is a fertiliser?](#)

[Fertiliser products](#)

[Nutrient Analysis of Fertiliser products](#)

Fertilisers come in many forms (for example, [liquid](#), [granular](#) and [organic](#)) and can contain one or more of the nutrients required by plants. When you know what nutrients your pastures need, you must then find the fertiliser or fertilisers that can supply those nutrient needs.

11.2 What is a fertiliser?

A fertiliser is any material added to the soil or applied to a plant to improve the supply of nutrients and promote plant growth.

Any natural or manufactured material that contains at least 5% of one or more of the three primary nutrients - nitrogen (N), phosphorous (P), or potassium (K) - can be considered a fertiliser. Industrially manufactured fertilisers are sometimes referred to as "mineral" fertilisers. Fertilisers contain varying proportions of plant essential major (N, P, K, etc.) and minor (Zn, Mn, Fe, etc.) elements, as well as impurities and other non-essential elements. This definition includes both inorganic (mineral) and organic fertilisers and also soil conditioners, such as lime and gypsum (discussed in Chapter 7), which may promote plant growth by increasing the availability of nutrients that are already in the soil or by changing the soil's physical structure.

11.3 Fertiliser products

Prior to the mid-1960s, only a limited range of fertiliser products was available in Australia. Advances in agricultural and manufacturing technology have resulted in a wider range of fertiliser products, and new terms are now being used to describe the fertilisers on the market.

Today, the term *fertiliser* is applied to a number of products. Those called *inorganic fertilisers* (sometimes called commercial, synthetic or artificial fertilisers) mostly contain chemicals with the essential plant nutrients in available forms, the production of which involves some industrial process. Examples include urea, superphosphate and muriate of potash. [Organic fertilisers](#) are made up of organic material containing carbon from animal and plant products. Examples of organic fertilisers include: animal manures, dairy and dairy factory effluent (refer to Chapter 13), compost and blood and bone.

The main terms used to describe fertilisers are further discussed below.

11.3.1 Low-analysis fertilisers

Low-analysis fertilisers are the less concentrated products. They have a lower percentage of nutrients in their analysis. Examples include single superphosphate. These products are made using a different manufacturing process to that used to make high-analysis fertilisers. As a result,



they have higher sulphur levels than the high-analysis fertilisers; and it is usually in the form of sulphate sulphur, which is readily available to plants.

11.3.2 High-analysis fertilisers

High-analysis fertilisers are the more concentrated products. They have a higher percentage of nutrients in their analysis. They cost more per tonne to purchase because they are more concentrated, but spreading and freight costs are reduced because you need less product to apply the same quantity of nutrient per hectare. An example of a high-analysis fertiliser is triple superphosphate.

11.3.3 Straight fertilisers

The term straight fertilisers is a bit misleading and not regularly used. It is more commonly used by the manufacturers in the factories. It is used to describe fertilisers that contain only one of the macronutrients, such as urea which contains nitrogen, or muriate of potash which contains primarily potassium.

Many of the 'straight' fertilisers, such as single superphosphate and sulphate of ammonia, also contain other essential nutrients, such as sulphur.

11.3.4 Compound fertilisers

Compound fertilisers are products that have been manufactured by a chemical reaction and contain two or more of the major nutrients. All granules are similar in size and contain the same nutrients. They are generally more expensive per tonne but not on a per kg nutrient basis than mixed or blended fertilisers. Examples include di-ammonium phosphate (DAP) and mono-ammonium phosphate (MAP).

11.3.5 Blended fertilisers or mixed fertilisers

Blended fertiliser is the term applied to fertilisers that are a physical mixture of one or more of the 'straight' or compound fertilisers. Examples include SuPerfect Potash 3 & 1, PastureBoosta, Greentop K, and HayBoosta. The fertiliser companies are now able to provide a wide range of blended products to suit specific nutrient requirements. Many of their blends are listed on their product list. You would need to contact them regarding the cost of special 'prescription blends'; that is, blends with stipulated types and proportions of nutrients (See Appendix F for a range of online product lists, including blends).

The final analysis of blended products will be the result of the overall proportions of the various products not simply an addition of the percentages.

For example: Super Potash 2 & 1 is a blend of two parts single superphosphate (each containing 8.8% P) and one part muriate of potash (which is 50% K). It's like putting two bags of superphosphate plus one bag of muriate of potash into a spreader and then mixing them together.

In essence you have two granules of single super phosphate containing 8.8% P for each granule of muriate of potash containing 50% K – Refer Figure 11.1.

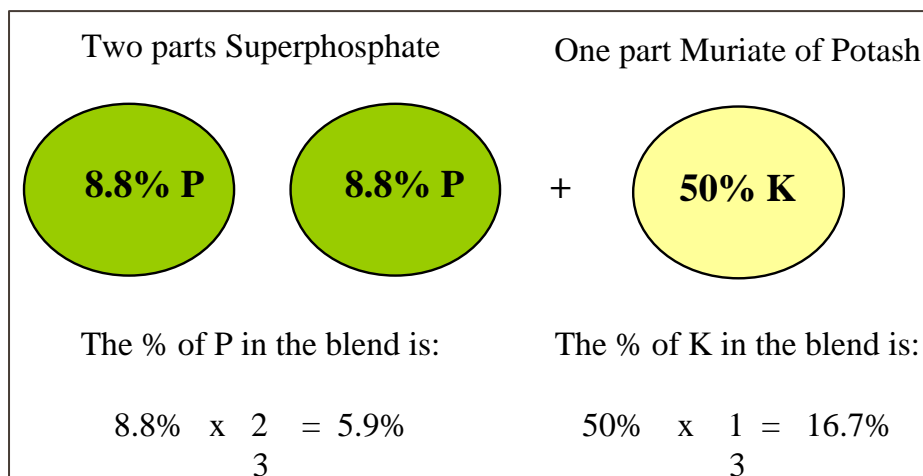


Figure 11.1 Diagrammatic representation of Super Potash 2 & 1 in granular form

11.3.6 NP and NPK fertilisers

The terms NP fertiliser and NPK fertiliser are often used in conjunction with the term ‘mixture’ or ‘compound’. They refer to fertilisers that contain nitrogen and phosphorus (NP) or nitrogen, phosphorus and potassium (NPK). See Chapter 12 for more information on nitrogen and nitrogen fertilisers.

11.3.7 Granulated or pelleted fertilisers

Granulated fertiliser or pelleted fertiliser is a term applied to fertilisers that have been treated in such a way that they form granules to improve handling and spreading.

Granulation provides a number of advantages: it reduces the quantity of fine particles in a fertiliser, and it increases the flow and ease of spreading.

11.3.8 Organic fertilisers

The term *organic fertiliser* generally refers to fertilisers supplied or manufactured from animal or plant by-products. Examples include blood and bone, compost, chicken manure, dairy effluent and fishmeal products. There are, however, blurred definitions of what exactly is an organic fertiliser. This is because other fertilisers not from animal or plant by-products, can be classified as Australian Certified Organic, including potassium sulphate, [reactive rock phosphate](#) and seaweeds.

Nutrients contained within organic fertilisers will be released at varying rates depending on the complexity of how they are bound, their form and solubility within the fertiliser. Some nutrients can be released quite rapidly (e.g. potassium and nitrates) however, in general organic fertilisers tend to be slower releasing than mineral fertilisers. In other words, it takes time for the nutrients to become available in the soil for plants. They also usually contain fewer nutrients per kilogram than the inorganic fertilisers.

Organic fertilisers supply varying quantities of the major nutrients: nitrogen, phosphorus, potassium and sulphur, as well as some trace elements; and their composition can be quite variable. Generally, unless using very high application rates, the kg/ha of a plant available nutrient provided from organic fertilisers is low and may not keep up with crop removal. Hence conventional mineral fertilisers may also be required to balance soil nutrients and to maintain optimal soil fertility. They also contribute some organic carbon to the soil, which may improve the soil structure. Table 11.1 shows the averages and ranges of the major nutrients (N, P, and K) for a variety of animal manures.



Table 11.1 'Typical' nutrient analyses (dry matter basis) for animal manures (average and ranges)

| SOURCE | NITROGEN (%) | PHOSPHORUS (%) | POTASSIUM (%) | MOISTURE (%) |
|------------------|-----------------|-----------------|-----------------|--------------|
| Poultry (cage) | 3.4 (2.8 - 4.8) | 2.5 (1.9 - 4.0) | 1.5 (1.2 - 2.1) | 35 (15 - 65) |
| Poultry (litter) | 2.6 (1.4 - 4.2) | 1.8 (1.6 - 2.8) | 1.0 (1.1 - 1.9) | 25 (10 - 51) |
| Cattle | 1.5 (0.7 - 2.5) | 0.5 (0.2 - 1.4) | 1.2 (0.7 - 1.8) | 40 (9 - 54) |
| Horse | 1.2 (1.0 - 1.5) | 0.2 (0.1 - 0.4) | 0.8 (0.3 - 1.0) | 35 (6 - 62) |
| Sheep | 1.7 (1.3 - 2.6) | 0.5 (0.3 - 0.8) | 1.2 (0.6 - 2.5) | 30 (8 - 60) |
| Pig | 2.3 (1.4 - 2.7) | 2.3 (1.4 - 3.7) | 0.6 (0.2 - 1.3) | 60 (50 - 76) |

Note: Moisture content must be taken into account when costing the nutrients provided in organic fertilisers and when calculating the rate of the spread nutrients.

For more information on organic fertilisers:

[Poultry manure](#)

[Making the most of animal by-products](#)

[Composting Spoiled Hay](#)

[Compost](#)

Dairy Effluent – See Chapter 13.

There has been interest recently in the use of various humic substances in agriculture, namely **humic acids and fulvic acids**. Humic substances are the major part of humus. They are naturally occurring products found in soils and other places that are the result of the decomposition of plant and animal residues. Humic acids are generally used either in a liquid form when applied to plant foliage, or in a solid form when spread and incorporated into soil. Humic and fulvic acids are generally combined with other synthetic inputs to form a commercial product.

There are numerous advantages attributed to these two humic substances including:

- Enhanced soil structure and fertility through the addition of vital organic matter in the soil;
- Efficient transfer of fertiliser nutrients and micronutrients;
- Increased microbial and enzyme activity in the soil;
- Increased plant availability of nutrients like phosphorus;
- Increased moisture holding capacity of soil; and
- Increased cation exchange capacity within the soil

However caution is urged to try these products first in a "[test strip](#)" capacity (See Chapter 8.6 for information on setting up test strips).

11.3.9 Trace elements or micronutrients

Trace elements or micronutrients are the terms applied to the essential elements for plant growth and animal health that are required in only small quantities. Trace elements can be added to most fertilisers to meet particular needs. The most commonly added trace elements in eastern Australia are molybdenum, copper, zinc, boron, selenium, and cobalt. It is rare, however, for all these trace elements to be required at the same time, or to be added in one product. See Chapter 3.4 for more information on trace elements.

11.3.10 Slow-release fertilisers

In order to better synchronise the availability of nutrients to plant demand and, in doing so, increase nutrient use efficiency, slow-release fertilisers have been developed. These fertilisers have been produced in such a way that they are not readily water soluble. Treatment usually involves coating



the fertiliser granules with a slowly soluble material, such as sulphur or wax. Because of the extra processes involved in coating the granule, these products are usually more costly than non-coated products. Examples of **coated slow-release fertilisers** include horticultural products, such as Osmocote.

Reactive rock phosphates are very slow release in that they dissolve slowly in acid soils to become available to plants naturally. Similarly, elemental sulphur must be converted to the plant-available sulphate sulphur form before it can be used by plants. Therefore, elemental sulphur is also considered a slow-release fertiliser compared to sulphate sulphur.

Fertilisers are now commercially available that modify or reduce the rate by which fertiliser nitrogen becomes plant available. Known as **nitrification inhibitors**, they have specific coatings or treatments that work by slowing the release of nutrients, or by delaying the conversion to less stable forms. The slower release of nitrogen during the nitrification process, and potentially greater nutrient use efficiency, is due to the inhibition of specific enzymes and nitrifying bacteria. By inhibiting these enzymes, more nitrogen is retained in the stable ammonium (NH_4^+) form. The effect of the inhibitors on specific nitrifying bacteria reduces the amount of the very soluble nitrate nitrogen which can be more readily lost through leaching and denitrification. For more information on the nitrification process and denitrification refer to Chapter 12.

11.3.11 Liquid fertilisers

Liquid fertilisers refer to nutrient solutions, suspensions and slurries and are usually sprayed onto pastures. According to the *Dairying for Tomorrow Survey* they are not widely used in the Australian dairy industry, apart from the spreading of dairy effluent (Dairy Australia, 2012). However, some nitrogen solutions are gaining popularity in northern Victoria, especially through fertigation under centre pivots.

11.3.12 Alternative fertilisers

The term *alternative fertiliser* refers to those products that fall outside the category of products generally known as fertilisers to the farming community.

Many products, making a wide range of beneficial claims, continually arrive on the market. When prices of conventional fertilisers rise, it is often tempting for some farmers to look towards alternatives. It is sometimes difficult to know whether alternative fertilisers will perform as claimed by the company. There are a number of checks that can be done to avoid costly mistakes, including the following:

- Ask for the nutrient analysis, and check the analysis was conducted by a reputable testing laboratory.
- Compare the product nutrient analysis, the form or plant availability of each nutrient, and the cost per kg of nutrients with other fertilisers - Refer to [Section 11.4.1](#) and Chapter 14 to work out nutrient costs.
- Check that nutrients contained in the product are required by the soil, plant or livestock.
- Ask for the research to back the product claims. Question the credibility of the research – was it a simple side by side demonstration or a replicated trial? Where was the research done – Australia or overseas? Was it conducted by an independent organisation? Was the research peer reviewed? Is it only anecdotal observation?



- Sometimes products may make claims which cannot be explained by their nutrient content or fertiliser value. In these cases, if the product works it would be due to some growth promotant effect and could not be directly compared with traditional fertilisers or manures. If you believe the products could be beneficial, but there is no existing product analysis or credible research to back the claims, reduce the risk by trialling the product with fertiliser test strips. Always include a nil strip and, if possible, include a standard product for comparison - Refer to Chapter 8.7 for details on setting up a fertiliser test strip.

Other alternative fertilisers include the various forms of manures, composts and biosolids. These have increased in popularity due to commercial fertiliser price rises and their contribution to soil health. It is important to weigh up the costs and benefits of alternative fertilisers in comparison to other products.

Biosolids, whilst being an attractive nutrient source, currently have to be incorporated into the soil within hours of application for legal and health reasons. This is obviously not feasible for pastures. In addition, there are concerns about substantial nutrient losses (nitrogen) and nutrient accumulations (trace elements and phosphorus) when this product is applied to the soil.

Manures and composts when applied to pastures will provide a range of nutrients (See [Table 11.1](#)) some being immediately available and others requiring decomposition before becoming plant available. The application of manures and composts to crops and pastures should not be on the basis of “getting rid of a waste product” but applied in accordance with soil nutrient requirements (See Chapter 15, Nutrient Planning).

11.4 Nutrient analysis of fertiliser products

When applying fertilisers it is important to be clear about the terms used. There are many colloquial and imperial terms lingering which can add to the confusion and create errors; for example, bags/acre or so many units of a particular nutrient.

As suggestions, when making **fertiliser recommendations**:

- Use the amount of *fertiliser product* per hectare; e.g. urea at 100 kg/ha.
- **Do not** mix imperial and metric measurements; e.g. kg/acre
- Keep in metric if possible
- Keep numbers rounded to nearest “0” or “5”; e.g. 10 kg/ha or 15kg/ha not 13.2 kg/ha.

Appendix A contains conversion tables to help you convert fertiliser application rates and weights from the imperial system to the metric system. Appendix B contains explanatory information about the metric system.

11.4.1 NPKS system

The NPKS system describes the **nutrient analysis** of a fertiliser in terms of the percentage of nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) that it contains. By law, the NPKS nutrient analysis must be displayed on the fertiliser product label and on the fertiliser company’s product list - See Appendix F for examples of product lists. This system allows you to quickly and accurately see what nutrients the product contains and calculate the amount (weight) of each nutrient in the product.



NPKS nutrient analyses are often written with a colon (:) between each percentage. For example, the nutrient analysis for single superphosphate is 0:8.8:0:11, which means 0% nitrogen, 8.8% phosphorus, 0% potassium, and 11% sulphur. When the nutrient analysis is written this way, it always gives the nutrient percentages in the same order: N, P, K and S. The analysis of commercial fertilisers can be easily obtained from a product list for each fertiliser company (See Appendix F). For an analysis of common fertilisers please refer to Appendix G

The amount (weight) of N, P, K and S nutrients in a fertiliser product can be calculated from the percentages given in the nutrient analysis. 'Per cent' means 'in every hundred', so, 8.8% means 8.8 in every hundred, and 11% means 11 in every hundred.

For example, 100 kg of single superphosphate with a nutrient analysis of 0:8.8:0:11 will contain:

| | | | |
|-----------|-------------|-----------|------------|
| 0 kg of N | 8.8 kg of P | 0 kg of K | 11 kg of S |
|-----------|-------------|-----------|------------|

Therefore, the amount of nutrients in 1 tonne (1000 kg) of a fertiliser will be ten times the amount of nutrients in 100 kg. So, 1 tonne of single superphosphate with a nutrient analysis of 0:8.8:0:11 will contain:

| | | | |
|-----------|------------|-----------|-------------|
| 0 kg of N | 88 kg of P | 0 kg of K | 110 kg of S |
|-----------|------------|-----------|-------------|

Fertilisers used in Australia express the percentage of the individual nutrient in its elemental form e.g. 8.8% P for single superphosphate.

As you can see, 1 tonne of this single superphosphate contains a total of 198 kg of NPKS nutrients. The remaining 802 kg in the tonne contains the other elements that formed the less plant available forms.

The nutrient analyses of a typical single superphosphate and a typical triple superphosphate are shown as a diagram in Figure 11.2.

Practice Exercise:

Incitec Pivot Triple Super contains 0% N, 20.2% P, 0% K and 1% S

How many kilograms of N, P, K, and S are in 1 tonne (1000 kg) of Incitec Pivot Triple Super?

| | | | |
|--|--|--|--|
| | | | |
|--|--|--|--|

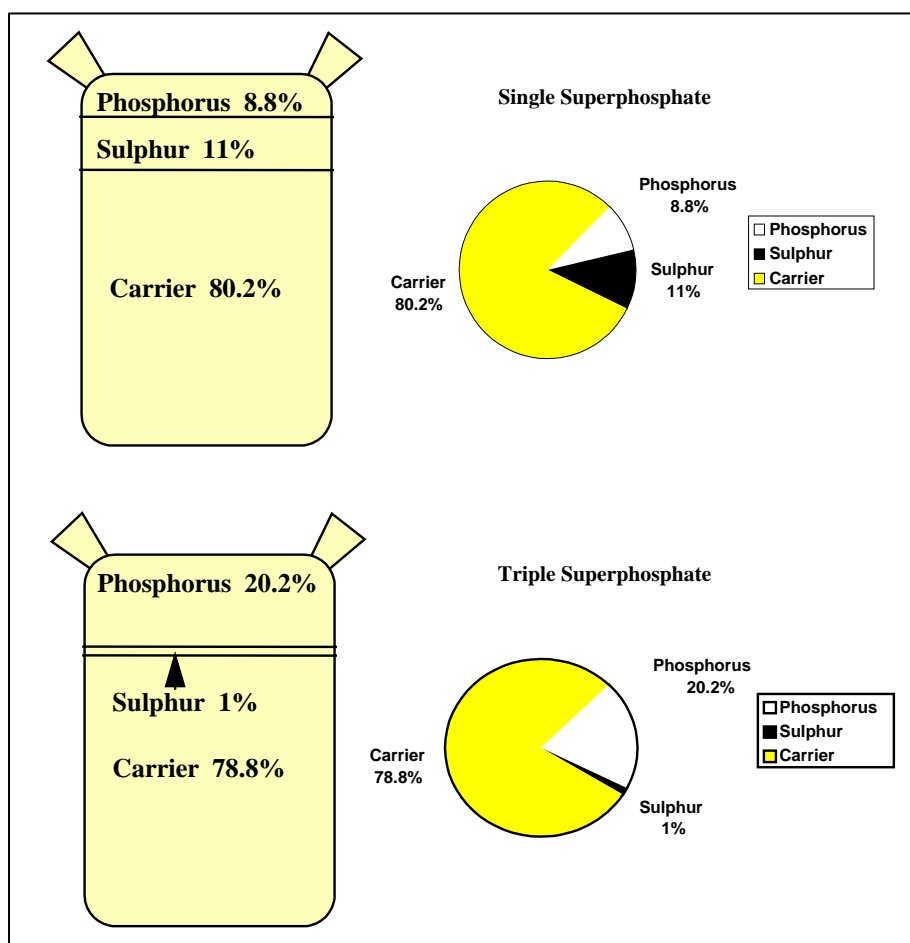


Figure 11.2 Diagrammatic representation of typical single superphosphate and triple superphosphate nutrient analyses

11.4.2 Available or elemental versus total nutrient

Fertiliser nutrients are shown on fertiliser labels and in product charts in their elemental form (e.g. %N, % P, %K) however this is not how nutrients exist in their natural state in the soil or in fertilisers. For example, phosphorus exists in combination with other elements including calcium, oxygen, hydrogen, iron and aluminium. Collectively all these forms would add up to the total P, however only a relatively small fraction of this is plant available. Plants take up phosphorus in the phosphate or orthophosphate form ($H_2PO_4^-$, HPO_4^{2-}) which is water soluble and plant available. It is therefore important to know the water soluble percentage of the total P nutrient analysis in order to match the nutrient availability to pasture demand. These water soluble forms are changeable and may combine with other nutrients (calcium, iron or aluminium) over time to become less water soluble and less plant available.

Currently fertiliser companies are required to label fertilisers according to State legislation which stipulates that fertiliser labels provide the following detail:

- Total elemental form of a nutrient, e.g. %N.
- The forms in which the nutrients are presents, e.g. N as urea.
- The percentages of each form present (e.g. nitrate-N at 7.8% and ammonium-N at 4.8%).

There is an [Australian National Code of Practice](#) that will unify the state legislations, however it has not yet been formally recognised across state and territory borders.



11.4.3 Using the nutrient analyses to find comparable products

Once you know what nutrients you need to apply to your paddocks, you may want to compare products from different companies to see which nutrient analysis and price combination is the most cost-effective. Although the product names may not be similar, you can use the nutrient analyses given in the product lists to find similar products.

For example, you may want to apply a product containing phosphorus, potassium, and sulphur, such as Incitec Pivot SuPerfect Potash 2 & 1, which has a nutrient analysis of 0:5.9:16.6:7.3. The other product lists in Appendix G contain similar products, although the product names may not include the term '2 & 1' or 'super potash'.

11.5 Summary

- A fertiliser is any nutrient or substance that promotes plant growth.
- There are many individual types of fertilisers produced.
- Nutrient sources can be organic or inorganic.
- Fertiliser product lists and labels are required to show the product's NPKS percentages.
- The NPKS system refers to the percentage of N, P, K, and S in fertiliser products.
- Fertiliser nutrients are mixed in with varying proportions with other less plant available forms; usually oxides.
- Fertilisers should be purchased on the basis of their nutrient analyses and ability to overcome a specific nutrient deficiency.

Practice Exercises 7 & 8 >>>

11.6 References

Dairy Australia. (2012). 'Dairying for Tomorrow Survey of Natural Resource Management on Dairy Farms' Survey Report, Dairy Australia, Melbourne.



Chapter 12

Nitrogen and Nitrogen Fertilisers

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12 Nitrogen and Nitrogen Fertilisers

12.1 Introduction

In this Chapter:

[The basics of how nitrogen \(N\) cycles around a dairy pasture system.](#)

[The sources of N for plant growth and how to maximise the availability of N in order to maximise pasture growth.](#)

[What happens to N in plants and grazing animals.](#)

[The sources of N entering pasture systems.](#)

[The environmental issues associated with N and how to minimise N losses.](#)

[The role of N fertilisers in feed budgeting.](#)

[The optimum time to apply N fertilisers.](#)

[The optimum time to graze N fertilised pastures.](#)

[The factors that affect pasture response to N fertilisers.](#)

Nitrogen (N) forms the largest component (78%) of air that we breathe and is a key component of proteins and amino acids, DNA and nucleic acids in plants.

Pastures require N in large amounts, therefore N is generally the major limiting nutrient in terms of plant growth.

Nitrogen is a very changeable and mobile nutrient, existing in many forms in the soil, water and air. It is important to understand the basics of how N cycles around a grazed pasture system to make the best use of this valuable nutrient.

The national [Accounting for Nutrients](#) project looked at how N cycled around 41 dairy farms in Australia using a nutrient budgeting approach. They calculated the N use efficiency of each farm by calculating the amount of N exported off the farm (as milk, animals and feed sold etc.) divided by the amount of N imported on to the farm (in fertiliser, feed and N fixation by legumes etc.). The project found that Australian dairy farms had a wide range of N use efficiencies ranging from 14-50%. These results suggest that some farms are using N very efficiently, whereas others are not. Although the drivers of N use efficiency are complex, these data show that there is an opportunity to improve N management in Australian dairy systems. This chapter discusses how to manage both existing N in the soil and fertiliser N to maximise the value of this valuable resource.

Losses of N to the surrounding environment are an increasing concern and this chapter also discusses how N is lost from dairy pasture systems through denitrification, volatilisation, surface runoff and leaching. This chapter highlights the important aspects of N management and how farm management can optimise the economic use of N, whilst minimising losses to the environment.

12.1.1 Summarised version of the N cycle

Legumes (e.g. clover and lucerne) are unique in their ability to use N from the atmosphere as a source of N for growth. Legumes form a relationship with bacteria that live in their roots, and which can 'fix' N from the atmosphere and convert it into ammonia.



Pastures can only take up N in the form of ammonium and nitrate.

The N in pastures is eaten by grazing cows and most is returned to the soil in urine and manure deposition - see Figure 12.1. The urea in urine or urea fertilisers is converted to ammonium and can be lost via [volatilisation](#) (as ammonia gas) or converted to nitrate and then lost via [leaching](#). Nitrate can also be lost through [denitrification](#) which produces the greenhouse gas nitrous oxide and di-nitrogen gas. Ammonium and nitrate in the surface soil or from fertiliser can also be lost when water moves over the surface as [runoff](#).

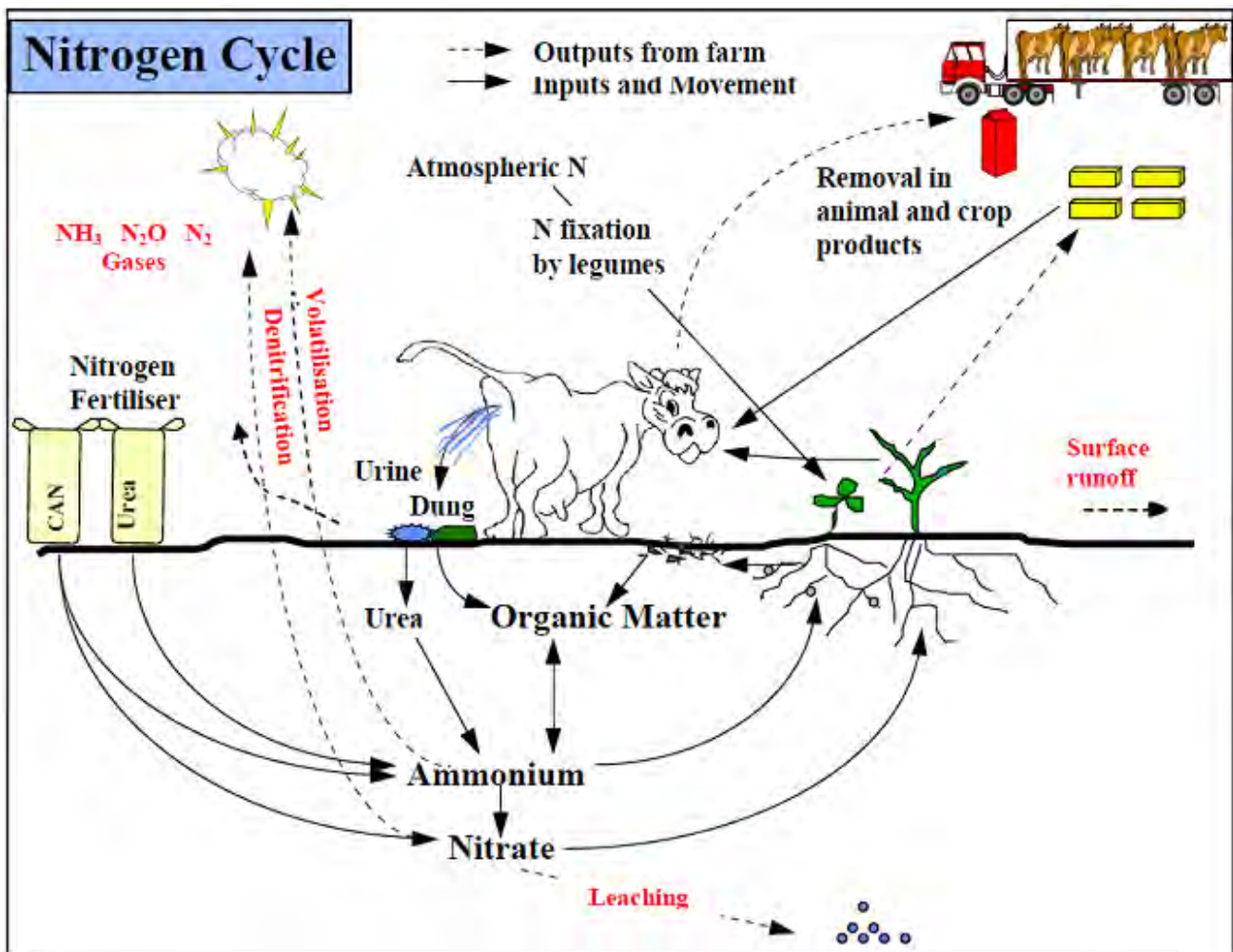


Figure 12.1 Summarised version of a nitrogen cycle in a dairy pasture system. Red labels represent N is lost to the environment.

12.1.2 Nitrogen in soil

Almost all (98%) of the N in soil is in the organic form. However, plants can only take up N as inorganic N forms (nitrate or ammonium), so organic forms of N need to be mineralised by soil microbes before they can be taken up by pasture. It is important to understand that although N fertiliser and legume fixation add N to the soil, changes in the large organic N content in the soil can have a large impact on the amount of N pasture can take up and the loss of N to the environment.



For example, when soils are warm and moist, soil bacteria and fungi break down the soil organic N to the ammonium and nitrate forms, causing a flush of these nutrients which can be taken up by pasture. This process is called *mineralisation*. When soils are cultivated to sow fodder crops or sow new pasture, soil organic N is often mineralised causing a flush of plant available N. Ammonium and nitrate can also be *immobilised* back to the organic form when decaying plant material breaks down. It is important to consider these processes as there may be times of the year when adequate N is available for pasture uptake and N fertilisation is not required.

The positively charged ammonium ion is held in soil by the negative charges on clay particles and soil organic matter, in a similar fashion to how potassium is held in soil. In comparison, nitrate is not held by the soil and is easily lost via leaching as water drains through the soil or when water moves over the surface of the soil. When soils are warm and moist, much of the ammonium is converted to nitrate by soil bacteria and fungi in a process called *nitrification*. An important message is that nitrate leaching can increase when soils are warm and moist, due to this rapid conversion of ammonium to nitrate. However if soils are water logged and there is a lack of oxygen, nitrate undergoes *denitrification* by soil bacteria and fungi, converting it to nitrous oxide and di-nitrogen gas.

Soil organic N can be an important source of N for plant uptake, so it is important to keep this in mind when determining N fertiliser requirements.

12.1.2.1 Soil testing for N

Due to the changeable nature of N, there is currently no reliable measure to test soil N availability, as in the time it takes to collect the sample and have it analysed by a laboratory, plant N availability could have changed dramatically. Soil N levels also change widely across a paddock, so it is difficult to get a reliable result. It is possible to measure the total amount of N in a soil and the amounts of ammonium and nitrate, however from the discussion above, it is clear that the plant available forms of N (ammonium and nitrate) can change quickly depending on the temperature and moisture of the soil and from where the sample is taken, whether or not the soil has been cultivated, the amount of N the pasture is taking up and any losses to the environment.

Where soil N testing may be more useful is to assess the potential availability of soil N for a future crop.

For example, a 20 t DM/ha crop of maize may be able to access some of the 200-240 kg N/ha/year required for production from organic N mineralised when the soil is cultivated prior to planting in Spring (see [Section 12.4.3.2](#)).

For more information of how to take soil samples see Chapter 8.3.

12.1.3 Nitrogen in plants

Plants contain N in a number of forms, including nitrates, amino acids and proteins. Nitrogen in plant herbage (total leaf material, available to grazing animals) is generally measured/estimated in a laboratory using either the Kjeldahl digestion method or near infrared (NIR) and reported as 'crude protein', which reflects the total N concentration multiplied by 6.25. Nearly all of the N in plants is present as amino acids in proteins and the average N content of proteins is 16%, therefore $1/(16/100) = 6.25$. Crude protein is then used as a standard measure of how much N is available to ruminants for a given type of feed, including pastures, forage crops, and concentrates. It is important to be aware that N measured using the Kjeldahl method measures ammonia and organic N forms, whereas 'total' N measures nitrate, nitrite, ammonia and organic N forms.



The uptake of most nutrients is closely controlled in plants, which means that large increases in soil nutrient concentrations only result in a small or negligible change in plant nutrient concentration. Nitrogen and potassium are two nutrients that plants can take up in amounts greater than what's immediately required for growth. This is sometimes called '*luxury uptake*' and can lead to a range of issues as discussed in [Section 12.1.4](#). As an example, N levels in plant herbage can vary from 1.5% of dry matter (= 9% crude protein) up to 5.5% of dry matter (= 34% crude protein). This range represents levels that are, on the one hand, marginal for sustaining animal production, to levels that are far in excess of what's required by high-producing animals, and might even contain a high percentage of nitrates, which are toxic to ruminants (see [Section 12.6.1.1](#)).

$$\text{Crude protein (\% DM)} = \text{total N concentration (\%)} \times 6.25$$

Nitrogen is taken up from the soil N pool by the plant root system, and moves from the roots to the tiller bases (stubble) and then to the youngest growing leaf, which is the site of greatest demand. Some of this N is incorporated into plant structure, and as more leaves grow, the remainder of the soluble N is redistributed within the plant to these new leaves. Therefore as the pasture regrows after grazing, the concentration of N in the herbage is initially high and then decreases.

This can be seen in Figure 12.2, where crude protein concentration (% of leaf dry matter) decreases with leaf regrowth in a range of grass pasture types.

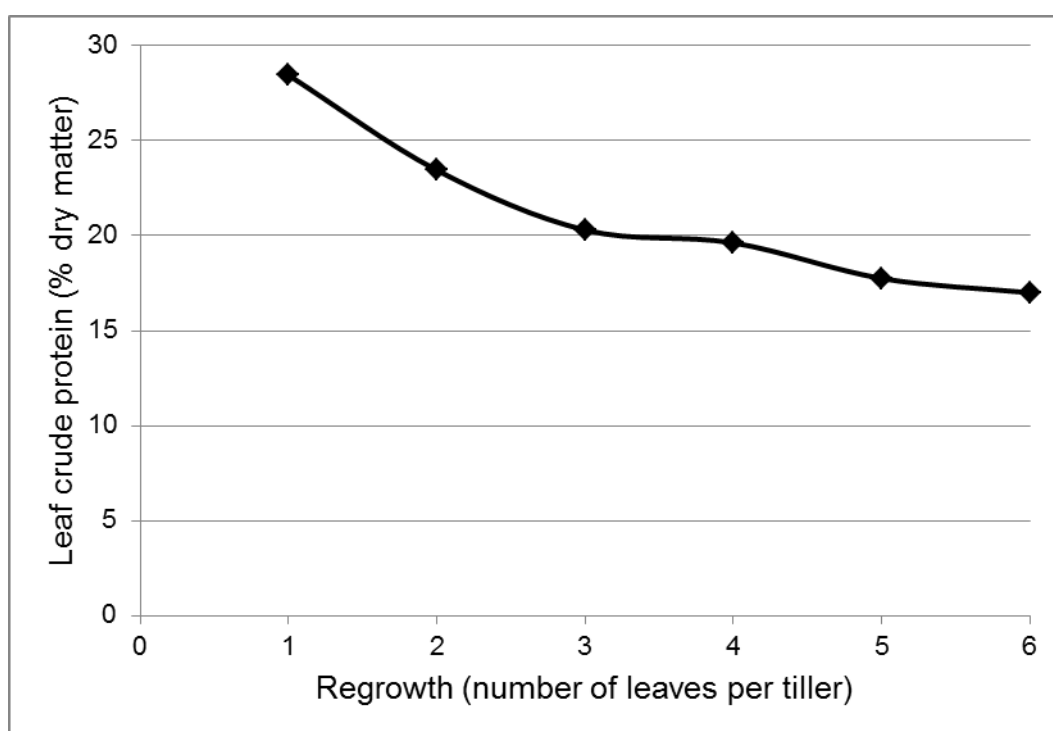


Figure 12.2 Crude protein in herbage of grass-based pastures (averaged across a range of studies investigating perennial ryegrass (Fulkerson *et al.* 1998), tall fescue (Donaghy *et al.* 2008), cocksfoot (Rawnsley *et al.* 2002), prairie grass (Turner *et al.* 2006) and kikuyu (Reeves *et al.* 1996). Crude protein content was measured in the herbage of plants cut at each leaf stage to 3 leaves (ryegrass), 5 leaves (tall fescue), or 6 leaves (cocksfoot, prairie grass and kikuyu), in both field and glasshouse experiments.

In practice, crude protein concentrations in herbage will vary with soil fertility levels, fertiliser management, pasture species composition and grazing management. What Figure 12.2 indicates however, is that herbage will always have higher crude protein concentrations with early regrowth (soon after grazing), reducing over time. In other words, there is a 'dilution' of N in pasture herbage



with regrowth, with levels that can be far in excess of what animals require in an early stage of regrowth, reducing to more reasonable levels at later stages. For example, cows in early lactation require about 22-24% crude protein, and requirements decline later in lactation (see [Section 12.1.4](#)). Supplying levels of N (crude protein) in excess of animal requirements can have an adverse effect on animal performance and results in greater N losses to the environment.

High N concentrations in the early stages of pasture regrowth can be detrimental to animal health, production and the environment.

The important message is that there are 2 ways of influencing N levels in the plant - firstly through fertilising, and secondly through grazing management, and these will be further discussed in [Section 12.4](#).

Nitrogen is an important stimulator of growth, and its application results in longer, wider leaves, particularly in the grass component of mixed pastures. It also stimulates tillering in grasses (tillers are the shoots from the base of the plant stem), which is important as tillers only live for about a year, and their replacement - usually in autumn and spring each year - is what drives future production and persistence. Lastly, N may have a role in helping plants survive stress periods such as drought, frost and heat, and can keep grasses in a healthy state that reduces the effects of infestations by rust fungus. Identifying the reasons for applying N fertiliser should be a first step in N management, and is discussed further in [Section 12.4.1](#).

12.1.3.1 Plant tissue testing for N

Plant tissue testing measures the nutrient concentration in a plant tissue and is a good method of measuring how much N has been taken up by pastures. However, the N content of pasture changes with its growth. Figure 12.2 shows how crude protein decreases with pasture leaf stage, so it is important to sample pasture when it is ready for grazing as this will accurately show the N concentration cows are eating. Although measuring pasture N levels are useful to monitor the effect of N fertiliser management, plant tissue analyses for N faces the same issues as those faced when soil testing – see [Section 12.1.3.1](#). Concentrations can change across the paddock and with the time of day. Additionally, in the time it takes to collect the sample and have it analysed by a laboratory, plant N availability could have changed dramatically.

For more information of how to take plant tissue samples see Chapter 8.4.

12.1.4 Nitrogen in animals

Animals require different levels of crude protein in their diet depending on production. For example, high-producing cows (30 kg milk per cow per day or about 2.4 kg milk solids/cow/day) in early lactation require a diet containing between 22-24% crude protein. This falls to a requirement of around 16% crude protein in mid-lactation, to 14% in late lactation, and 12% when cows are dried off or on a maintenance diet.

Cows fed mostly on pasture might be deficient in protein in summer under dryland conditions, or with tropical pastures, which are both naturally lower in N. Under these situations, farmers often supplement the animals' diet with feed types that are higher in N, for example lucerne hay, lupins, high protein pellets, etc., so that the total crude protein level in the diet increases.

However, a situation more often seen in pastoral systems, especially in spring when growth is fast, or in highly-fertilised pastures, is that the N content of the pasture is well in excess of animal requirements. When cows eat a diet too high in N, excess N is converted to ammonia in the rumen, but this is toxic to the animal, and needs to be quickly converted to urea. This leads to increases in



urea levels in the blood, milk and urine as the animal excretes the excess N. The energy used to do this could be more effectively used for milk production, growth or reproduction, and so continually feeding diets that are too high in N can have detrimental effects on animal production and even reproduction.

Under these situations, farmers often supplement the high N pasture with feed sources that are higher in energy and/or lower in N, e.g. cereal grains, maize silage. If the high N levels in pasture are a natural result of high soil N levels and optimal climatic conditions for growth, then this is a sound management decision. However if the high N levels in pasture are a result of other management imposed (e.g. fast grazing rotations, high rates of N fertiliser applied), then there are more basic and cost-effective strategies that could be implemented, and these will be discussed further in [Section 12.4](#).

12.2 Sources of nitrogen in pasture systems

12.2.1 Fixation by legumes

The amount of N fixed by legumes (eg. clovers) in dairy pastures is generally low in Australia due to the low content of legumes in pastures. Legume contents of pastures tend to be < 30% of the total pasture dry matter, so legumes may only contribute 50 kg N/ha/year or less to soil N (Unkovich 2012). A pasture producing 12 t DM/ha/year requires approximately 350 to 550 kg N/ha/year. It is clear that N fixation by legumes will not provide enough N to maximise pasture production, so additional N is required on most productive dairy farms.

12.2.2 Brought in feed

Common feed supplements such as lupins, palm kernel and pasture silage have higher concentrations of N compared to barley and pasture hay (Table 12.1). The amount of supplement brought in to Australian dairy farms continues to increase, so it is important that these sources of N are accounted for when considering N fertiliser requirements. For example, feeding out 250 t DM of round bale pasture silage across a 100 ha farm will add about 50 kg N/ha to soil, as approximately 75-80% of N eaten by dairy cows is deposited back on to soil as urine and manure. Although the average N contents of common feeds are presented in Table 12.1, it is important to note that these concentrations can vary depending on the quality or source of the feed, so feed testing is recommended if an accurate figure is required.

Table 12.1 Average nitrogen concentration of common feeds brought in to Australian dairy farm systems.

| SUPPLEMENT | N% |
|----------------|------|
| Pasture silage | 2.64 |
| Pasture hay | 1.71 |
| Palm kernel | 2.57 |
| Barley grain | 1.92 |
| Lupins | 4.16 |

Source: [Accounting for Nutrients project](#) (Gourley *et al.* 2010).

12.2.3 Recycling of N

Cattle grazing high-quality pastures return about 75-80% of the N they consume in both dung and urine, with the majority (80%) of excreted N coming from urine. Experimental work has found that dairy cows stocked at 3 cows/ha consumed 377 kg N/ha/year. Of that amount, 50 kg was used for milk and weight gain, 87 kg was excreted as dung, and most (240 kg N) was excreted as urine. Most of the N is recycled back into localised dung and urine patches and non-productive areas,



such as around water troughs and gateways and in laneways and the dairy yard. Due to the small area over which urine is deposited, research has found that a single urine patch can apply up to 1000 kg N/ha. Of this returned N, only about 33% is used for pasture growth. The rest is lost through leaching, denitrification and volatilisation (see [Section 12.3](#)).

12.2.4 Dairy effluent

Dairy cows urinate between 30-120 kg N/cow/year and defecate between 20-70 kg N/cow/year, which means that effluent collected from the dairy or feed pad can have high concentrations of N. The liquid component of dairy effluent often contains the more N rich urine. Dairy effluent is a valuable nutrient source and it is important that effluent is spread evenly back on to pasture soils, to grow more pasture. However, there are some important aspects to consider when applying effluent on farms. The area of the farm receiving effluent needs to be large enough to ensure that the rate of N being applied per year is not too high. In New Zealand, many regional councils recommended that the annual N loading from dairy effluent should not exceed 150 kg N/ha (DairyNZ 2013). If excessive rates of N are being applied in effluent, this increases the risk of N loss to the environment through surface water runoff or leaching (see [Section 12.3](#)). The amount of potassium being applied per ha is also important to consider when applying effluent.

12.2.5 Other organic sources of N

Organic sources of nutrients such as poultry manure and organic waste products, supply a range of N, P, K, and S and some trace elements, although their analysis and moisture content can be variable. The unit cost of N can be high compared to other N fertiliser products, and they are not commonly used on dairy pastures.

However, spreading them is a useful method of disposal and can slowly increase the organic matter content and improve soil structure. The nutrient content of animal manures is usually quoted on a dry matter basis.

Example

If poultry manure is 50% DM, then 100 kg of fresh, or wet, poultry manure with an analysis of 3.4% N (dry matter basis) provides only 1.7 kg N. Therefore, to apply 30 kg N/ha, approximately 1750 kg/ha of wet poultry manure would need to be applied.

12.2.6 Fertiliser

Table 12.2 contains a summary of analyses and recommendations for use of the more commonly used N fertilisers.

12.2.6.1 Straight nitrogenous fertilisers

Straight nitrogenous fertilisers supply N only and should be used where the soil is not deficient in other nutrients (e.g. P, K, S, Mo). Examples include urea and calcium ammonium nitrate (CAN).

12.2.6.2 Nitrogen blends

NPKS blends are designed to supply various proportions of nutrients (N:P:K:S) and were developed for various times of the year when the nutrients are in highest demand or are likely to be removed in fodder conservation. When using blended fertilisers, it is important to consider the environmental risks of the other nutrients in the fertiliser product. For example, DAP contains both N and P and it is important to avoid the risk of surface P runoff when applying this fertiliser.



Blended N and P fertilisers should be used where the P levels are known to be lacking. Examples include di-ammonium phosphate (DAP), mono-ammonium phosphate (MAP), and urea blends.

Blended N and S fertilisers should be used where the S levels are known to be lacking. Examples include sulphate of ammonia.

Table 12.2 Nutrient analysis and recommended usage of some common nitrogenous fertilisers

| TYPE OF N FERTILISER | NUTRIENT ANALYSIS (%) | | | | RECOMMENDED USE FOR OPTIMUM RESPONSE |
|--|-----------------------|----|----|----|--|
| | N | P | K | S | |
| Urea | 46 | 0 | 0 | 0 | Where P, K and S are not limiting. Dry or drying conditions may result in volatilisation losses. |
| Sulphate of Ammonia (also called Ammonium Sulphate or SOA) | 21 | 0 | 0 | 24 | Where P and K are not limiting, but extra S is required. |
| Calcium Ammonium Nitrate (CAN) | 27 | 0 | 0 | 0 | Where P, K and S are not limiting. Dry or drying conditions may result in volatilisation losses. |
| Pasture blend | 24 | 4 | 13 | 4 | Supplies low levels of P, K and S with high N content. |
| Fodder blend | 12 | 8 | 20 | 6 | Increased levels of P and S for early spring growth. |
| Hay blend | 12 | 5 | 24 | 5 | To replace nutrients removed in conserved fodder or where K is limiting. |
| Grass blend | 30 | 0 | 0 | 15 | For an N response when S may be limiting. |
| DAP | 18 | 20 | 0 | 1 | Where extra P and N are required, but K and S are not limiting. |

12.2.7 Nitrogen sources - summary

The choice of fertiliser should be made on the cost per unit of N, taking account of the cost of additional nutrients if using a blend. However, where there are conditions that will adversely affect the performance of a particular fertiliser after application, these should also be taken into account. For example, applying a nitrate based fertiliser (e.g. CAN) to pasture that frequently becomes waterlogged may result in lower than expected benefits, as large losses of N by denitrification and/or leaching can occur. In this situation, other fertilisers may be more appropriate, even at a higher cost.



12.3 Losses of N to the environment

Significant amounts of N either from the soil or from fertiliser may be lost to the environment under certain climatic, soil and management conditions. There are four main processes that can cause N to be lost from pasture systems. These processes are [denitrification](#), [ammonia volatilisation](#), [surface runoff losses following irrigation or rainfall](#) and [leaching losses](#).

12.3.1 Denitrification

Denitrification in soils mainly occurs when soil oxygen concentrations become very low following heavy rainfall, flood irrigation or poor drainage. Under these conditions, micro-organisms convert soil nitrate into gaseous forms of N called nitrous oxide (a harmful greenhouse gas) and di-nitrogen gas, which are lost to the atmosphere.

Denitrification losses from dryland pastures at Ellinbank were measured at less than 10% of N applied, or between 6 and 17 kg N/ha/year, in non-waterlogged soil (Eckard *et al.* 2003). However, denitrification losses increased greatly when the soil was saturated (i.e. greater than field capacity).

Losses of 10 - 30% have been measured from nitrate-based fertilisers (i.e. Calcium Ammonium Nitrate - CAN), particularly when applied to warm, wet soils. These losses decline rapidly once soils are no longer saturated. However, denitrification losses are negligible with N fertilisers such as urea, DAP or ammonium sulphate. Consequently, nitrate forms of fertiliser are often not recommended when pastures are flood irrigated in the warmer months. Urea or DAP are safer and more efficient sources of N to use under these conditions. During the wetter periods of the year, it is advisable to watch the weather reports and allow soils to drain before applying N fertiliser, but also to avoid N sources containing nitrate. This strategy will also minimise nitrate leaching losses and surface runoff of N.

Denitrification losses don't just occur after N fertiliser application, but also occur as a result of grazing animals and under legume based pastures. Grazing animals can reduce soil aeration through soil compaction, increasing nitrous oxide emissions. In northern Victoria, nitrous oxide emissions from grazing cow urine deposition was 4.2-4.5 kg nitrous oxide-N/ha over a 2 year period (Galbally *et al.* 2005). Gaseous losses under legume based systems have been measured at 8 kg N/ha/yr from a pasture that was fixing approximately 108 kg N/ha/yr.

Recommendations to reduce denitrification losses

- Do not apply N fertiliser to saturated soils. If N fertilisation is necessary, apply urea or ammonium based fertilisers.
- Avoid applying N fertiliser to warm (>10°C) waterlogged soils, as this increases the rate of denitrification.

12.3.2 Ammonia volatilisation

Ammonia volatilisation is a process where N is lost to the atmosphere as a gas. Ammonia volatilisation following recently applied urea or ammonium based fertilisers (i.e. DAP, ammonium sulphate) or urine deposition tends to increase when conditions are warm and dry. When ammonium based fertilisers or urine is deposited on soil, they undergo a process called ammonification which increases the soil pH to >7.5 (more alkaline) and results in ammonia volatilisation to the atmosphere. Urine patches are the major source of ammonia volatilisation from dairy pasture systems, however Australian and New Zealand research has shown that urea fertiliser is more likely to result in ammonia volatilisation compared to DAP or ammonium sulphate.



12.3.2.1 Nitrogen fertiliser and acid soils

Research at Ellinbank in Victoria has shown that ammonia volatilisation losses from urea fertiliser applied between May and November are usually below 8% of the N fertiliser applied and are thus of little environmental or economic concern (Eckard *et al.* 2003). However, ammonia volatilisation losses in summer may average 14% of the N applied as urea, with losses as high as 22% likely where urea is applied after a light rainfall, followed by hot and dry weather.

To minimise the risk of N loss by volatilisation during the hotter months and where irrigation is not available, urea fertiliser can be applied 2-3 days before grazing, as the pasture canopy reduces the wind speed near the fertiliser granules reducing gaseous loss. However, care needs to be taken to ensure that cows do not ingest lumps of fertiliser as this could lead to ammonia toxicity (see [Section 12.4.3.2](#) to consider other issues associated with applying N fertiliser prior to grazing). However, in this case, it is important to consider if soil moisture and temperature will limit the response to N fertiliser application (see [Section 12.4.3.3](#)).

At other times of the year when irrigation is not possible, urea can be applied to moist soil provided that temperatures and evaporation rates are not high. Avoid applying N fertiliser after light summer rainfall if soils are dry and evaporation rates are high, as volatilisation rates can be high. In hot dry conditions, use a weather forecast to time N fertiliser application to occur just prior to a rainfall event. Approximately 8 to 10 mm of rain is required to reduce volatilisation in dry soils. Heavy dew does not provide enough moisture. Ammonium based fertilisers (i.e. DAP) or sulphate of ammonia may be more appropriate to apply when conditions are dry (because they are subject to less volatilisation), but they are often more expensive per unit of N compared to urea, and this cost difference is seldom justified by the environmental benefit.

Although ammonia volatilisation is not an immediate environmental concern, loss of N to the atmosphere reduces the cost effectiveness of applying N fertiliser and should be avoided if possible. The following sets out the best management practices for reducing ammonia volatilisation under dryland and irrigated dairy systems.

Recommendations to reduce volatilisation losses- dryland pastures (Eckard 2001)

- Between the cooler, wetter months (May to November in south eastern Australia), ammonia volatilisation losses from urea fertiliser are too small to be of economic or environmental concern, and do not justify switching to higher-cost N fertiliser sources.
- If urea fertiliser is applied in the drier months (November to March in south eastern Australia) without irrigation, apply fertiliser 2 to 3 days prior to grazing to minimise wind speed at ground level and reduce ammonia volatilisation. Care must be taken to avoid cows ingesting lumps of fertiliser as this could lead to ammonia toxicity.
- In summer, where soils are dry and evaporation is high, avoid applying urea fertiliser after a rainfall event, as this may increase volatilisation losses above 22%.



Recommendations to reduce volatilisation losses - spray irrigated pastures (R. Eckard pers. comm. 2013)

- Apply N fertiliser within 24 hours prior to spray irrigation.
- In summer, where evaporation is high, avoid applying urea fertiliser after a spray irrigation as this is likely to increase volatilisation losses.

Recommendations to reduce volatilisation losses - border check irrigation (Mundy 1997; K. Kelly pers. comm. 2013)

- In summer, apply urea fertiliser after border check irrigation as soil moisture will be adequate to dissolve the urea and minimise volatilisation. Take care not to damage wet soils with fertiliser spreaders.
- If urea is applied prior to border check irrigation, it is important to apply close to irrigation (within 24 hours), but care is required not to over water and generate surface N runoff into drains.

12.3.2.2 Nitrogen fertiliser and alkaline or heavily limed acid soils

Ammonia volatilisation can occur with other ammonium fertilisers, particularly ammonium sulphate and DAP, when they are used on alkaline or heavily limed acid soils (soil pH>8 in water). Urea should not be applied to pastures that have been recently top dressed with lime. Substantial N may be lost as ammonia due to chemical reactions with the lime on the soil surface. If lime must be applied at a similar time to urea, then apply the urea first and apply the lime at least 2 weeks later.

12.3.2.3 Urine deposition

Recent research conducted in Western Australia as part of the [Greener Pastures](#) project (Bennett *et al.* 2011) has shown that 45% of the N contained in urine volatilised in summer, 20-30% in winter and only 0-5% in spring.

12.3.3 Leaching

When soils are saturated, free draining or artificially drained (e.g. mole or subsurface pipe or tile drains – see Chapter 7.4.5.2) soils may leach nitrate as water drains through the soil. In countries like New Zealand, Europe and the USA, there are stringent controls to minimise N losses by leaching. The major concern is nitrate leaching into ground water that may be used for drinking water and the environmental impact of elevated nitrate in rivers and lakes. Unlike ammonium, nitrate is not held by soil and is readily lost when water drains through soil.

There has been little research on nitrate leaching in Australia, but research conducted at Ellinbank in Victoria has shown when high N rates (above about 70 kg N/ha) are applied to free-draining soils or when heavy rainfall followed N fertiliser application, nitrate leaching losses ranged from 5 kg N/ha/yr in a low rainfall year to 38 kg N/ha/yr in a higher drainage year (Eckard *et al.* 2004). Leaching is generally not considered to be a major cause of N loss in duplex soils because of low water flow through the subsoil. However, on well-drained soils, as in many dairying areas around Australia, N losses through leaching may be significant.

It is important to understand that nitrate leaching is not only due to fertiliser application. Other factors such as the amount of N in soil which is leachable and urine deposition from grazing animals are also very important. Research has shown pastures to be generally efficient in uptake of N fertiliser, therefore the timing of N fertiliser application to maximise plant uptake and reduce the



amount of N that remains in soil, can reduce leaching losses. Nitrate leaching losses under dryland systems are generally lower in spring when pastures are actively growing and rapidly absorbing nitrate. The first leaching event of the season often results in the greatest nitrate leaching losses due to the build-up of soil nitrate over the summer and autumn period when pasture is not actively growing.

The largest source of N leached in dairy pasture systems is from urine deposition.

Grazing animals excrete around 80% of their total N waste as urine and considering cows urinate 10-12 times per day and the urine falls on a small area, the N application rate can be as high as 1000 kg N/ha. This rate of N deposition is much higher than a pastures' requirement for N, therefore if water drains through the soil, much of this urine-derived N can be leached. Studies in south Australia have shown that 26-33 kg N/ha/year were leached under irrigation and 10-13 kg N/ha under rain-fed dairy pasture following a single application of urine which contained 650 kg N/ha/year and 2 applications totalling 1604 kg N/ha/year (Pakrou and Dillon, 2004). Most urine gets deposited around water troughs, gateways, shelter belts, laneways and milking sheds. Urine spots in paddocks may get additional N inputs from fertiliser and dung and this increases the risk of nitrate leaching further.

Nitrate leaching occurs when excess soil water drains from the soil, taking with it soluble N in the form of nitrate. To minimise nitrate leaching losses, leachable nitrate must be minimised in the soil during times of potential high drainage. Some ways to manage this are listed below.

Recommendations to reduce leaching losses

- Only apply N fertiliser to actively growing pasture at a rate between 25 and 50 kg N/ha in any single application.
- New Zealand research suggests that annual applications greater than 200 kg N/ha increase the risk of nitrate leaching (Cameron *et al.* 2002; Meneer *et al.* 2004).
- Avoid grazing until ryegrass or tall fescue pastures have grown at least 2 new leaves, and brome (prairie grass), cocksfoot and kikuyu pastures have grown at least 3 new leaves, to reduce the intake of N in the cows diet and therefore the amount of N excreted.
- Avoid applying N fertilisers on areas where animals congregate i.e. gateways, water troughs, shelter belts, as these areas will already have high soil N.
- If N must be applied during the wetter period, use a weather forecast to wait at least 2 days after any significant rainfall event to allow the soils to drain to just below field capacity before applying N.
- If irrigating, take care to avoid overwatering, as this may result in nitrate leaching.

12.3.3.1 Other management options to reduce N leaching

If nitrate leaching is likely to be an issue, then it may be necessary to stand cows off pasture during the wettest period of the year either on feed pads or agist on to another property. These management practices are currently being used in New Zealand to deal with tighter restrictions on nitrate leaching, however such environmental restrictions are currently not in place in Australia. It is important to consider that N excretion can increase if cows are consuming excessive amounts of N in their diet, so take care not to apply too much N fertiliser or graze before pastures have grown enough leaves to dilute the plant N concentration (see [Section 12.1.3](#) and [Section 12.4](#)). If N fertiliser or grazing rotation length is not an issue, then another management option is to feed low



protein forages such as maize silage, as a way of reducing the amount of nitrate which is excreted in cattle urine.

12.3.3.2 Reducing N leaching from effluent application

It is important to reduce the risk of nitrate leaching following effluent application, by making sure that effluent is not irrigated on to soils which are at field capacity (i.e. very wet). If soils are at field capacity, then effluent application should be delayed until a soil water deficit is created. Soil water deficit is the amount of water removed from the surface soil where pasture has active roots (root zone). It is also the amount of water required to refill the root zone back to field capacity. Effluent should only be applied to the point where the soil water deficit is back to 0, otherwise any additional effluent is prone to leaching or runoff. Applying effluent at low application rates using [K-lines](#) or over-head sprinklers and not exceeding the soil water deficit, is recommended in New Zealand as an effective way of reducing leaching and runoff (DairyNZ 2012).

12.3.4 Loss of N in surface runoff after rainfall or irrigation

Surface runoff can occur when rainfall or irrigation falls on saturated soils, or rainfall or irrigation rate is extremely high and soils are unable to absorb all of the water. Most forms of N fertiliser are readily soluble and dissolve in surface water runoff, but soils also release N to runoff water as it moves across the soil surface. Nutrient loss in surface runoff water means a potential loss of valuable nutrients from the farm and can lead to nutrient enrichment of rivers and streams.

Although Australian research on the loss of N in surface water runoff following N fertiliser application shows that losses are generally low (<5 kg N/ha/yr), losses under border check irrigation or hump and hollow drainage (i.e. parts of western Victoria or north west Tasmania) have ranged from 3-23 kg N/ha/yr.

Management practices which minimise surface N runoff losses should be incorporated into farm practice and include the following recommendations:

Recommendations to reduce surface runoff losses

- Do not apply N fertiliser near (generally within 20 metres) drains, channels, dams, lakes or riparian areas.
- The volume of water lost as runoff has a big influence on the amount of nutrient lost in runoff, so avoid overwatering and generating surface runoff.
- Use a weather forecast to avoid runoff within days of N fertiliser application, to allow N time to be absorbed by plants.
- Where possible, re-use drainage water.
- Maintain good ground cover and avoid soil erosion.
- If re-sowing pasture, consider minimum tillage practices.

12.3.5 Use of nitrification inhibitors to reduce N loss to the environment

Nitrification inhibitors are chemical products which can reduce the conversion of ammonium to nitrate and therefore reduce the rate of denitrification and greenhouse gas losses and nitrate leaching following urea or urine application. Dicyandiamide (DCD) has been used to reduce N losses in New Zealand. The effectiveness of DCD is affected by the soil and climatic conditions and New Zealand research has shown that DCD works best to reduce nitrate leaching in late autumn through to early spring when average soil temperatures are below 10°C and drainage is high (Di



and Cameron 2004). Another New Zealand study found that DCD application slowed nitrification and reduced soil nitrate concentration and reduced nitrous oxide emissions by an average of 50% from urine patches (Gillingham *et al.* 2012). In some regions, DCD application resulted in more N being available for pasture growth and pasture production increased.

However, Western Australian studies have found that their higher soil temperatures and soil types reduced the usefulness and cost effectiveness of DCD use (Fillery and Bolland 2007). A northern Victorian study under border check irrigation found that DCD was effective at reducing nitrous oxide emissions for approximately 50 days in mid-spring and 25 days in mid-summer (Kelly *et al.* 2008), but like the Western Australian study, concluded that higher soil temperatures in northern Victoria were likely to reduce the effectiveness of DCD in this region.

It is important to note that DCD is currently not being sold in New Zealand due to the recent detection of low level traces of DCD in dairy products.

12.4 Responsible management of N fertiliser on farms

Responsible management of N fertiliser begins with the question - [why should it be applied?](#) It then comes down to the 4Rs: use the [Right Source](#) of fertiliser, at the [Right Rate](#), in the [Right Place](#) and at the [Right Time](#). Find out how to work through each of these steps, and how to work out the [economics of N fertiliser use](#).

12.4.1 Why to apply?

The first question to ask before N is used should be why you want to use it, or what you expect it to do. As previously discussed, N stimulates growth and so its most frequent use is to increase pasture or crop growth rates or overall yield, to help fill expected feed gaps. This can be in a strategic context, where there is a budget for N use over the year, targeted at periods when it's expected that it could have an impact, or in a tactical context, where N is used usually at shorter notice, often to address unexpected feed gaps. However, many farmers are regularly applying N after most grazings throughout most of the year, with variable results.

A less common, but still valid, use of N is to increase tillering at certain times of the year. Nitrogen might also help plants survive stress periods if applied up to a month prior to the stress - e.g. late autumn to better survive winter frosts, late spring to better survive summer heat/drought. However care must be taken in timing of N application, as if applied too close to the stress period (e.g. within 1-2 weeks), the stress effect could be worse.

Since stimulating growth is by far the most common reason for farmers to apply N, the following sections will focus more on this, with any additional benefits of stimulated tillering or healthier plants being taken as secondary effects which may occur.

Once the question of why N should be used has been addressed, the next steps should be to work out where and when it might best be used.

12.4.2 Right Place

Nitrogen fertiliser application will have greatest response when it is the major limiting factor to growth. What this important fact means is that in situations where plants are stressed or growth is being held back by lack of other nutrients, or low soil pH, dry/hot/cold conditions, or overgrazing, then applying N will have little or no effect, might even make the situation worse, and will result in a waste of the N applied.



So when determining where to apply N, the following key aspects should be taken into account to ensure the best result from N fertiliser application:

- Apply N to pastures with a high density of desirable (i.e. sown) species. Applying N to pastures where weed species have invaded, will result in larger, healthier weeds and have no beneficial effect on feed supply for grazing cows.
- Apply N to pastures with a good ground cover. Gaps or bare areas in pastures will result in more N lost through leaching and/or volatilisation.
- Apply N to pastures that have no limitations to major soil nutrients. Regularly soil testing will establish the nutrient status of the soil and if other major nutrients or pH are limiting growth, these can be addressed before or at the same time as the N application.
- Apply N to pastures that are not waterlogged, or in drought, or being overgrazed (grazed at less than the 2-leaf regrowth stage for most sown grass species).

The general principles of using N fertiliser are not affected by differences between pasture types, or between pastures and crops. Remembering that N will have the greatest effect when it is the most limiting factor to growth, is important when planning to use N.

12.4.3 Right Time

In considering timing of N fertiliser to pastures or crops, the key considerations are in relation to season, stage of growth or regrowth, and soil conditions. These will be considered in the following sections, along with the economics of N application with season, which is a key consideration by many farmers.

12.4.3.1 Season

Timing in relation to season might use a feed budgeting approach, which is a tool that estimates likely pasture shortages and can indicate where N fertiliser might best be applied, as well as develops a strategy for supplementary feeding. A basic form of feed budgeting is to consider demand for feed from stock in relation to supply of feed from pasture and crops, and use this to indicate when N is best applied.

For example, depending on region, soil type, irrigation availability and climatic conditions, pasture shortages can occur at any time of the year - in autumn as daylength and temperature decrease, over winter as overcast and cold conditions limit growth, in dry spring conditions, and over summer under dryland conditions. Pasture types can have a further effect: in subtropical and tropical regions when tropical grasses such as kikuyu stop growing over cooler winters, and in areas where hot summers cause ryegrass to become dormant and species such as paspalum or kikuyu may form the basis of summer pasture production (parts of northern Victoria and Western Australia).

As previously explained, using N when growth is mainly limited by dry soil conditions for example, is a waste of time, however N can successfully be used in the majority of the above situations, either before, or even during, the period of pasture shortage, to stimulate growth to reduce the shortage.

12.4.3.1.1 Economics of seasonal N fertiliser application

The cost of alternative feed sources can influence the cost effectiveness of applying N fertiliser. Research conducted in the [3030 Project](#) in western Victoria found that assuming an N response efficiency of 10 kg DM per kg of N applied and a cost of 8.7 cents per extra kg of DM grown, application of N in autumn was highly profitable, but only marginally profitable in spring. This was due to the high cost of alternative feed in autumn. If there is enough soil moisture, application of N fertiliser in summer may also be cost effective, due to the shortage of other feed products. In comparison, additional pasture grown in spring is often more than the milking herd needs and therefore needs to be conserved as hay and silage, which increases the cost of growing the grass in



the first place. Figure 12.3 highlights the important things to consider when assessing the economics of N fertiliser application.

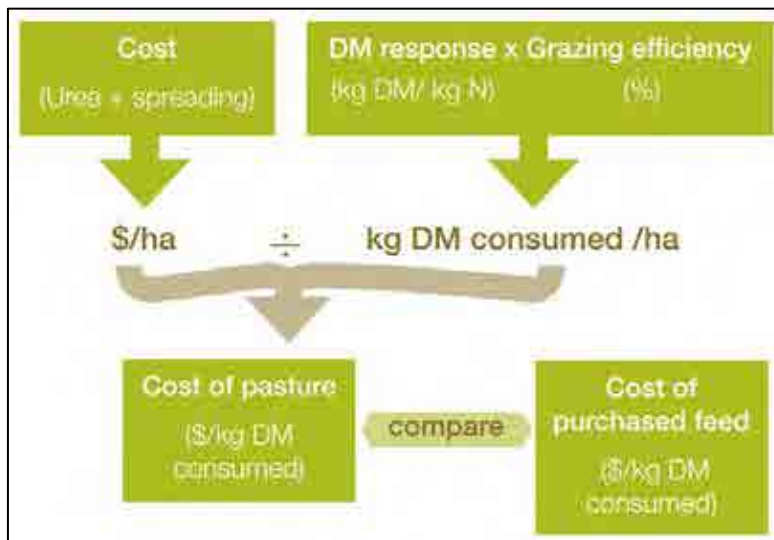


Figure 12.3 Things to consider when assessing the economics of N fertiliser application.
Source: 3030 Project ([Perennial ryegrass management: V. Use of N fertiliser](#)).

12.4.3.2 Stage of growth/regrowth

When applying N to pastures, key considerations are when to apply in relation to grazing, and how long to graze again after N has been applied.

Nitrogen is most often applied in the first few days after a pasture has been grazed, when plants are beginning to regrow, and this is a successful strategy as long as pastures are actively regrowing, with no other major limitations to growth, as mentioned previously. When regrowth is fast, as in spring or summer under good irrigation, best results are obtained from applying N within the first 1-3 days after grazing. When growth slows, as in winter, the timing can be extended to the first week after grazing. Nitrogen is far less efficient when applied partway through regrowth.

Urea can also be applied to pastures up to 2-3 days prior to grazing, as long as there is adequate soil moisture to allow the N fertiliser to dissolve and move into the soil, to reduce the risk of fertiliser being ingested by cows and causing ammonia toxicity (see [Section 12.6.1](#)). This is based on the understanding that it takes a few days in total for N to dissolve from the fertiliser granules, move into soil solution, be taken up by plants, and end up in leaves. It is very important to realise however, that in periods of rapid growth, fertiliser N might start appearing in plant leaves 3-4 days after being applied. If N is applied more than 2 days before plants are grazed, potentially a large amount of the N can be grazed off while it's still in a soluble form in the plant and before it has contributed to plant growth. As well as being a waste of N in terms of not stimulating plant growth, it can also cause animal health issues as discussed in [Section 12.1.4](#) and [Section 12.6.1](#).

After N has been applied, it is important to remember the dilution effect discussed in [Section 12.1.3](#). If pastures are grazed too soon after N application, then a high proportion of the N applied will still be in a soluble form in the younger leaves of the plant, will have contributed only marginally to extra growth, and will be very likely to be grazed off by stock, causing an upset to the rumen and resulting in more N being excreted in the urine. Applying the dilution effect means waiting for 2 leaves/tiller to regrow after applying N to ryegrass and tall fescue pastures, and waiting for 3 leaves/tiller to regrow after applying N to brome (prairie grass), cocksfoot and kikuyu pastures. This may be between 18-25 days at the earliest when growth is fast (e.g. spring), and 30-40 days at the earliest when growth is slow (e.g. winter), but will vary between regions, within seasons and years. The most accurate measurement is to not assume leaf growth, but to measure it.



It is important to wait for 2 leaves/tiller to regrow after applying N to ryegrass and tall fescue pastures, and waiting for 3 leaves/tiller to regrow after applying N to brome (prairie grass), cocksfoot and kikuyu pastures to allow pasture N concentrations to decrease before grazing.

So the key in applying N to pastures is to firstly add the N when plants are responsive, either 1-2 days before grazing or within 3 days after grazing when growth is fast (e.g. spring), or up to 5-7 days after grazing when growth is slow (e.g. winter). Then leave a long enough period after applying N, to allow the N to be taken up by the plant and result in extra growth, and not nitrate toxicity (see [Section 12.6.1](#)) or excess protein issues with grazing stock.

When applying N to crops, the key timing consideration is when to apply in relation to crop growth and harvest. Nitrogen is often applied to ensure high yields from pasture conservation (silage and hay) as well as from fodder crops (e.g. brassicas, maize, cereals, chicory).

In the case of pasture conservation, it is recommended to apply N at a higher rate (up to 50 kg of N/ha, see [Section 12.4.4](#)) after grazing when the pasture is closed up for conservation. This strategy is most efficient when there is a genuine surplus of pasture, so that the pasture receiving higher rates of N doesn't have to be grazed off prematurely, as might be the case when growth rates temporarily drop in a period when pasture isn't in surplus. Results from using split applications of N, for example after grazing and again partway through regrowth, are more variable, and this practice isn't recommended.

In the case of crops, especially those with a long period prior to harvest (e.g. 10-20 weeks), it is recommended to apply a smaller amount of N early in growth (20-30 kg N/ha soon after crop emergence, when plants are actively growing), followed by several applications (40-50 kg N/ha) as the crop develops, but prior to maturity and harvest.

In all cases, in deciding how much N to apply, applications should be based on a budget and appropriate soil or plant testing (see [Section 12.1.2.1](#) and [Section 12.1.3.1](#)). For example, harvesting a 20 t DM/ha crop of maize removes around 200-240 kg N/ha (Kaiser *et al.* 2003), and a 10 t DM/ha crop of turnips can contain up to 320 kg N/ha (DairyNZ, 2008). The N fertiliser inputs required to achieve these high yields will largely depend on the existing soil N pool at each site, and so it is recommended to undertake a soil test prior to a crop being established, followed by tissue testing of the crop as it develops, to best match N demand with N fertiliser supply.

12.4.3.3 Soil conditions

Timing of N in relation to soil conditions relies on appropriate temperature and moisture levels.

Temperate pasture grasses (e.g. ryegrass, cocksfoot, tall fescue, phalaris, brome (prairie grass)) generally respond to N fertiliser when soil temperatures are above 4°C, and subtropical pasture grasses (e.g. kikuyu) respond to N fertiliser when soil temperatures are above 10°C.

If pastures are no longer growing due to low soil temperatures, then pastures are unlikely to respond to N fertiliser applications.

In cold conditions, plants tend to take up N as ammonium in preference to the nitrate. This is because less ammonium is being nitrified to nitrate. Under warm, aerobic soil conditions, more nitrate will be available for pasture uptake compared to ammonium. However, under wet and cold soil conditions, ammonium is the dominant source of N for growing pasture.



12.4.4 Right Rate

Australian dairy industry research has found that the most efficient pasture growth responses occur when N fertiliser is applied at rates of between 25-50 kg N/ha at any one time. Rates below or above these recommended rates produce pasture responses which are unlikely to be economic.

The most efficient pasture growth responses occur when N fertiliser is applied at rates of between 25-50 kg N/ha at any one time.

Effective use of N fertiliser involves good grazing management to utilise the extra feed grown. This improves the economics of applying N fertiliser, as strategic use of N fertiliser can be effective at filling feed gaps. High pasture utilisation from each grazing must be achieved to maximise production and to minimise the cost of applying the N fertiliser. Table 12.3 shows the cost of extra pasture grown at various levels of pasture utilisation using urea (at \$500/t ex Geelong, June 2013) over a range of application rates.

Table 12.3 Effect of pasture utilisation on cost of N-fertilised pastures over a range of application rates. Based on average 2013 urea prices.

| SEASON | N Rate (kg N/ha) | Response to N (kg DM/kg N) | Cost at 100% Utilisation (\$/kg DM) | Cost at 70% Utilisation (\$/kg DM) | Cost at 50% Utilisation (\$/kg DM) |
|--------|------------------|----------------------------|-------------------------------------|------------------------------------|------------------------------------|
| Autumn | 30 | 16 | 0.07 | 0.10 | 0.14 |
| | 45 | 14 | 0.08 | 0.11 | 0.16 |
| | 50 | 13 | 0.08 | 0.12 | 0.17 |
| Winter | 30 | 11 | 0.10 | 0.14 | 0.20 |
| | 45 | 8 | 0.14 | 0.19 | 0.27 |
| | 50 | 7 | 0.16 | 0.22 | 0.31 |
| Spring | 45 | 23 | 0.05 | 0.07 | 0.09 |

There is great debate over how much N fertiliser can be used in one year and its effects on N losses to the environment. There are no clear recommendations for Australian dairy systems, however New Zealand researchers suggest that N fertiliser rates above 200 kg/ha/year, substantially increase the risk of N leaching losses (Cameron *et al.* 2002; Meneer *et al.* 2004).

12.4.5 Right Source

The type of N fertiliser to be applied will depend on the cost per unit of elemental N and whether other nutrients are being applied (see [Section 12.2.6](#)). For example, if soil P is low, it may be more cost-effective to use DAP instead of urea and an additional fertiliser product containing P. When choosing an N fertiliser product it is important to select a product which will minimise environmental losses (see [Section 12.3](#)). For example, it is better to apply urea or an ammonium based fertiliser on waterlogged soils rather than nitrate based fertilisers, in order to reduce denitrification and greenhouse gas emissions.

Examples of comparing fertiliser costs are given in Chapter 14 in this manual.

The amount of fertiliser to apply (the fertiliser application rate) can be calculated from the desired nutrient application rate and the per cent of nutrient in the fertiliser, using the formula below:



Nutrient application rate (kg/ha) = % of nutrient in the fertiliser x 100 = Fertiliser application rate (kg/ha)

12.5 Expected pasture growth response to N application

Pasture growth responses to N are greatest when conditions for pasture growth are optimal - in other words, when soils are not dry or waterlogged, when there is adequate sunlight, and temperatures are not too hot or cold. Optimal temperature for growth is between about 18-25°C for temperate grasses such as ryegrass, cocksfoot, phalaris and prairie grass, with a slightly higher upper limit (26-28°C) for tall fescue, and between about 25-35°C for subtropical grasses such as kikuyu. Growth usually ceases above about 30°C for ryegrass, cocksfoot, prairie grass and phalaris, about 35°C for tall fescue and about 40°C for kikuyu, and below about 4°C for the temperate grasses and 10°C for the subtropical grasses, as explained in [Section 12.4.3.3](#).

In southern Australia, the highest responses of pasture growth to N are in mid- to late spring, and can range from 12 to 25 kg DM/kg N, depending on climatic conditions, species present (grass-dominant pastures respond best) and soil fertility. These high response rates can continue into summer under adequate irrigation, as long as temperatures don't exceed about 30°C. In late autumn through to early spring when pasture growth rates are slow (between 5-15 kg DM/ha/day), then responses to N fertiliser are likely to be between 0-5 kg DM/kg N. Late autumn and early winter are not very effective times at which to apply N.

In northern Australia, the highest responses of pasture growth to N are in late winter through to mid-spring (pastures based on ryegrass), and mid-spring through to early autumn (pastures based on kikuyu), and can range from 15 to 30 kg DM/kg N, depending on climatic conditions, species present (grass-dominant pastures respond best) and soil fertility. In the cooler months from mid-autumn to mid-winter, pasture growth rates are slow (between 5-20 kg DM/ha/day), and responses to N fertiliser are likely to be between 0-5 kg DM/kg N. Late autumn and early winter are not very effective times at which to apply N.

12.6 Other issues to be managed when applying N fertiliser

In addition to environmental issues with use of N fertiliser discussed in [Section 12.3](#), there are several other issues that need to be considered, including potential poisoning effects of nitrates/nitrites, soil acidification and maintenance of clover in mixed pastures.

12.6.1 Nitrate/nitrite poisoning in cattle

The potential for nitrate or nitrite poisoning in cattle occurs because the plants can absorb the applied N very quickly once it is in a form (ammonium or nitrate) that they can use. The ammonium and nitrate are then converted to proteins and other nitrogen-containing substances.

12.6.1.1 When might nitrite/nitrate poisoning occur?

Nitrate accumulation in plants is increased in the following situations:

- High rates of N fertilisers.
- Grazing using a short rotation and not allowing grasses to grow between 2 new leaves (ryegrass and tall fescue) or 3 new leaves (brome (prairie grass), cocksfoot and kikuyu) to dilute N concentration in leaves prior to grazing (see [Section 12.4.3.2](#)).
- After rainfall following a drought. Soil nitrate accumulates during the drought period due to minimal leaching, reduced uptake by plants and plant decay.
- Moisture stress.
- Decreased light (overcast weather, short day-length).



- Low temperatures.
- Spraying with hormone-type herbicides, such as 2,4-D.
- Presence of species known to be 'high-nitrate' accumulators (such as capeweed, annual or short-rotation ryegrasses, brassicas, oats etc.).

Nitrate/nitrite poisoning in livestock can occur when they eat plants that have been subject to the above situations.

In addition, high consumption of various weeds (capeweed, variegated thistle, pigweed), crops (maize, sorghum, millet, wheat, oats, barley, immature brassicas in high-fertility situations) and some pasture plants (lucerne, subterranean clover, annual or short-rotation ryegrasses) can also cause nitrate/nitrite poisoning.

12.6.1.2 Symptoms of nitrate poisoning

Ruminants can tolerate high levels of nitrates if the intake is spread over the whole day and if the diet contains high levels of readily available carbohydrates. If these conditions are not achieved, nitrate poisoning may occur, causing irritation in the gut and resulting in scouring and loss of production.

Symptoms may appear as profuse scouring, sudden drop in milk production, rough coat, and occasionally shivering and staggers. If nitrate intake is too high or if conditions in the rumen cause a slow conversion of the nitrites to ammonia, then nitrites build up and may be absorbed into the blood. Nitrite levels can also be high on wet or mouldy hay due to microbial action. The nitrites reduce the ability of the blood to carry oxygen, and death may occur through oxygen starvation.

Symptoms may include animals breathing rapidly and acting in a stressed manner. Their pulse will be weak but rapid. The blood will be dark due to lack of oxygen, and the visible mucous membranes on the gums and inside the nose appear blue.

12.6.1.3 How to avoid nitrate/nitrite poisoning

Plant nitrate levels may be high at an early stage of regrowth (before the 1-leaf stage in most grasses), and then levels decline as the plants grow and synthesise proteins.

Avoid grazing N fertilised pastures until the 2-leaf stage in ryegrass and tall fescue pastures, and the 3-leaf stage in brome (prairie grass), cocksfoot and kikuyu pastures to reduce the risk of nitrate poisoning.

This period also allows for a greater response to the applied N.

In crops such as brassicas which can accumulate nitrates, do not apply N or effluent closer than 6 weeks from the expected grazing date.



12.6.2 Soil acidification

Every nutrient that a plant absorbs has either a positive or a negative charge. When plants take up N (regardless of whether it is from fertiliser or legumes), then they need to exude another nutrient or ion with the same charge in order to balance their overall charge, otherwise they could become too positively or too negatively charged. Ammonia is a positively charged ion (NH_4^+) and so plants need to exude another positively charged ion to keep their charge balanced, when they take up ammonia. The positive charge they normally exude is a hydrogen ion (H^+). The amount of hydrogen ions present in the soil affects the soils pH, with more hydrogen ions resulting in more acidic soil. Therefore, the application of ammonium based fertiliser and the uptake of ammonia by pasture plants acidifies soil.

All N fertilisers that contain ammonium (for example, sulphate of ammonia and DAP) or that produce ammonium (for example, urea) have an acidifying effect on the soil. Nitrogen fixation by legumes also has a minor acidifying effect on the soil. The various N fertilisers have different potentials for acidifying the soil. See Table 12.4.

Table 12.4 Approximate lime requirement to neutralise the potential acidifying effect of N fertiliser.

| Form of N Fertiliser | Amount of lime (kg lime/ha) needed to neutralise 30 kg N/ha |
|-----------------------------|---|
| Sulphate of ammonia | 160 |
| Di-ammonium phosphate (DAP) | 110 |
| Urea | 50 |

Source: Roberts and Ledgard (1998) (New Zealand)

Note: In practice, soils have a natural pH buffering capacity, which means that, at recommended N rates (25 to 50 kg N/ha), the acidification effect will be slow and farmers should regularly monitor soil pH and apply lime when pH drops below the recommended pH range (see Chapter 7.6.9 for how to correct soil acidity).

If annual N application rates exceed 250 kg N/ha/year, more regular soil pH testing and liming is recommended to prevent soil acidification (Eckard, 2001).

12.6.3 Maintaining clover in mixed species pastures

Regular use of N fertiliser is associated with lower levels of clover in mixed species pastures. However, legumes such as clover aren't 'damaged' by N fertiliser, as although they can capture their own N from the atmosphere with the help of bacteria in roots (see [Section 12.1.1](#)), they will readily use fertiliser N when it's available. But regular applications of N fertiliser reduce the amount of N fixation by clovers, which removes their competitive advantage over grasses.

Nitrogen fertiliser also stimulates growth of grass more than clover, and this results in increased competition for light, water and other nutrients. Clover plants hate to be shaded, and it's mainly this effect of N fertiliser in a mixed species pasture that reduces clover content.

Clover shading is the main cause of clover demise in mixed pastures.



Maintaining clover in mixed pasture swards is therefore a combination of grazing appropriately, and applying moderate amounts of N per year (100-150 kg N/ha). Appropriate grazing management includes grazing at the optimal leaf regrowth stage (2-3 leaves for ryegrass and tall fescue, 3-4 leaves for cocksfoot, prairie grass and phalaris, and 4-5 leaves for kikuyu and Rhodes grass) or when significant shading starts to occur (more than 25% of the pasture area is shaded to the point that the base of the pasture can't be seen through the canopy when standing directly above), and grazing down to an average height of 4-5cm for all species except Rhodes grass which should be grazed to an average of 7-8cm.

12.7 Summary

- Before deciding to apply N fertiliser, consider the economics of growing extra pasture verses buying in alternative feed sources.
- Apply N strategically at times of the year when soil conditions are right for pasture growth and extra pasture growth is required and will be utilised.
- Apply N at rates of 25 to 50 kg N/ha per application to actively growing pastures.
- Maximum annual applications of 200 kg N/ha/yr are recommended to improve the efficiency of use and reduce risk of environmental loss.
- Do not apply urea when climatic conditions are warm and dry or cold and excessively wet.
- Avoid applying N when pastures are waterlogged. Denitrification or leaching losses can be significant, and uneconomical pasture growth responses will occur.
- Avoid grazing until ryegrass or tall fescue pastures have grown at least 2 new leaves, and brome (prairie grass), cocksfoot and kikuyu pastures have grown at least 3 new leaves, to maximise the efficiency of N application and reduce the risk of nitrate poisoning in cattle.
- Ensure that the extra pasture grown is utilised either through grazing or as harvested forage.



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Chapter 13

Using Dairy Effluent

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13 Using Dairy Effluent

13.1 Introduction

Australian dairy farmers, industry and government agencies can now access a wealth of technical information that has been collated from around Australia and overseas with respect to the design and management of dairy effluent systems.

The [Effluent and Manure Management Database for the Australian Dairy Industry](#) is a source of reliable and scientifically-validated technical information on dairy effluent management that is adaptable to all dairying regions in Australia. The database is updated and maintained regularly, and outlines the principles for effective effluent management. It includes performance based design criteria for components of effluent containment and reuse systems, and appropriate management principles for optimal operation.

This database can be found on the Dairy Australia's Dairying for Tomorrow website (<http://www.dairyingfortomorrow.com/index.php?id=48>) and is recognised as a principal reference.

Key points:

- Dairy effluent is a natural fertiliser and soil conditioner and, if managed effectively, can enhance pasture growth and improve soil structure.
- Effluent can be utilised safely and effectively if it is applied to meet the agronomic needs of the crop or pasture intended for its reuse.

13.2 Legal requirements of dairy effluent management

Dairy effluent is considered a potential point source for pollution of waterways. Mismanagement has the potential to impact water quality resulting in degradation of environmental assets.

All Australian States and Territories have set minimum standards that all dairies, irrespective of size, must comply with. These standards include State and industry legislation, codes of practices, guidelines and planning provisions to prevent any adverse impact from dairy effluent.

It is important to note that the environment protection frameworks and associated policies across Australia place the onus of environment protection on those that manage the land and water resources.

The fundamental principles regarding the management of dairy effluent should ensure:

- All effluent from the dairy, feedpads, standoff areas, underpasses and tracks must be contained and reused (most commonly spread back on pastures and crop).
- Effluent must not enter surface waters (including billabongs, canals, springs, swamps, natural or artificial channels, lakes, lagoons, creeks and rivers).
- Runoff containing effluent must not leave the property boundary.
- Effluent must not enter ground waters either directly or through infiltration.
- Effluent must not contaminate land (that is, avoid nutrient overload).



- Offensive odours must not impact beyond property boundaries.

Farmers should also be aware that recent changes in various States have seen risks associated with effluent management being incorporated into Dairy Food-Safety Audits to ensure a more consistent approach.

13.3 Nutrients in manure; how much is there?

Understanding the characteristics and quantity of manure being generated by the farm's dairy herd is the logical starting point for developing management strategies to utilise the resource and ultimately achieve production gains.

As the nutrient concentration in effluent is dependent on a range of site specific factors and is therefore variable from farm to farm (see [Section 13.3.4](#)), it is often more useful to start by estimating the total amount of each nutrient that is captured by the effluent system. The mass of those nutrients recoverable from the effluent system (i.e. in the sludge or in the liquid effluent after taking losses into account), and subsequently how much of each is available for plant uptake, can then be estimated.

While monitoring 43 dairy farms located across Australia, the [Accounting for Nutrients](#) project determined that almost half a kilogram of nitrogen is excreted daily by each cow – see Table 13.1. That is about 7 times the amount of phosphorus excreted. Therefore, for an average herd size of 250 cows over a 300-day lactation, 32.4 and 4.6 tonnes of nitrogen (N) and phosphorus (P) respectively are excreted around a dairy farm.

Table 13.1 Daily nutrient excretion by lactating cows from Accounting for Nutrients project; 43 farms over 5 visits. Source: Gourley *et al.*, 2010.

| NUTRIENT | MEAN g/cow/day | MEDIAN g/cow/day | MINIMUM g/cow/day | MAXIMUM g/cow/day | STD. ERROR OF THE MEAN |
|----------------|-------------------|---------------------|----------------------|----------------------|------------------------------|
| Nitrogen (N) | 432.3 | 430.9 | 199.0 | 792 | 7.39 |
| Phosphorus (P) | 61.1 | 59.4 | 19.9 | 131.6 | 1.39 |
| Potassium (K) | 339.6 | 329.4 | 120.2 | 670.8 | 6.90 |
| Sulphur (S) | 43.8 | 42.1 | 18.5 | 101.7 | 0.88 |
| Calcium (Ca) | 91.3 | 88.2 | 9.6 | 210.3 | 2.69 |
| Magnesium (Mg) | 52.4 | 49.9 | 20.8 | 264.2 | 1.39 |

The volume and nature of excreta produced by the cow will vary depending on dry matter intake and composition of the diet, with higher production cows producing more excreta compared to lower producing animals.

It is important to be aware that dietary nutrient content in excess of requirements is excreted.

Excess dietary potassium is excreted in urine, as is excess protein in the form of urea. Excess phosphorus, however, is excreted in faeces, with only negligible amounts appearing in the urine. Because of the excretion of excess dietary nutrients, it is often suggested that manure management should focus at the front of the cow, rather than the back end. Similarly, adding excess salt in



various feed additives to stimulate appetite can compound problems with salinity management when reapplying effluent, or in areas with heavy stock movement.

More detailed techniques for estimating manure and nutrient excretion can be found in the [Effluent and Manure Management Database for the Australian Dairy Industry](#).

13.3.1 How much of that nutrient enters the effluent system?

Most existing guidelines assume that 10% to 15% of the daily manure output generated by the dairy herd is deposited onto surfaces from which effluent is collected – see Table 13.2. Although that is a reasonable estimation for the holding yard at the dairy, industry trends towards feeding increasing levels of supplements or mixed rations on a feedpad suggest this assumption needs to be adjusted on some farms to avoid underestimating the volume of manure and nutrients to be handled.

Surveys with farmers utilising permanent feedpad systems indicate it is common for these facilities to accommodate the herd for a significant majority of the day depending of seasonal climatic conditions and farm activities. Effluent system design and nutrient management practices on these farms will be significantly different to more typical, predominantly grazing-based farms.

Table 13.2 Amount of nutrients expected to be deposited in different areas for a typical (grazing-based) 250 cow farm over a 300 day lactation. *Source: Gourley et al., 2010.*

| AREA OF FARM | % OF TIME SPENT IN THAT AREA | NITROGEN (N) (tonnes) | PHOSPHORUS (P) (tonnes) | POTASSIUM (K) (tonnes) |
|--------------------|------------------------------|-----------------------|-------------------------|------------------------|
| Paddocks | 80% | 25.4 | 3.7 | 20.4 |
| Laneways | 8% | 2.5 | 0.4 | 2.0 |
| Dairy shed & yards | 12% | 3.8 | 0.5 | 3.1 |

13.3.2 Nutrient movement within the pond system

The fate of nutrients entering the effluent system is an important consideration in dairy effluent management. An understanding of whether nutrients are partitioned with solids in the sludge or remain in the liquid effluent is the key to effective nutrient management and allows farmers to fine-tune fertiliser decisions.

This knowledge also allows farmers to allocate some monetary value to the nutrients recovered during desludging to credit against synthetic fertiliser inputs, thereby justifying the additional cost associated with their reuse further from the dairy.

Sedimentation of settleable solids is a key treatment process in ponds treating dairy shed effluent, partitioning both solid material and nutrients to the sludge in primary anaerobic ponds – see Figure 13.1. However, the fraction of manure nutrients partitioned to sludge is lower than for separated solids for two reasons. Firstly, organically bound N and P tend to be concentrated in fine, poorly settleable manure particles, and secondly, a fraction of the organic nutrients that do settle to the sludge are mineralised and released back into the effluent (*Fyfe 2013*).

Volatilisation of ammonia-N from the pond surface is responsible for some loss of nitrogen from the effluent system. While some past rules of thumb suggested this loss may be as high as 50% of total N, recent research on a commercial dairy in NSW suggests this loss may be less than 30% (*Fyfe 2013*).

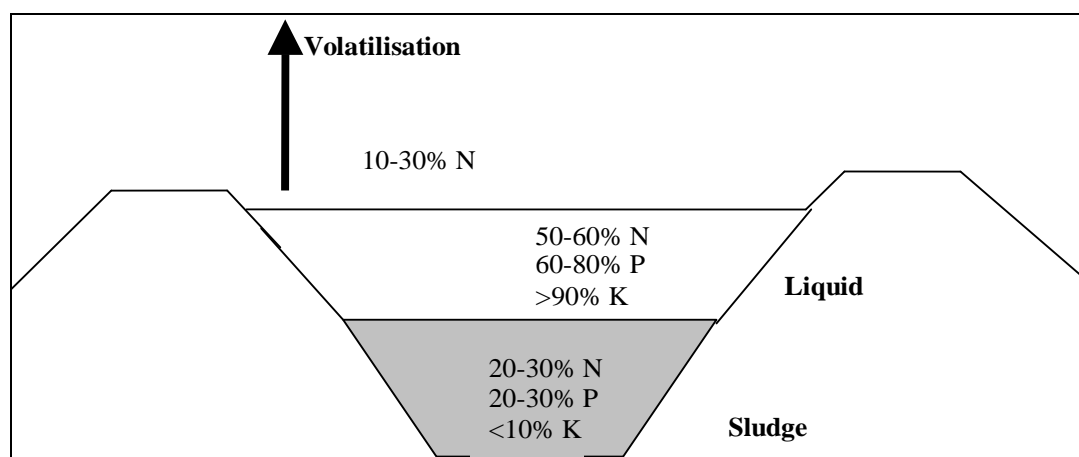


Figure 13.1 The proportions of nitrogen (N), phosphorus (P) and potassium (K) in the liquid (effluent) and sludge components of an anaerobic treatment pond and the proportion of N lost by ammonia volatilisation.

Potassium is highly soluble and non-reactive; therefore it is not prone to sedimentation or precipitation and is conserved through the effluent system and mostly recovered in the liquid effluent – see Table 13.3.

Table 13.3 Fate of nutrients in ponds, and the percentage of these nutrients available for plant uptake (shown in brackets). *Source: Fyfe, 2013*

| POND COMPONENT | N (%) | P (%) | K (%) |
|---|--------------------|------------------|------------|
| Effluent | 50-60 (70) | 60-80 | > 90 (100) |
| Sludge | 20-30 (10) | 20-30 (5) | < 10 (100) |
| Losses | 10-30 ^a | <10 ^b | – |
| Note: ^a Volatilisation losses ^b Precipitation losses | | | |

13.3.3 Nutrient availability

Some of the nutrients in effluent will be in a form that is not immediately available for uptake by plants.

For example, the N contained in dairy ponds can be separated into five different pools as follows:

1. Nitrate (usually negligible amounts),
2. Exchangeable ammonium ions or other nitrogenous materials that can be readily converted to ammonium (which is plant-available),
3. Organic N compounds which are potentially available for mineralisation,
4. Microbial biomass, and
5. Essentially unavailable N which is resistant to microbial attack and the mineralisation process.

While 1 and 2 are available for plant uptake, mineralisation of 3 and 4 is necessary before plant uptake can occur, and this takes time.

Depending on the source, effluent will contain varying proportions of N in each of the above five pools. For example, sludge from the primary pond in an effluent system contains a large proportion of relatively stabilised organic material, with varying resistance to microbial attack and hence N



release. Sludge only contains small amounts of immediately plant-available ammonium ions with much of the organic material in the sludge requiring mineralisation to release plant-available N over time. Thus primary pond sludge should be considered a slow-release nutrient source.

Second pond effluent however, typically has a very low solids content and has therefore quite different characteristics to that of sludge. It usually has a high ammonia N content (typically 50 to 90% of total N in southern Victorian surveys) and comparatively low amounts in an organic N form. As a high proportion of the total-N is in readily plant available forms, the application of second pond effluent will give quick plant responses. Research by Ward (2010) indicates that for first pond sludge, N uptake by plants over three years totalled 70 to 83% of N applied. Between 40 and 50% of the N applied was taken up in the first year, 10 to 30% in the second and 5 to 12% in the third. For the second pond effluent, responses to the ammonium-N applied were limited to within five to six months of application.

13.3.4 Typical nutrient concentrations in ponds

Before effluent or sludge is spread on the reuse area, it is best practice to decide what application rate (usually ML/Ha for effluent, or t/Ha for manure solids) is your target so that you apply the appropriate amount of nutrient – see [Section 13.5.4](#). For this exercise, it is necessary to know the nutrient concentration (usually kg/ML or mg/kg) in the material to be applied.

A large number of dairy effluent ponds have been sampled across Victoria, and to a lesser extent, other dairy regions in Australia. To provide some indication of potential nutrient content in effluent ponds, the following tables (13.4, 13.5 and 13.6) present average constituent concentrations for effluents from primary, secondary and single ponds, respectively. *Note:* The amount of nutrients is expressed in milligrams per litre (mg L^{-1}) which is equivalent to kilograms per megalitre (kg/ML) of effluent. A megalitre is one million litres.

Table 13.4 Reported primary pond effluent characteristics (standard deviations in brackets).

| | | CROSS-SECTIONAL SAMPLING | | | | LONGITUDINAL SAMPLING | | | |
|-------------------|-----------------------|---------------------------------|---------|-------------------|-------|------------------------------|------|-------------------------|-------|
| Region | | Southwest Victoria | | Northern Victoria | | Hunter Valley, NSW | | Southern Highlands, NSW | |
| Year | | 2001 | | 2006 | | 1998 | | 2005-2006 | |
| Number of samples | | 60 | | 61 | | NR | | 28 | |
| Source | | Kane (2004) | | McDonald (2013) | | Geary & Moore (1999) | | Fyfe (2013) | |
| EC | $\mu\text{S cm}^{-1}$ | 4903 | (2,031) | | | 3549 | | 3902 | (471) |
| pH | | 7.4 | (0.3) | | | | | 8 | (0.1) |
| VS | mg L^{-1} | | | | | | | 1222 | (165) |
| SS | mg L^{-1} | | | | | | | 700 | (181) |
| COD | mg L^{-1} | | | | | | | 1412 | (323) |
| Total N | mg N L^{-1} | 437 | (369) | 535 | (386) | 227 | (66) | 215 | (28) |
| Ammonia-N | mg N L^{-1} | 258 | (198) | | | 126 | (59) | 151 | (25) |
| Total P | mg P L^{-1} | 80 | (39) | 122 | (127) | 59 | (11) | 53 | (6) |
| K | mg L^{-1} | 410 | (243) | 484 | (256) | | | 463 ^a | (63) |
| Na | mg L^{-1} | 307 | (160) | | | | | 152 ^a | (15) |
| Ca | mg L^{-1} | 283 | (446) | | | | | 99 ^a | (12) |
| Mg | mg L^{-1} | 115 | (70) | | | | | 81 ^a | (11) |
| Total S | mg L^{-1} | 39.6 | (42) | 143 | (181) | | | 19 ^a | (2) |

^a Soluble fraction. Total fraction not analysed.

**Table 13.5** Reported secondary pond effluent characteristics (standard deviations in brackets).

| | | CROSS-SECTIONAL SAMPLING | | | LONGITUDINAL SAMPLING | |
|--------------------|-----------------------|---------------------------------|-------------------|-----------------------|---|-------------------------|
| Region | | Southwest Victoria | Northern Victoria | South East Queensland | Southwest Victoria | Southern Highlands, NSW |
| Year | | 2001 | 2006 | 2005 | 2002 - 2006 | 2005-2006 |
| Number of samples | | 60 | 61 | 7 | 30 | 28 |
| Source | | Kane (2004) | McDonald (2013) | Skerman (2006) | Jacobs & Ward (2007a; 2007b; 2008), Jacobs <i>et al.</i> (2008) | Fyfe (2013) |
| EC | $\mu\text{S cm}^{-1}$ | 4467 (1,798) | | 2823 (1,618) | 7495 (1,106) | 3749 (281) |
| pH | | 7.7 (0.3) | | 8.3 (0.4) | 8.1 (0.1) | 8.1 (0.1) |
| VS | mg L^{-1} | | | | | 923 (114) |
| SS | mg L^{-1} | | | | | 411 (111) |
| COD | mg L^{-1} | | | | | 981 (216) |
| TN | mg L^{-1} | 196 (178) | 286 (268) | 175 (98) | 163 (27) | 171 (30) |
| NH ₃ -N | mg L^{-1} | 119 (98) | | | 117 (32) | 122 (10) |
| TP | mg L^{-1} | 47 (39) | 107 (206) | 22 (7) | 29 (6) | 39 (5) |
| K | mg L^{-1} | 364 (204) | 474 (447) | 85 (57) | 461 (52) | 480 ^a (59) |
| Na | mg L^{-1} | 348 (222) | | 158 (107) | 598 (108) | 158 ^a (14) |
| Ca | mg L^{-1} | 159 (73) | | 77 (57) | 163 (31) | 98 ^a (8) |
| Mg | mg L^{-1} | 111 (71) | | 91 (78) | 209 (32) | 85 ^a (11) |
| S | mg L^{-1} | 23 (20) | 58 (119) | | 21 (7) | 17 ^a (2) |

^a Soluble fraction. Total fraction not analysed.

Table 13.6 Reported single pond effluent characteristics (standard deviations in brackets).

| | | CROSS SECTIONAL SAMPLING | | | | LONGITUDINAL SAMPLING |
|---------|-----------------------|---------------------------------|--------------------|-------------------|-------------------|------------------------------|
| Region | | South East Queensland | Southwest Victoria | Northern Victoria | Northern Victoria | Northern Victoria |
| Year | | 2005 | 2001 | 2006 | Not reported | Not reported |
| Samples | | 11 | 36 | 12 | 20 | 8 |
| Source | | Skerman <i>et al.</i> (2006) | Kane (2004) | McDonald (2013) | | McDonald (2013) |
| EC | $\mu\text{S cm}^{-1}$ | 4593 (2,159) | 4432 (1,703) | | 5 (3) | 3 (3) |
| pH | | 7.6 (0.5) | 7 (1) | | 7.3 (0.5) | |
| TN | mg N L^{-1} | 220 (164) | 313 403 | 429 (279) | 311 (209) | 230 (277) |
| TP | mg P L^{-1} | 46 (23) | 65 (65) | 113 (66) | 86 (70) | 95 (57) |
| K | mg L^{-1} | 394 (331) | 316 (173) | 479 (192) | 361 (256) | 421 (309) |
| Na | mg L^{-1} | 268 (190) | 304 (199) | | 231 (299) | |
| Ca | mg L^{-1} | 112 (45) | 192 (166) | | 149 (92) | |
| Mg | mg L^{-1} | 111 (59) | 97 (58) | | 97 (59) | |
| S | mg L^{-1} | | 28 (23) | 112 (105) | 113 (80) | 17 (24) |



As expected, results varied widely with significant ranges reported across farms (**cross-sectional sampling**). This variation is due to factors such as:

- the age of effluent in ponds,
- desludging frequency,
- time of year sample was taken,
- presence of any solid separation pre-pondage, and
- the level of dilution caused by rainfall, runoff and varying amounts of washdown water.

For these reasons, it is always strongly recommended that farmers sample their own effluent or sludge and base their reuse activities on their own data.

Tables 13.4 and 13.5 generally show that there was less variation on individual farms monitored over time (**longitudinal sampling**). This suggests that without significant changes in operation or management, it is preferable to use the results of previous effluent analyses on a specific farm rather than rely on “typical” data. The variation over time for single ponds (Table 13.6) was higher than for other ponds because of the interaction of the filling and emptying cycle with settled solids.

A complicating factor is that nutrient concentrations in the primary pond will vary with depth. Table 13.7 shows the range in nutrient concentrations (kg/ML) at depth in the primary pond at DemoDAIRY (south-west Victoria) prior to (P) and after (A) agitation.

Table 13.7 Nutrient concentrations at depth (kg/ML) in the primary pond prior to and after agitation

| POND DEPTH (m) | NITROGEN (N) (P/A)* | PHOSPHORUS (P) (P/A) | POTASSIUM (K) (P/A) | SULPHUR (S) (P/A) |
|---------------------------|--------------------------------|---------------------------------|--------------------------------|------------------------------|
| 0 | 260/370 | 39/57 | 510/500 | 26/62 |
| 1 | 270/700 | 40/120 | 510/560 | 27/200 |
| 2 | 1300/750 | 210/120 | 670/550 | 410/210 |
| 3 | 1700/970 | 230/150 | 660/610 | 470/300 |
| 4.5 (bottom) | 1400/1500 | 190/230 | 620/720 | 370/530 |

*P = prior to agitation; A = after agitation.

Source: Nutrient sampling conducted by John Kane (DPI Warrnambool) and Worldwide Organics Pty Ltd at the Terang Demo Dairy (2003).

The DemoDAIRY data shows that when unagitated, nutrient concentrations in the *first pond* increase with depth for N, P and S but not for K. Agitating (stirring) the pond did have an effect on mixing nutrients throughout the pond. Therefore, be aware that basing your application rate on the nutrient concentration at the top of the pond could mean that you will be out by a factor of over threefold if you use effluent from the bottom. You may be applying excessive amounts of nutrients to some areas and be at risk of burning crops and seedlings.

When emptying a *first pond* that has been collecting nutrients for a number of years, it is recommended that this effluent be applied to an established pasture or to paddocks prior to cultivation.

In other words, apply it *before* sowing a new crop or pasture. Consider taking samples of the agitated sludge as you are desludging the pond and use that data to improve the target application



rate next time you desludge. If farm operational details and the desludging period remain close to the previous period, then the data will be useful.

There was no nutrient gradient at depth with the *second* (storage) pond at DemoDAIRY, which indicates that taking a sample at any level in a second pond will give a reasonably representative result.

13.3.4.1 Attributes of a primary effluent pond

- Solids content variable – requires specialised extraction and spreading equipment
- Very high in organic matter
- Higher than 25mm per application could lead to potential risks
- High concentrations of nutrients, especially N, P, Ca & Mg
- Small proportion of nutrients in readily plant available forms
- Most nutrients in various organic forms that require mineralisation over time before plant-available
- Effectively a slow release, sustained release organic fertiliser

13.3.4.2 Attributes of a second effluent pond

- Low solids – comparatively easy to pump and apply
- A high proportion of nutrients in readily plant available forms, but nitrogen responses relatively short lived
- Effectively salty irrigation water with large slugs of urea and potash
- Well suited to:
 - Replacing potassium on hay/silage paddocks
 - Boosting growth of summer forage crops

13.4 Sampling and testing of effluent ponds

Sampling effluent ponds prior to the application of effluent is often recommended to provide a more accurate guide to the nutrient content than can be gleaned from published tables of 'typical' values. When sending samples for analysis the following analyses should be requested: Phosphorus (P), Potassium (K), total Nitrogen (N), ammonia-N and salinity (Electrical Conductivity - EC). The ammonia-N content provides a good indication of N availability for plant uptake and use. Knowing P and K content will assist in formulating any subsequent fertiliser requirements for the paddock.

Any laboratory that routinely conducts water testing should be able to test effluent samples.

Any activities conducted in and around effluent ponds must be undertaken with extreme caution as effluent ponds can be very deep, with steep internal walls. It may even be difficult to locate the edge of the pond due to plant growth.

13.4.1 Procedure for sampling:

13.4.1.1 Sample source

As with soil testing, the key to effluent sampling is to take a sample that will represent the effluent being applied to the pasture or crop. In many cases, it would be more appropriate to collect samples from the final pond, the gate valves or even from the pump.



Direct application systems are best sampled at the sump or pump.

Farmers who use flood irrigation would sample at the gate valve, as this is the easiest place to test. It is best to allow the pump or gate valve to flow for at least 10 minutes before collecting a sample.

When sampling from ponds, the following applies. If you intend to desludge the pond, take samples from the sludge layer of the pond. As indicated in Table 13.7, the levels of nutrients at the bottom of the pond will be higher than the liquid fraction at the top of the first pond. If you are only removing the liquid fraction of the first pond without any agitation, take samples from that part of the pond. It would be best to take a sample when the first pond is being stirred. It is, however, unlikely that the pond will be stirred by a contractor, sampled and then stirred again and applied after the results of the test have arrived. If you are pumping from a second or storage pond, the nutrient gradient is relatively constant, so sampling depth is not critical.

13.4.1.2 Equipment required for sampling:

You will need the following equipment for sampling:

- An extendable pole with a clamp at one end to hold a sample bottle.
- A plastic bucket.
- Three or four 1-litre, water-washed sample bottles.
- Insulated carrier boxes.
- Crushed ice.

13.4.1.3 Procedure

Collect 250ml to 500ml samples from various sites around the final pond or from the pump or pipe outlet, using the sample bottle clamped to the pole until 3 to 4 litres have been collected. Collection from ponds should take place close to the surface but should exclude any crust material.

As each sample is collected, place it in the plastic bucket. Hands and foreign objects should not contact sampled effluent or the inside of the bucket.

Each 1-litre, water-washed sample bottle should be filled to the brim with thoroughly mixed effluent from the bucket, unless the sample will be frozen prior to sending it to the laboratory, in which case, leave enough space below the top of the bottle to allow for expansion.

If samples are refrigerated, ensure they reach the laboratory within 2 days of sampling. If samples are frozen, 7 days is acceptable. To prevent unnecessary waiting and sample spoiling, the laboratory should be notified that the samples are being sent.



13.5 Applying dairy effluent and sludge to pastures and crops

Numerous production studies have shown that the application of dairy effluent and sludge to either pasture or crops is an effective way of increasing forage production on-farm.

These studies have demonstrated that this is a desirable way of returning and reusing increasingly valuable nutrients back onto the farm. Further, economic analyses of the results strongly support the costs associated with installing an effective effluent system to contain, store and apply effluent back to farm land. Payback periods are very dependent on the effluent system installed and the various components selected.

13.5.1 Underlying principles for application of dairy effluent and sludge

A number of key principles need to be followed to effectively utilise and safely return effluent and sludge back onto the farm. These include:

- Allow sufficient land area to apply effluent at an agronomically sensible rate to meet the crop or pastures nutrient requirements.
- The main nutrients in effluent are not 'balanced' and each must be considered individually. The nutrient that requires the largest reuse area sets the application rate - see [Section 13.5.4](#).
- Total potassium per application should be no more than **60 kg K/ha**, and no more than **120 kg K/ha** per year. This applies for both liquid effluent and sludge.
- For liquid effluent, the total nitrogen application should be no more than **60-80 kg N/ha**. However, nitrogen application rates as sludge can be much higher due to the slow release nature of much of the organic N in the sludge.
- Heavier applications increase the risk of problems such as nitrate poisoning, mineral imbalances and make less efficient use of the applied N as well as increasing the risk of losses to the environment.
- Treat effluent and sludge as a nutrient source rather than just something that needs disposing of.
- A lighter rate over a larger area is preferable to overloading a small area. If no chemical analysis is available, effluent should be spread at a rate of 1 megalitre per 12 hectares. This is based on typical nutrient concentrations found in surveys of farm treatment systems.
- Apply effluent or sludge to paddocks when there is no likelihood of runoff from the property.
- Rotate effluent applications around at least three or four different areas if possible to avoid excessive build-up of nutrients in the soil.
- Conduct regular soil testing of the areas where effluent is being applied to monitor nutrient levels and soil health.
- Isolate the paddock and restrict cattle grazing for at least 21 days after the application of effluent to pasture or crops. This withholding period will overcome any palatability or fouling issues, reduce the risk of any pathogens and allow the plants time to respond to the nutrients. For direct application of sludge to pasture, up to 6 – 8 weeks may be required due to the solids content.



13.5.2 Strategies to reduce problems

Any effluent or sludge applied to land should not leave the farm boundary or pollute any surface waterway or ground water. In addition, steps should be taken to reduce the risk of odours. Strategies to minimise these risks include:

- Where possible, effluent should be applied to land during the drier months. Applications in the wetter months increase the risk of runoff to streams or leaching to ground water when soils are saturated.
- Apply effluent or sludge on areas well away from watercourses or drainage lines.
- Apply effluent at such a rate that the liquid does not remain ponded for more than one hour after application.
- For all spray applications, use sprinkler nozzles that produce large droplets rather than a fine spray. Note, the lower the nozzle height, the lower the odour potential.
- Where possible apply effluent, or spread sludge or manure during the day rather than in the early morning or late evening when odours can travel further before being dispersed.
- Consider the wind direction and velocity on days when applying effluent or spreading sludge or manure. Adjust application times to suit.
- If the spreading of sludge or manure could result in odour, consider direct injection into the soil, soil incorporation soon after spreading or applying only light rates.

13.5.3 Where and when to apply effluent and sludge

13.5.3.1 Effluent

- Dairy effluent typically contains relatively large amounts of readily plant available nutrients, particularly nitrogen (N) and potassium (K) in addition to a range of other essential plant nutrients. Depending on the farm, the effluent can also be quite saline.
- Best plant growth responses are obtained when effluent is applied to actively growing crops or pastures in the warmer months of the year. This is due largely to responses to the N content and to a lesser extent the water content. Forage crops, such as turnips or rape, have been found to give excellent responses to effluent. Responses to actively growing pastures are good, but considerably lower for drought stressed or dormant pastures.
- Due to its usually high salt content, effluent should not be regarded as an irrigation water. While plants do respond to the water content, application rates should be based on the nutrient (especially N and K) content of the effluent rather than water requirements. Effluent can be shandied with irrigation water to reduce the salinity levels.
- Again due to the salt content, effluent should not be applied to young seedlings or to irrigate a crop up due to the risk of burning.
- The application of effluent is also an effective way of increasing the K content of soils. This can be a useful method of correcting induced low soil K levels in paddocks that have been repeatedly cut for hay or silage.
- Where possible effluent applications should be synchronised with herd and paddock rotations to allow sufficient time between application and grazing. A standard practice is for at least a 21 day interval to allow time for the pasture to respond and reduce pathogen risks.



13.5.3.2 Sludge

- Dairy sludge extracted from the bottom of treatment ponds is physically and chemically quite different to the liquid effluent. Its high solids content, typically 6-8% DM as spread, requires specialist handling equipment which influences when and how it can be used.
- Importantly, while a proportion of the nutrients such as ammonium-N in the sludge are in readily plant available forms, the majority of the nutrients are in various organic forms. These need to be mineralised to convert them to plant available forms. As a result, applied sludge acts as a long-acting, slow-release nutrient source for pasture and crop growth.
- Sludge can be applied directly to established pasture, preferably in the drier months, to enable the water content to drain and evaporate off leaving the nutrient rich solids on the soil surface. These solids then act as an effective, long-acting nutrient source. Direct applications at wetter times of the year run the risk of rainfall washing these solids off the pasture.
- Application rates are usually limited by trafficability over the spread area and typically are not more than 5 – 10 mm (50,000 – 100,000 L/Ha).
- Sludge can also be applied to cultivated ground and incorporated into the soil prior to sowing of a crop. As with direct application to pasture, this is best done in the drier part of the year.
- Overseas, sludge is often injected directly into soil using specialist equipment. This minimises odours and N losses by ammonia volatilisation. However, suitable equipment is not commonly available in Australia.

13.5.3.3 Manure

See the following links for information on the re-use of manure:

- [Land application of manure and pond sludge](#)
- [Making the Most of Animal By-Products](#)



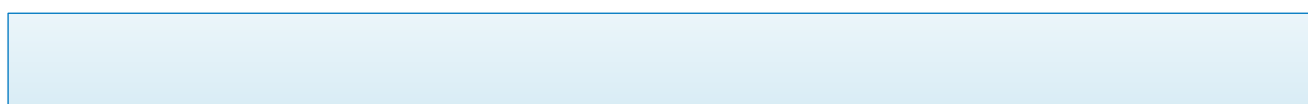
13.5.4 Worked example; calculating application rates when applying effluent.

Scenario; effluent is to be applied to grazed pasture with the nutrient application to not exceed 60 to 80 kg N each application (see [Section 13.5.1](#)) or 120 kg K annually. The nutrient concentration in the effluent was tested to be 200 mg total Nitrogen per Litre, 30 mg P/L, and 400 mg K/L.

Often, testing laboratories report nutrient concentrations in effluent using units of mg/L (milligrams per litre). Fortunately, this is equivalent to expressing nutrient concentration as kg/ML (kilograms per megalitre) which is a more useful measure.

It is also useful to know that an application rate of 1 ML/Ha is equivalent to a depth of 100mm. Therefore a 10 mm application of effluent represents an application rate of 0.1 ML/Ha.

The target application depth can be calculated according to:





13.6 References

Birchall, S., C. Dillon & R. Wrigley 2008, 'Effluent and Manure Management Database for the Australian Dairy Industry', Dairy Australia. <http://www.dairyingfortomorrow.com/index.php?id=48>

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Chapter 14

Calculating Rates and Costs

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14 Calculating Rates and Costs

14.1 Introduction

Fertiliser inputs are a significant portion of the farm budget, and it is therefore important to provide the *Right Source* of fertiliser, at the *Right Rate*, in the *Right Place*, and at the *Right Time* (4Rs). Under application of nutrients can lead to reduced pasture and stock performance, while over application of nutrients can be an unnecessary waste of money.

Learning outcomes

At the completion of this chapter, you should be able to:

- Calculate the amount of fertiliser needed to apply the required amount of nutrients.
- Calculate the amount of nutrient applied by a particular amount of fertiliser.
- Calculate the cost of various fertilisers, and compare fertiliser products for value.

14.2 Fertiliser application rates and nutrient application rates

With an increasing range of fertiliser products now available on the market, fertiliser recommendations are often given as kilograms of nutrient per hectare (*kg nutrient/ha*), rather than as an amount of a specific fertiliser product. For example, the unit of measure for phosphorus is **kg P/ha**. This is called the **nutrient application rate**. To order your fertiliser, you need to know how to convert the nutrient application rate into the fertiliser application rate.

On the other hand, if your fertiliser recommendation has been given as an amount of fertiliser (for example, 350 kg/ha of superphosphate), then it is useful to know how to convert this **fertiliser application rate** into a nutrient application rate, so you can record how much N, P, K, S or other nutrients you will be applying to your paddocks.



14.2.1 What is the fertiliser application rate required to apply a particular nutrient application rate?

To calculate the fertiliser application rate required for a particular nutrient application rate, use the formula:

$$\begin{array}{|c|} \hline \text{Nutrient application} \\ \text{rate (kg/ha)} \\ \hline \end{array} \div \begin{array}{|c|} \hline \% \text{ of nutrient in the} \\ \text{fertiliser} \\ \hline \end{array} \times 100 = \begin{array}{|c|} \hline \text{Fertiliser application rate} \\ \text{(kg/ha)} \\ \hline \end{array}$$

Example. How much *single superphosphate* per hectare is required to provide 25 kilograms per hectare of phosphorus (25 kg P/ha)?

If you decide to apply 25 kg P/ha, you can calculate the fertiliser application rate required when using single superphosphate. This example uses a generic single superphosphate, which contains 8.9% total P (see Appendix G).

$$\begin{array}{|c|} \hline \text{Nutrient application} \\ \text{rate (kg/ha)} \\ \hline \mathbf{25} \\ \hline \end{array} \div \begin{array}{|c|} \hline \% \text{ of nutrient in the} \\ \text{fertiliser} \\ \hline \mathbf{8.9} \\ \hline \end{array} \times 100 = \begin{array}{|c|} \hline \text{Fertiliser application rate} \\ \text{(kg/ha)} \\ \hline \mathbf{281} \\ \hline \end{array}$$

Example. How much *triple superphosphate* per hectare is required to provide 25 kg P/ha?

The fertiliser application rate needed to apply 25 kg of P/ha when using triple superphosphate can also be calculated using the above formula. This example uses a generic triple superphosphate, which contains 20% total P.

$$\begin{array}{|c|} \hline \text{Nutrient application} \\ \text{rate (kg/ha)} \\ \hline \mathbf{25} \\ \hline \end{array} \div \begin{array}{|c|} \hline \% \text{ of nutrient in the} \\ \text{fertiliser} \\ \hline \mathbf{20} \\ \hline \end{array} \times 100 = \begin{array}{|c|} \hline \text{Fertiliser application rate} \\ \text{(kg/ha)} \\ \hline \mathbf{125} \\ \hline \end{array}$$

So, if you use triple superphosphate, you need less fertiliser to apply the same amount of phosphorus/ha because it is a high-analysis fertiliser.

Exercise 14.1 provides additional practice in calculating the fertiliser application rate required to apply a particular nutrient application rate.



Exercise 14.1

What is the fertiliser application rate required to apply a particular nutrient application rate?

You have calculated that your farm needs 20 kg P/ha applied per year.

The following formula allows you to calculate the fertiliser application rate that will result in a particular nutrient application rate. You can use the same formula with a different nutrient application rate or with a different nutrient, such as N, K, or S. Just follow the three steps given below.

Step 1. Write the required nutrient application rate in the boxes in column 1 of the table below. (In this exercise, we have done this for you, using a rate of 20 kg P/ha.)

Step 2. Using the generic fertiliser product links (Appendix G); write the percentage of phosphorus for each product in the boxes in column 2. Remember to use total P, not available P.

Step 3. Calculate the rate of fertiliser to be applied, using the formula below, and fill in the boxes in column 3.

$$\boxed{\text{Nutrient application rate (kg/ha)}} \div \boxed{\% \text{ of nutrient in the fertiliser}} \times 100 = \boxed{\text{Fertiliser application rate (kg/ha)}}$$

| Fertiliser Product (Nutrient) | 1 Nutrient application rate (kg/ha) | 2 Percent of nutrient in the fertiliser | x 100 = | 3 Fertiliser application rate (kg/ha) |
|---|--|--|---------|--|
| Generic single superphosphate Phosphorus | 20 | 8.9 | x 100 = | 225 |
| Generic MAP Phosphorus | 20 | | x 100 = | |
| Generic DAP Phosphorus | 20 | | x 100 = | |



Exercise 14.1 Answers

What is the fertiliser application rate required to apply a particular nutrient application rate?

The following formula allows you to calculate the fertiliser application rate that will result in a particular nutrient application rate. You can use the same formula with a different nutrient application rate or with a different nutrient, such as N, K, or S. Just follow the three steps given below.

Step 1. Write the required nutrient application rate in the boxes in column 1 of the table below. (In this exercise, we have done this for you, using a rate of 20 kg P/ha.)

Step 2. Using the fertiliser product links (Appendix G), write the percentage of phosphorus for each product in the boxes in column 2. Remember to use total P, not available P.

Step 3. Calculate the rate of fertiliser to be applied, using the formula below, and fill in the boxes in column 3.

$$\boxed{\text{Nutrient application rate (kg/ha)}} \div \boxed{\% \text{ of nutrient in the fertiliser}} \times 100 = \boxed{\text{Fertiliser application rate (kg/ha)}}$$

| Fertiliser Product (Nutrient) | 1 Nutrient application rate (kg/ha) | 2 Percent of nutrient in the fertiliser | x 100 = | 3 Fertiliser application rate (kg/ha) |
|---|--|--|---------|--|
| Generic single superphosphate Phosphorus | 20 | 8.9 | x 100 = | 225 |
| Generic MAP Phosphorus | 20 | 22 | x 100 = | 91 |
| Generic DAP Phosphorus | 20 | 20 | x 100 = | 100 |



14.2.2 How many kg/ha of nutrient are applied by a particular fertiliser application rate?

To convert the *fertiliser* application rate (kg/ha) to the *nutrient* application rate (kg *nutrient*/ha), use the formula:

| | | | | | |
|---|---|------------------------------------|-------|---|--------------------------------------|
| Fertiliser application rate (kg/ha) | x | % of nutrient in the fertiliser | ÷ 100 | = | Nutrient application rate (kg/ha) |
|---|---|------------------------------------|-------|---|--------------------------------------|

Example. What is the nutrient application rate of P/ha when 450 kg/ha of single superphosphate is applied? This example uses generic superphosphate, which contains 8.9% total P.

| | | | | | |
|---|---|------------------------------------|-------|---|--------------------------------------|
| Fertiliser application rate (kg/ha) | x | % of nutrient in the fertiliser | ÷ 100 | = | Nutrient application rate (kg/ha) |
| 450 | x | 8.9 | ÷ 100 | = | 40 |

Example. What is the nutrient application rate of S/ha when 450 kg/ha of single superphosphate is applied? This example uses a generic single superphosphate, which contains 11% total S.

| | | | | | |
|---|---|------------------------------------|-------|---|--------------------------------------|
| Fertiliser application rate (kg/ha) | x | % of nutrient in the fertiliser | ÷ 100 | = | Nutrient application rate (kg/ha) |
| 450 | x | 11.0 | ÷ 100 | = | 50 |

Exercise 14.2 provides practice in calculating the amount of nutrient applied when you know the fertiliser application rate.



Exercise 14.2

How many kg/ha of nutrient are applied by a particular fertiliser application rate?

You have just bought more land, and the previous farmer tells you he has used 400 kg/ha of single superphosphate every year. The two farmers next door have been using the same fertiliser application rate but different fertiliser products. You want to know what amount of nutrients they have been applying.

The following formula allows you to calculate the nutrient application rate that will result from a particular fertiliser application rate. You can use the same formula with different fertiliser application rates or with a different nutrient, such as N, K, or S. Just follow the three steps given below.

Step 1. Write the fertiliser application rate in column 1. (For this exercise, we have done this for you, using a rate of 400 kg/ha for each product.)

Step 2. Using the fertiliser product links (Appendix G), write the percentage of phosphorus for each product in the boxes in column 2. Remember to use total P, not available P.

Step 3. Calculate the nutrient application rate, using the formula below, and fill in the boxes in column 3.

$$\begin{array}{|c|} \hline \text{Fertiliser} \\ \text{application rate} \\ \text{(kg/ha)} \\ \hline \end{array} \times \begin{array}{|c|} \hline \% \text{ of nutrient in the} \\ \text{fertiliser} \\ \hline \end{array} \div 100 = \begin{array}{|c|} \hline \text{Nutrient application rate} \\ \text{(kg/ha)} \\ \hline \end{array}$$

| | 1 | | 2 | | 3 |
|---|--|---|--|---------|--|
| Fertiliser Product (Nutrient) | Fertiliser application rate (kg/ha) | x | Percent of nutrient in the fertiliser | ÷ 100 = | Nutrient application rate (kg/ha) |
| Generic single superphosphate Phosphorus | 400 | x | 8.9 | ÷ 100 = | 36 |
| Generic MAP Phosphorus | 400 | x | <input type="text"/> | ÷ 100 = | <input type="text"/> |
| Generic DAP Phosphorus | 400 | x | <input type="text"/> | ÷ 100 = | <input type="text"/> |



Exercise 14.2 Answers

How many kg/ha of nutrient are applied by a particular fertiliser application rate?

The following formula allows you to calculate the nutrient application rate that will result from a particular fertiliser application rate. You can use the same formula with different fertiliser application rates or with a different nutrient, such as N, K, or S. Just follow the three steps given below.

Step 1. Write the fertiliser application rate in column 1. (For this exercise, we have done this for you, using a rate of 400 kg/ha for each product.)

Step 2. Using the fertiliser product links (Appendix G), write the percentage of phosphorus for each product in the boxes in column 2. Remember to use total P, not available P.

Step 3. Calculate the nutrient application rate, using the formula below, and fill in the boxes in column 3.

$$\begin{array}{|c|} \hline \text{Fertiliser} \\ \text{application rate} \\ \text{(kg/ha)} \\ \hline \end{array} \times \begin{array}{|c|} \hline \% \text{ of nutrient in the} \\ \text{fertiliser} \\ \hline \end{array} \div 100 = \begin{array}{|c|} \hline \text{Nutrient application rate} \\ \text{(kg/ha)} \\ \hline \end{array}$$

| Fertiliser Product (Nutrient) | 1 Fertiliser application rate (kg/ha) | x | 2 Percent of nutrient in the fertiliser | ÷ 100 = | 3 Nutrient application rate (kg/ha) |
|---|--|---|--|---------|--|
| Generic single superphosphate Phosphorus | 400 | x | 8.9 | ÷ 100 = | 36 |
| Generic MAP Phosphorus | 400 | x | 22 | ÷ 100 = | 88 |
| Generic DAP Phosphorus | 400 | x | 20 | ÷ 100 = | 80 |



14.3 Calculating the cost of fertilisers and nutrients

The next step is to work out the cost of the fertiliser per hectare and the cost of individual nutrients per hectare for various fertiliser products. The most accurate costing will include all costs and discounts. For example:

| | |
|-------|--|
| | Product cost ex factory |
| plus | Bin hire |
| plus | Cost of delivery |
| plus | Costs of spreading |
| minus | Discounts for early purchase, prompt payment, etc. |

When the 'as-spread' cost is considered, high-analysis fertilisers are often cheaper per hectare than are low-analysis fertilisers because of the smaller amount of fertiliser product to be transported and spread to achieve the same nutrient application rate.

14.3.1 The cost of fertiliser per hectare

When calculating the following fertiliser and nutrient costs, refer to the following table of generic bulk fertiliser costs which are ex-factory and excluding GST as of March 2013.

Table 14.1 Generic bulk fertiliser costs as quoted ex-factory and excluding GST as of March 2013.

| FERTILISER PRODUCT | BRISBANE | NEWCASTLE | GEELONG | ADELAIDE |
|--------------------------------|----------|-----------|---------|----------|
| Urea | \$ 618 | \$ 632 | \$ 628 | \$ 628 |
| Calcium Ammonium Nitrate (CAN) | \$ 577 | \$ 644 | \$ 577 | \$ 577 |
| Di Ammonium Phosphate (DAP) | \$ 716 | \$ 704 | \$ 704 | \$ 704 |
| Mono Ammonium Phosphate (MAP) | \$ 716 | \$ 704 | \$ 704 | \$ 704 |
| Triple Superphosphate (TSP) | \$ 851 | \$ 801 | \$ 756 | \$ 801 |
| Muriate of Potash (MOP) | \$ 670 | \$ 670 | \$ 658 | \$ 681 |
| Sulphate of Potash (SOP) | \$ 890 | \$ 890 | \$ 890 | \$ 890 |
| Sulphate of Ammonia (SOA) | \$ 529 | \$ 529 | \$ 503 | \$ 503 |
| Single Superphosphate | \$ 454 | \$ 364 | \$ 342 | \$ 358 |

Fertiliser cost per hectare is calculated using the following formula:

$$\begin{array}{|c|} \hline \text{Cost of fertiliser} \\ \text{(\$ / tonne)} \\ \hline \end{array} \times \begin{array}{|c|} \hline \text{Fertiliser application} \\ \text{rate (kg/ha)} \\ \hline \end{array} \div 1000 = \begin{array}{|c|} \hline \text{Cost of fertiliser} \\ \text{(\$ / ha)} \\ \hline \end{array}$$



Example. What is the total cost per hectare to apply 25 kg P/ha using single superphosphate?

In [Section 14.2.1](#), we worked out that you need a fertiliser application rate of 281 kg of generic single superphosphate (8.9% P) per hectare to apply 25 kg P/ha. The total cost per hectare can then be calculated using the formula:

$$\begin{array}{|c|} \hline \text{Cost of fertiliser} \\ (\$/\text{tonne}) \\ \hline \end{array} \times \begin{array}{|c|} \hline \text{Fertiliser application} \\ \text{rate (kg/ha)} \\ \hline \end{array} \div 1000 = \begin{array}{|c|} \hline \text{Cost of fertiliser} \\ (\$/\text{ha}) \\ \hline \end{array}$$

If you assume a freight and spreading cost of \$40/tonne and a bulk cost of \$364/tonne (ex. Newcastle – see Table 14.1), then the total cost is \$404/tonne, or \$113.52/ha.

$$\begin{array}{|c|} \hline \text{Cost of fertiliser} \\ (\$/\text{tonne}) \\ \hline \end{array} \times \begin{array}{|c|} \hline \text{Fertiliser application} \\ \text{rate (kg/ha)} \\ \hline \end{array} \div 1000 = \begin{array}{|c|} \hline \text{Cost of fertiliser} \\ (\$/\text{ha}) \\ \hline \end{array}$$

$$\begin{array}{|c|} \hline \$404 \\ \hline \end{array} \times \begin{array}{|c|} \hline 281 \\ \hline \end{array} \div 1000 = \begin{array}{|c|} \hline \$113.52 \\ \hline \end{array}$$

Example. What is the total cost per hectare to apply 25 kg P/ha using generic triple superphosphate?

Using generic triple superphosphate (20% P), you need a fertiliser application rate of 125 kg/ha to apply 25 kg P/ha (see [Section 14.2.1](#)). If you assume a freight and spreading cost of \$40/tonne and a bulk cost of \$801/tonne (ex. Newcastle – see Table 14.1), then the total cost is \$841/tonne, or \$105.13/ha.

$$\begin{array}{|c|} \hline \text{Cost of fertiliser} \\ (\$/\text{tonne}) \\ \hline \end{array} \times \begin{array}{|c|} \hline \text{Fertiliser application} \\ \text{rate (kg/ha)} \\ \hline \end{array} \div 1000 = \begin{array}{|c|} \hline \text{Cost of fertiliser} \\ (\$/\text{ha}) \\ \hline \end{array}$$

$$\begin{array}{|c|} \hline \$841 \\ \hline \end{array} \times \begin{array}{|c|} \hline 125 \\ \hline \end{array} \div 1000 = \begin{array}{|c|} \hline \$105.13 \\ \hline \end{array}$$

Note: Freight and spreading costs vary with both application rates and location.

14.3.2 Which product would you choose?

The obvious choice on the basis of the phosphorus cost per hectare would be triple superphosphate, but there are other factors that need to be considered. For example, are nutrients other than phosphorus needed? For instance, this generic triple superphosphate contains only 1% sulphur, whereas single superphosphate contains 11% sulphur. If your soil test result showed a sulphur deficiency, then you might choose single superphosphate or other products containing sulphur.

Comparing fertiliser products can be very difficult because of their different nutrient analyses. You should never compare only the price per tonne of fertiliser products. You should always take into account the nutrient analysis and then compare the cost per kilogram of the actual nutrients - See [Section 14.3.3](#).

There is usually not a great difference in price for similar products between the fertiliser companies. The biggest savings that can be made are by identifying what product you need. In other words, what nutrients are actually required as determined by careful soil testing or plant tissue testing and nutrient planning (see Chapter 15). The choice of product or company may depend on the reliability of supply and also financial incentives that may be offered for buying early.



14.3.3 The cost of a nutrient in a fertiliser product

The cost of a nutrient in a product can be calculated using the formula:

| | | | | |
|---|---|---|---|---------------------------------------|
| Cost of 1 tonne of fertiliser (\$ / tonne) | ÷ | Amount of nutrient in 1 tonne of fertiliser (kg / tonne) | = | Cost of 1 kg of nutrient (\$ / kg) |
|---|---|---|---|---------------------------------------|

14.3.3.1 Bulk cost per kg of N in urea

Urea is 46% nitrogen. Thus, 1 tonne of urea contains 460 kg of nitrogen. Using the formula and assuming the cost per tonne of urea is \$628 we can calculate the cost of 1 kg of nitrogen in urea.

| | | | | |
|---|---|---|---|---------------------------------------|
| Cost of 1 tonne of fertiliser (\$ / tonne) | ÷ | Amount of nutrient in 1 tonne of fertiliser (kg / tonne) | = | Cost of 1 kg of nutrient (\$ / kg) |
| \$628 | ÷ | 460 | = | \$1.37 / kg of N |

14.3.3.2 Bulk cost per kg of P in a generic triple superphosphate

A generic triple superphosphate has 20% phosphorus. Thus, 1 tonne contains 200 kg of phosphorus. Using the formula and assuming the cost per tonne is \$756 we can calculate the cost of 1 kg of phosphorus in this product.

| | | | | |
|---|---|---|---|---------------------------------------|
| Cost of 1 tonne of fertiliser (\$ / tonne) | ÷ | Amount of nutrient in 1 tonne of fertiliser (kg / tonne) | = | Cost of 1 kg of nutrient (\$ / kg) |
| \$756 | ÷ | 200 | = | \$3.78 / kg of P |

14.3.3.3 Bulk cost per kg of K in muriate of potash

Muriate of potash (MOP) is 50% potassium. Thus, 1 tonne of MOP contains 500 kg of potassium. Using the formula and assuming the cost per tonne of MOP is \$658 we can calculate the cost of 1 kg of potassium in MOP.

| | | | | |
|---|---|---|---|---------------------------------------|
| Cost of 1 tonne of fertiliser (\$ / tonne) | ÷ | Amount of nutrient in 1 tonne of fertiliser (kg / tonne) | = | Cost of 1 kg of nutrient (\$ / kg) |
| \$658 | ÷ | 500 | = | \$1.32 / kg of K |

14.3.3.4 Bulk cost per kg of S in gypsum

Gypsum products contain varying amounts of sulphur. For this example, we have chosen a gypsum source containing 17% sulphur. Thus, 1 tonne of this gypsum contains 170 kg of sulphur. Using the formula and assuming the cost per tonne of gypsum is \$140, we can calculate the cost of 1 kg of sulphur in this gypsum.

| | | | | |
|---|---|---|---|---------------------------------------|
| Cost of 1 tonne of fertiliser (\$ / tonne) | ÷ | Amount of nutrient in 1 tonne of fertiliser (kg / tonne) | = | Cost of 1 kg of nutrient (\$ / kg) |
| \$140 | ÷ | 170 | = | \$0.82 / kg of S |



14.3.3.5 Bulk cost per kg of P in MAP

Mono ammonium phosphate (MAP) has an NPKS analysis (see Chapter 11.4.1) of 10 : 21.9 : 0 : 1.5, so contains both nitrogen, phosphorus and a small amount of sulphur. In order to work out the cost of a kg of P in MAP, realistically the value of the nitrogen component should also be taken into account. The first formula will calculate the cost of 1 kg of P without considering the 10 % nitrogen component, assuming the cost per tonne of MAP is \$704.

| | | | | |
|---|---|---|---|---------------------------------------|
| Cost of 1 tonne of fertiliser (\$ / tonne) | ÷ | Amount of nutrient in 1 tonne of fertiliser (kg / tonne) | = | Cost of 1 kg of nutrient (\$ / kg) |
| \$704 | ÷ | 219 | = | \$3.21 / kg of P |

If however, *both* nitrogen and phosphorous are needed, and the value of the nitrogen in the MAP were considered, the calculations would give a very different figure for 1 kg of P. In 1 tonne (1,000 kg) of MAP there is 10% or 100 kg of nitrogen. Assuming that 1 kg of N is \$1.37 (as calculated from urea – see [Section 14.3.3.1](#)) then there is 100 kg x \$1.37/kg N = \$137 worth of nitrogen in 1 tonne of MAP. This value is then deducted from the total cost/tonne of MAP:

$$\text{\$704} - \text{\$137} = \text{\$567/tonne MAP}$$

| | | | | |
|---|---|---|---|---------------------------------------|
| Cost of 1 tonne of fertiliser (\$ / tonne) | ÷ | Amount of nutrient in 1 tonne of fertiliser (kg / tonne) | = | Cost of 1 kg of nutrient (\$ / kg) |
| \$567 | ÷ | 219 | = | \$2.59 / kg of P |

Following these steps will allow a cost comparison to be made of phosphorus on a \$/kg basis from a range of different phosphorus containing fertilisers.

14.3.3.6 Bulk cost per kg of N in Manure

Table 14.2 shows the averages and ranges of the major nutrients (N, P, and K) for a variety of animal manures.

Table 14.2 'Typical' nutrient analyses (dry matter basis) for animal manures (average and ranges)

| SOURCE | NITROGEN (%) | PHOSPHORUS (%) | POTASSIUM (%) | MOISTURE (%) |
|------------------|-----------------|-----------------|-----------------|--------------|
| Poultry (cage) | 3.4 (2.8 - 4.8) | 2.5 (1.9 - 4.0) | 1.5 (1.2 - 2.1) | 35 (15 - 65) |
| Poultry (litter) | 2.6 (1.4 - 4.2) | 1.8 (1.6 - 2.8) | 1.0 (1.1 - 1.9) | 25 (10 - 51) |
| Cattle | 1.5 (0.7 - 2.5) | 0.5 (0.2 - 1.4) | 1.2 (0.7 - 1.8) | 40 (9 - 54) |
| Horse | 1.2 (1.0 - 1.5) | 0.2 (0.1 - 0.4) | 0.8 (0.3 - 1.0) | 35 (6 - 62) |
| Sheep | 1.7 (1.3 - 2.6) | 0.5 (0.3 - 0.8) | 1.2 (0.6 - 2.5) | 30 (8 - 60) |
| Pig | 2.3 (1.4 - 2.7) | 2.3 (1.4 - 3.7) | 0.6 (0.2 - 1.3) | 60 (50 - 76) |

Note: Moisture content must be taken into account when costing the nutrients provided in organic fertilisers and when calculating the rate of the spread nutrients.



Therefore, to calculate the kg of nitrogen in **Cattle** manure (based on the results from the above table) the amount of moisture (water) in a tonne of fresh manure must be deducted.

1 tonne (1,000 kg) contains 40% moisture; therefore the amount of dry matter left is simply:

$$1,000 \text{ kg} - 40\% (400 \text{ kg}) = 600 \text{ kg dry weight}$$

The average nitrogen proportion is 1.5%, therefore $600 \times 1.5\% = 9 \text{ kg N/tonne}$ of manure. It is important to understand that nitrogen in manure is in many different forms with varying rates of plant availability. Hence not all of the N in manure will be available in the first year, and will require mineralisation over time before it is plant available.

Therefore, the value of total N in the manure can be estimated assuming that 1 tonne of manure will release 9 kg of nitrogen over a few years. Using the formula and assuming the cost per tonne of manure is \$15 we can calculate the cost of 1 kg of nitrogen in manure.

| | | | | |
|---|---|---|---|---------------------------------------|
| Cost of 1 tonne of fertiliser (\$ / tonne) | ÷ | Amount of nutrient in 1 tonne of fertiliser (kg / tonne) | = | Cost of 1 kg of nutrient (\$ / kg) |
| \$15 | ÷ | 9 | = | \$1.67 / kg of N |

It is important to remember that only a portion of the N valued will be plant available in the first year. Refer to [Making the Most of Animal By-Products](#) - Fact sheet #3, for more information on how to calculate what manure is worth.

Exercise 14.3 provides practice in calculating the cost of nutrients.



Exercise 14.3

Using the cost of one nutrient in various fertiliser products to compare prices.

In this exercise, we assume that you are interested in the cost of phosphorus in the various fertiliser products.

The following formula allows you to calculate the cost of one nutrient in a fertiliser product. You can use the same formula for different fertiliser products or for a different nutrient, such as N, K, or S. Just follow the three steps given below.

Step 1. Using Table 14.1, write the bulk price ex-factory for the products listed in the table below in the boxes in column 1.

Step 2. Using the fertiliser product lists (Appendix G), find the percentage of phosphorus for each product and write the amount of phosphorus per tonne in the boxes in column 2. Remember to use total P, not available P. (See Chapter 11.4.1 if you want to review how to calculate the amount of nutrient in 1 tonne of a fertiliser product.)

Step 3. Calculate the cost of 1 kg of phosphorus for each product, using the formula below, and fill in the boxes in column 3.

Note: When calculating the cost of nutrients for *your* farm, use the **total cost** (adding freight, spreading, etc. and deducting any discounts), not the ex-factory price.

$$\boxed{\text{Cost of 1 tonne of fertiliser (\$/ tonne)}} \div \boxed{\text{Amount of nutrient in 1 tonne of fertiliser (kg / tonne)}} = \boxed{\text{Cost of 1 kg of nutrient (\$/ kg)}}$$

| Fertiliser Product (Nutrient) | 1 Cost of 1 tonne of fertiliser (\$/tonne) | ÷ | 2 Amount of nutrient in 1 tonne of fertiliser (kg/tonne) | = | 3 Cost of 1 kg nutrient (\$/kg) |
|---|---|---|---|---|------------------------------------|
| Generic single superphosphate Phosphorus | \$342 | ÷ | 89 | = | \$3.84 |
| Generic MAP Phosphorus | \$704 | ÷ | <input type="text"/> | = | <input type="text"/> |
| Generic DAP Phosphorus | \$704 | ÷ | <input type="text"/> | = | <input type="text"/> |



Exercise 14.3 Answers

Using the cost of one nutrient in various fertiliser products to compare prices.

The following formula allows you to calculate the cost of one nutrient in a fertiliser product. You can use the same formula for different fertiliser products or for a different nutrient, such as N, K, or S. Just follow the three steps given below.

Step 1. Using Table 14.1, write the bulk price ex-factory for the products listed in the table below in the boxes in column 1.

Step 2. Using the fertiliser product lists (Appendix G), find the percentage of phosphorus for each product and write the amount of phosphorus per tonne in the boxes in column 2. Remember to use total P, not available P. (See Chapter 11.4.1 if you want to review how to calculate the amount of nutrient in 1 tonne of a fertiliser product.)

Step 3. Calculate the cost of 1 kg of phosphorus for each product, using the formula below, and fill in the boxes in column 3.

Note: When calculating the cost of nutrients for *your* farm, use the **total cost** (adding freight, spreading, etc. and deducting any discounts), not the ex-factory price.

$$\boxed{\text{Cost of 1 tonne of fertiliser (\$/tonne)}} \div \boxed{\text{Amount of nutrient in 1 tonne of fertiliser (kg/tonne)}} = \boxed{\text{Cost of 1 kg of nutrient (\$/kg)}}$$

| Fertiliser Product (Nutrient) | 1 Cost of 1 tonne of fertiliser (\\$/tonne) | ÷ | 2 Amount of nutrient in 1 tonne of fertiliser (kg/tonne) | = | 3 Cost of 1 kg nutrient (\\$/kg) |
|---|--|---|---|---|-------------------------------------|
| Generic single superphosphate Phosphorus | \$342 | ÷ | 89 | = | \$3.84 |
| Generic MAP Phosphorus | \$704 | ÷ | 220 | = | \$3.20 |
| Generic DAP Phosphorus | \$704 | ÷ | 200 | = | \$3.52 |



14.4 The cost saving of applying the correct blend of fertiliser

The financial benefit of applying the correct blend of fertiliser can be substantial. For example, a cost comparison of three options (each supplying 35 kg P/ha) is summarised in Table 14.3. This comparison clearly demonstrates the importance of the following:

1. Calculate nutrient requirements first - see Chapter 15.
2. Select fertiliser/s that supply the closest match of required nutrients, at the lowest cost.

Table 14.3 Effect of fertiliser choice on total fertiliser cost when applying 35 kg P / ha over a 200 ha farm

| OPTION | | NUTRIENTS SUPPLIED (kg/ha)* | | | TONNES REQUIRED (Cost/Tonne)** | TOTAL FERTILISER COST*** |
|--------|---|-----------------------------|-----|----|---|--------------------------|
| | | P | K | S | | |
| 1 | 600 kg/ha of Super Potash 2:1 (0 : 5.9 : 16.6 : 7.3) | 35 | 100 | 44 | 120 (\$446) | \$53,520 |
| 2 | 500 kg/ha of Super Potash 4:1 (0 : 7 : 10 : 8.8) | 35 | 50 | 44 | 100 (\$404) | \$40,400 |
| 3 | 169 kg/ha of Triple Super (0 : 20.7 : 0 : 1) plus 100 kg/ha of MOP (0 : 0 : 50 : 0) | 35 | 50 | 2 | 33.8 t Triple Super (\$756) plus 20 t muriate of potash (\$658) | \$38,713 |

*All nutrient quantities have been rounded to the nearest whole number.
 **Based on generic Fertiliser Price List effective March 2013, GST exclusive
 ***Costs for freight, spreading etc. have not been included.

This table highlights the potential savings (or potential extra cost) when working out a farm nutrient application strategy based on the P requirements. The cost of option 3 is \$14,807 less than option 1.

Options 1 and 2 would be more favourable if K and S were required in larger quantities. Option 1 applies P, K and S; option 2 applies less K than option 1; and option 3 applies less K and less S than option 1.

It is worth taking the time to do the calculations when deciding the fertiliser program on your farm.

14.5 Key Points

- The amount of fertiliser you apply should be based on the required amount of nutrients.
- Fertiliser rates are calculated in kilograms of nutrient per hectare.
- Calculate the amount of fertiliser you need to apply to obtain the required amount of nutrients per hectare.
- Calculate the amount of nutrient applied by a particular fertiliser application.
- Fertiliser costing should be based on the total cost delivered and spread to give cost/ha/nutrient as spread.



Chapter 15

Nutrient Planning

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15 Nutrient Planning

15.1 Introduction

Responsible nutrient planning involves soil testing and nutrient budgeting to match the nutrients being applied with the actual farm nutrient requirements. The benefits of this approach include potential \$ savings, increased productivity and a reduction in nutrients lost to the environment.

Nutrient planning follows the International Plant Nutrition Institute's 4Rs principles of applying the right source of nutrient, at the right rate, at the right time, and in right place.

To develop a nutrient plan, information is needed about existing soil fertility levels and farm production. The production level aims of the farmer also need to be considered to help determine soil nutrient targets.

Monitoring soil fertility trends in paddocks with soil testing is a key component of nutrient planning. By monitoring trends over time, the fertiliser program can be adjusted to match changing soil requirements.

Nutrient and soil fertility management is not an exact science. The figures used in this chapter are the best available at this point in time, but will change as more is discovered about nutrient management.

In this chapter the following key areas of nutrient planning are discussed:

- [Factors affecting nutrient requirements](#)
- [Phases of farm development](#)
 - [The concept of maintenance and capital fertiliser](#)
- [Key tools for nutrient planning](#)
 - [Soil testing](#)
 - [Farm management zones](#)
 - [Nutrient mapping](#)
- [Setting target nutrient levels](#)
- [Nutrient budgeting to determine nutrient requirements](#)
 - [Maintenance nutrient requirements](#)
- [Capital nutrient requirements to boost fertility](#)
- [Prioritising nutrient applications on farm](#)
- [Monitoring soil nutrient status](#)

15.2 Factors affecting nutrient requirements

To accurately plan for nutrient applications on a dairy farm the following must be taken into account:

- Soil type – different soil types either tie up or hold onto nutrients in different ways (see Chapter 4 for information on the physical and chemical properties of soil).
- Current soil nutrient status - affected by soil parent material, fertiliser history, climate, stage of farm development and management.
- The target soil nutrient levels you have set - for example, Olsen P of 20 mg/kg, Colwell K of 240 mg/kg (see Chapter 9.2.5 to 9.2.7).
- Nutrients bought in – grain, fodder, effluent applications.
- Nutrients removed – milk production, fodder conservation, cropping, stock sales.



As these factors are variable, nutrient requirements will vary from farm to farm, paddock to paddock and year to year. This will be discussed more in the sections on [setting target nutrient levels](#), [maintenance](#) and [capital requirements](#).

Nutrient planning is a vital part of the fertiliser planning process and should be reviewed on an annual basis.

15.3 Phases of farm development

Nutrients required will depend on the stage of development of the farm. In their natural state, most Australian soils have low levels of phosphorus (P) and sulphur (S) and, to a lesser extent, potassium (K). When converting land to a dairy farm, large inputs of nutrients may be required to raise the nutrient levels to adequate levels for pasture production. This is referred to as the **development phase** (Figure 15.1).

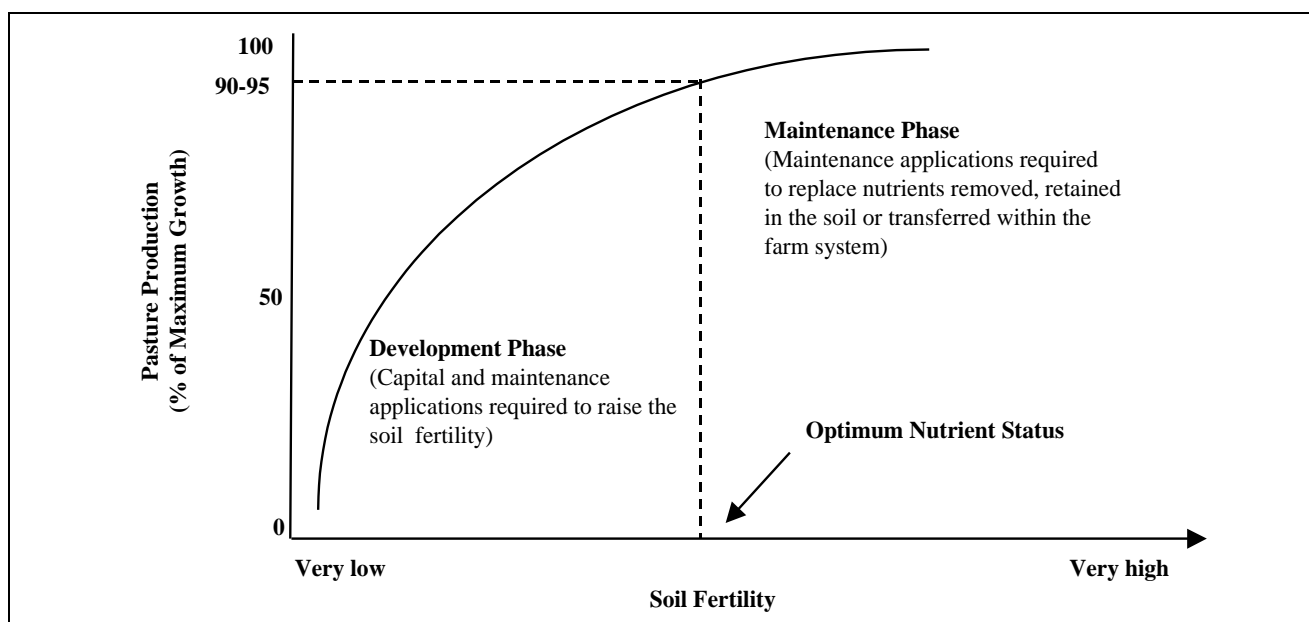


Figure 15.1 Development and maintenance phases of pasture production. *Source:* Adapted from Roberts A (1996) 'Farm for Profit' Conference Proceedings.

In the development phase, pasture response to nutrient applications will be high. For most dairy farmers, it is profitable to rapidly increase soil nutrient levels to the optimum, particularly P. Nutrients that are applied in excess of that required for maintenance (capital applications) raises the nutrient status of the soil.

Eventually, further increases in soil nutrient levels through capital applications will result in only very small increases in plant and animal production and the added nutrients provide no economic benefit. At this stage, optimum nutrient status has been reached and soil fertility is not limiting pasture production.

The optimum soil nutrient status on dairy farms is often regarded as being the point at which the production of existing pasture species is at 95% to 98% of potential. However, the economic optimum nutrient status may be lower on farms where pasture utilisation is low, product value is low or where seasonal production is not reliable.

When a soil reaches its optimum nutrient status, further applications of nutrients will be uneconomical and may increase risk of losses which pollute the environment (see Chapter 10.5). No further capital applications of fertiliser will be required. Such soils are referred to as being in the



maintenance phase (see Figure 15.1). Soils that are in the maintenance phase only require fertiliser applications that replace the nutrients that are removed from the soil through the farming operation.

So, to recap:

Nutrient applications are considered either as maintenance or capital applications.

- **Maintenance applications** keep the soil nutrient status at the same level while supporting pasture production.
- **Capital applications** increase soil fertility to a target level. Capital applications are the nutrients that are applied in **excess** of the maintenance requirement for any given production system.

The concept of capital and maintenance applications is used to estimate farm nutrient requirements. If a maintenance application of nutrients is spread annually, assuming stocking rate and product removal do not alter greatly, soil fertility will remain at a similar level over time. If a capital application is made, soil fertility will increase over time.

15.4 Key tools for nutrient planning

There are a number of key tools that are considered essential to the nutrient planning process. Soil testing has been discussed in Chapter 8 and Chapter 9 and will assess the nutrient status of the soil in order to develop target levels, as well as to monitor the effect of previous nutrient applications. Nutrient mapping and farm management zones are relatively new key tools that are also necessary for effective nutrient planning.

15.4.1 Farm Management Zones

There are a large number of paddocks on a dairy farm and therefore it is often more practical to soil test in farm management zones (FMZ) than to soil test in every paddock. Ideally, when soil testing the farm, a representative soil sample would be taken from each FMZ.

Areas on the farm that could form separate FMZs include:

- Different soil types
 - Different soil types will likely have different phosphorus buffering indexes, resulting in different amounts of phosphorous necessary for maintenance and capital applications, may also have different baseline K and S and different leaching potential which may affect soil nutrient status
- Within those different soil types, different nutrient status
 - For example areas of low phosphorus or potassium versus high phosphorus or potassium
- Different management
 - Day or night paddocks; areas where fodder is regularly cut or fed out; where effluent has been spread; run-off blocks; problem paddocks.
- New and old irrigation areas

Initially a farm should be divided into six to seven FMZs. After soil testing it may be that two to three FMZs have quite similar results and can therefore be grouped together resulting in only four to five FMZs on the farm. Refer to Figure 15.2 for an example of an Australian dairy farm divided into management zones.

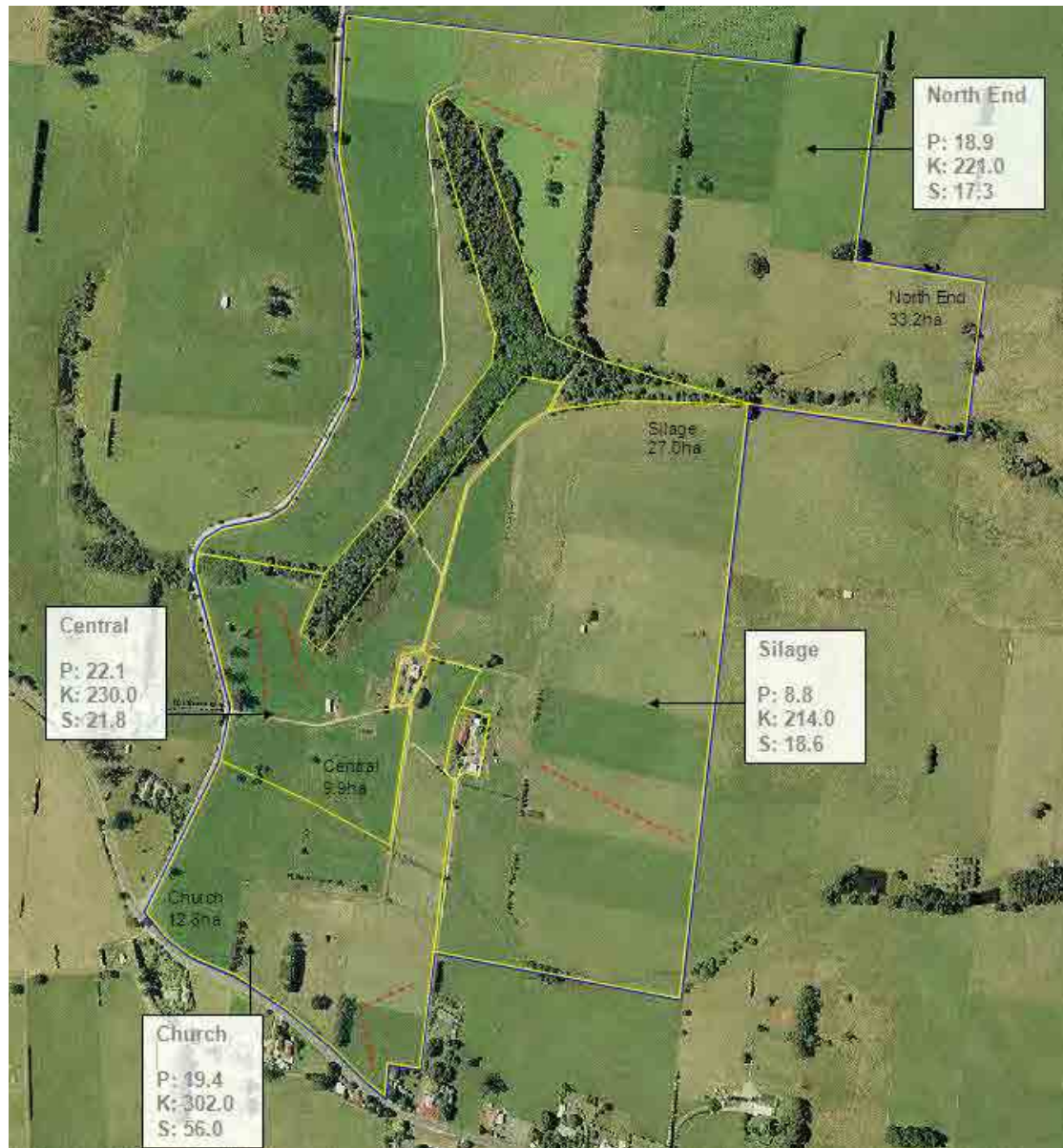


Figure 15.2 A map of an Australian dairy farm showing management areas. Red lines show where soil samples were taken, blue lines show the boundary, and the yellow line show the management areas.

The farm in figure 15.2 has been divided into four FMZs (North End, Central, Silage and Church). These areas correspond to different management areas and have been confirmed over a number of years with the aid of soil tests in other paddocks within the FMZs. Representative soil sampling is now used to monitor these areas. As you can see, the silage FMZ has a much lower P level than other areas of the farm and this will be a priority for fertiliser application. There is also high K and S levels in the Church FMZ, indicating potential to reduce or halt applications of these nutrients on these areas.

15.4.2 Nutrient Mapping

Nutrient mapping allows translation of soil tests into a visual representation of fertility across the farm. This assists with assessing variability across the paddocks on the farm. Colours are assigned to areas or paddocks depending on whether the nutrient level is low, marginal, good or excessive. Using nutrient mapping will allow quick visualisation of the variability within the farm and areas that have excessive nutrient levels, where consideration must be given to reducing inputs.



Nutrient maps can be as simple as using a farm map and highlighter pens to shade in different areas of fertility. Different colours are used to correspond to soil fertility guidelines and targets. Advisors may also assist in developing nutrient maps for the farm using different mapping programs. Nutrient maps can also help with grazing decisions on the farm. Areas with a lower nutrient status may not produce as much pasture dry matter as areas with good nutrient levels and this may influence how long and/or when these areas are grazed. This information can also aid in fodder conservation decisions; for example areas high in potassium should be identified and treated with caution as they can increase K levels in feed and therefore the risk of metabolic problems in livestock. Metabolic problems are discussed more in Chapter 3.

Nutrient maps are generally produced for phosphorus, potassium and sulphur. Some farms also produce maps for pH and salinity, as these can influence nutrient application decisions. Refer to Figure 15.3 for an example of a nutrient map on an Australian dairy farm.

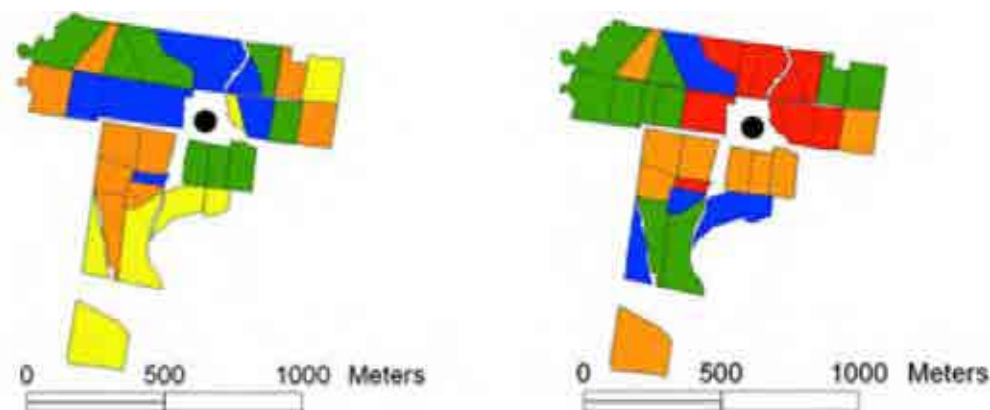


Figure 15.3 A nutrient map on an Australian dairy farm for Olsen P (left) and Colwell K (right). Red suggests very high, blue is high, green is adequate, orange is marginal and yellow is deficient nutrient P or K levels. *Source: Gourley et al (2007).*

Figure 15.3 illustrates how nutrient mapping can assist with nutrient decisions. P fertiliser will be a priority in the paddocks that are shaded yellow and orange and K fertiliser will be cut right back in the areas shaded red. The black dot in the figure is the dairy and as is often the case, K levels have built up close to the dairy where animals spend more time.

15.5 Setting target levels

It is important to set targets for the nutrients levels on a dairy farm – in particular phosphorus, potassium and sulphur. Setting targets will assist in determining whether the farm needs only a maintenance application or whether a capital application is required as well. Targets will be dependent on pasture species present, soil type and production levels.

The recommended target levels mentioned throughout this section are discussed in Chapter 9.2.5 to 9.2.7, 'Interpreting soil and tissue tests'.

15.5.1 The effect of soil nutrient status on different pasture species

Pasture species have a big impact on potential pasture production. An unimproved pasture may have less than half the production of a well fertilised, improved pasture sown to perennial ryegrass and white clover.

Soil nutrient status and grazing management will each affect the botanical composition of a pasture. The application of nutrients alone may not always improve pasture productivity. Applying nutrients to an unimproved pasture will usually give a poorer dry matter response than applying nutrients to an improved pasture.



Figure 15.4 gives an indication of some of the temperate species likely to be present under various rainfall and soil fertility conditions. Higher soil fertility levels and higher rainfall conditions suit the improved species (for example, perennial ryegrass/white clover species). Low soil fertility levels and low rainfall conditions suit the unimproved species (for example, native grasses, sweet vernal, bent grass, and fog grass). Sub clover and paspalum are not included in this diagram because they have a wide range of rainfall and fertility tolerances.

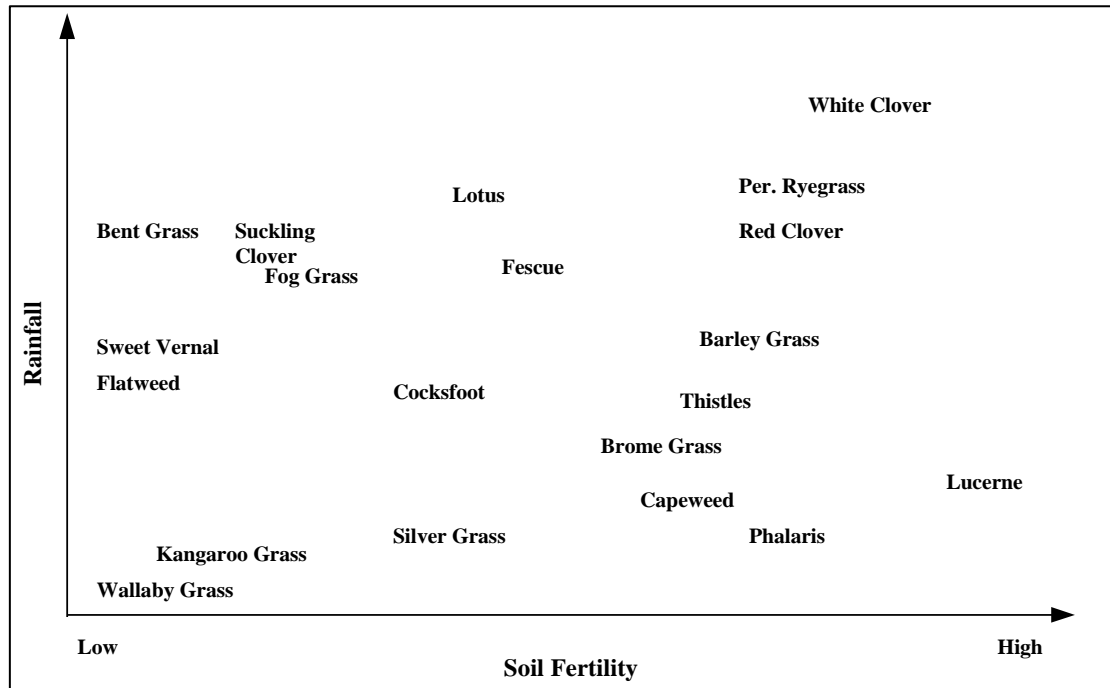


Figure 15.4 Rainfall and soil fertility requirements of a range of temperate weeds and pasture species. *Source:* Hill (1993).

15.5.2 Setting target levels for phosphorus, potassium and sulphur

The Olsen P test indicates the amount of phosphorus that is available to the plant in a soil and can therefore be compared across different soil types. The Colwell P test also measures available soil P as well as P that is less readily available to plants and will vary according to soil type. The optimum level of P when measured by the Colwell test will therefore be soil type dependent (see Chapter 9.2.5).

The Olsen P response curve in Figure 15.5 shows diminishing returns in pasture production as soil P level increases. This means there is a greater response to P applications at low Olsen P levels and that the response decreases at higher Olsen P levels.

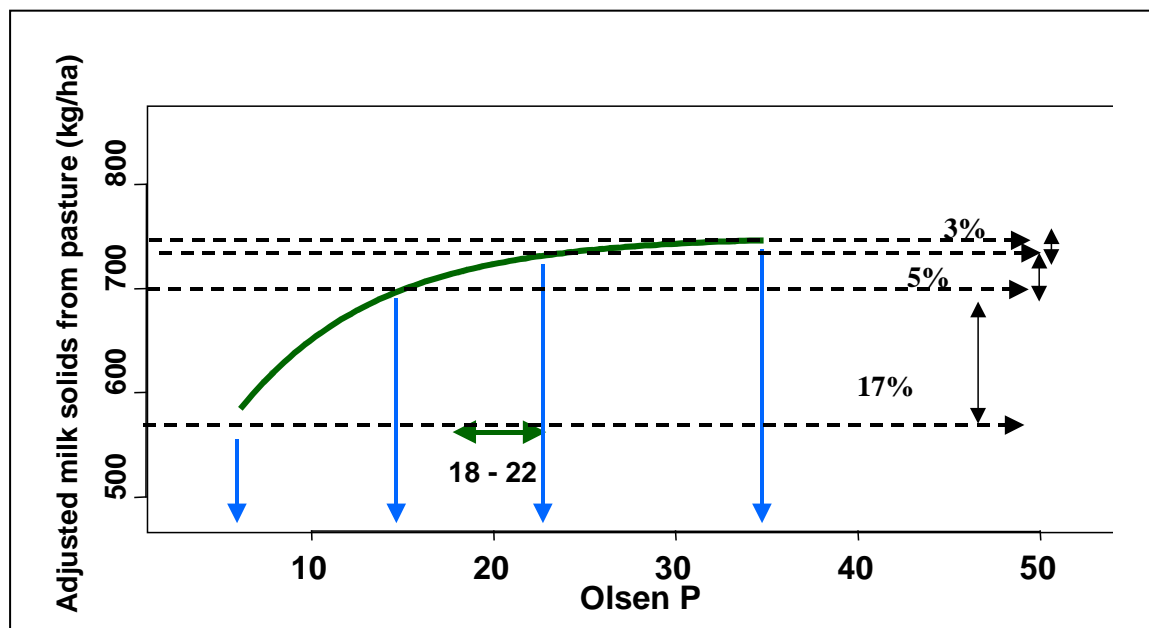


Figure 15.5 Relationship between soil Olsen P level and milk fat and protein responses to a range of Olsen P levels for soils sampled to a depth of 10cm. *Source:* DPI Phosphorus for Dairy Farms project.

The greatest response to applied P (17%) was at an Olsen P below 14, but a sizeable response (5%) still occurred from Olsen P 14. As can be seen from Figure 15.5, the response level above an Olsen P of 22 is only about 2%, and the response decreases further at the higher end of the range.

The ability of a soil to interact and hold on to phosphorus is referred to as a soil phosphorus buffering capacity. A soil with a high phosphorus buffering capacity requires a much greater application of P fertiliser (up to three times more) than a soil with a low phosphorus buffering capacity to give the same production result. The soil buffering capacity is measured on a soil test using the **phosphorus buffering index (PBI)**.

Soils with high iron and aluminium levels, such as red volcanic soils (Ferrosols) and acidic peats, generally have a high PBI. Soils with a coarse texture, such as sandy loams, tend to have a low PBI. When P fertiliser is applied across a wide range of soil types at the same application rate, phosphorus requirements may not be met on some soils, whereas on others there may be a P loss to the environment due to oversupply.

A vital part of the nutrient planning process is to set P, K and S target levels for each of the FMZs on the farm. The DPI 'Victorian Better Fertiliser Decisions' project developed targets for Australian dairy soils – See the soil fertility guidelines for P, K and S in the following sections of Chapter 9:

- Phosphorus soil test target guidelines (Chapter 9.2.5.2)
- Potassium soil test target guidelines (Chapter 9.2.6)
- Sulphur soil test target guidelines (Chapter 9.2.7)

As mentioned in Chapter 9, 'Interpreting Soil and Tissue Tests', 95-98% of pasture performance compared to potential is considered adequate for a dairy farm system based on the latest recommendations from research. However each farm will need to set their own target levels for soil fertility. Farmers operating with levels higher than these suggested targets in their soils may decide to apply only maintenance levels of phosphorous fertiliser. The maintenance level of nutrient applied would be based on the target phosphorus level they are aiming to achieve. Another option is to cut back or to stop applying any fertiliser at all, but when doing this it is essential to monitor soil phosphorus levels annually. Once soil levels have fallen back to target levels, it is important to



resume applying maintenance levels of nutrients, or the soil levels will continue to decline. This in turn would negatively affect pasture production and therefore milk production.

Phosphorus experiments undertaken on dairy farms in Western Australia between 2006 and 2010 as a part of the Greener Pastures Project (Bolland et al 2011), have also shown that no phosphorus fertiliser is required when soil test P is above the critical value for that soil. When soil test P is above the critical value for that soil, adding phosphorus fertiliser will have no effect on pasture production. The Green Pastures Project also showed the effect of applying no phosphorus fertiliser (Figure 15.6). The results highlighted that the rate of decline differ considerably depending on PBI of the soil and other factors. The soils with the lower PBI and lower critical Colwell P values tend to fall back quickly below critical values, whereas the higher PBI soils fell more slowly. Again the importance of monitoring fertility status with soil tests is highlighted.

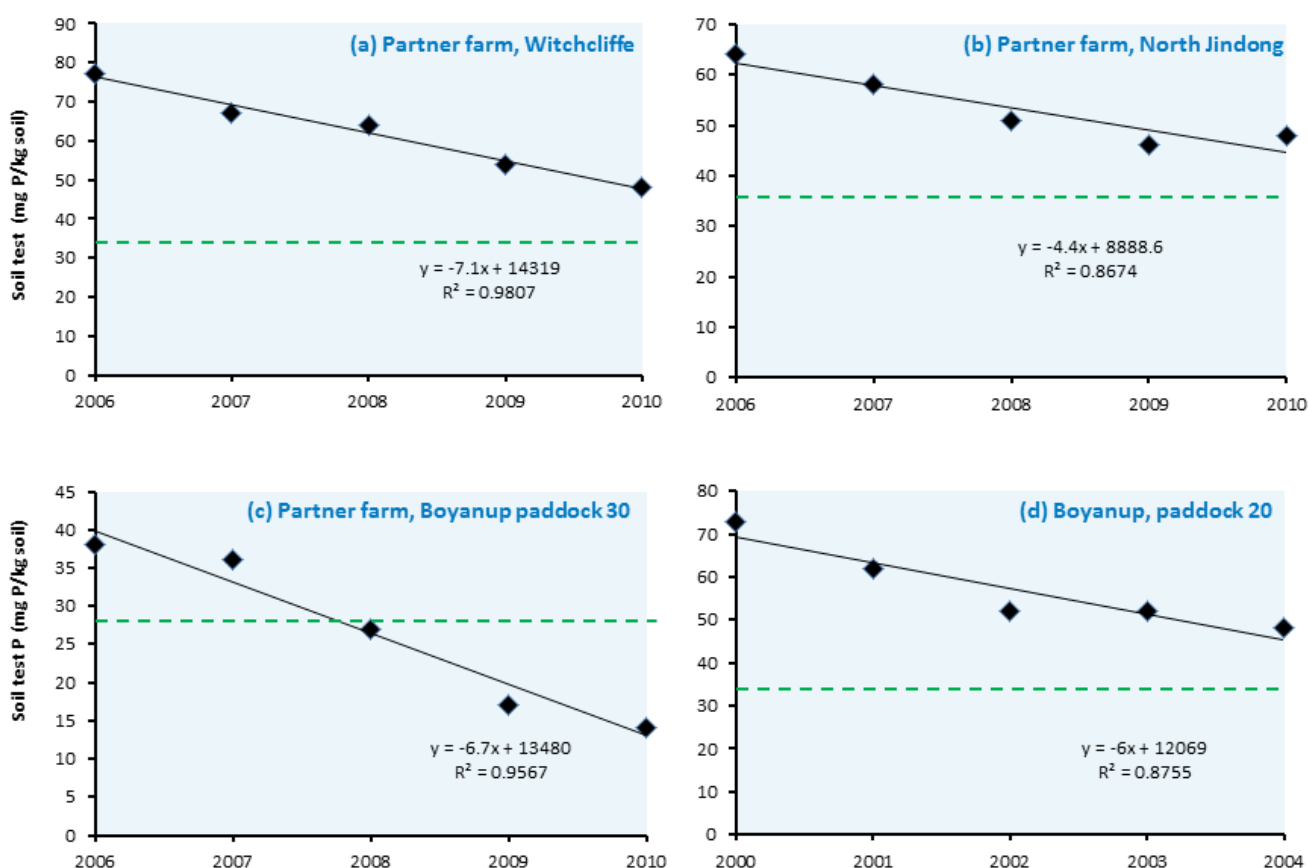


Figure 15.6 Colwell soil phosphorus test for the nil-P treatment of 4 experiments conducted in the dairy region of Western Australia. Critical soil test P values for each site are indicated by dotted lines – the critical value is for 95% of maximum pasture dry matter yield. *Source:* Adapted from Bolland et al (Feb 2011).



15.6 Nutrient budgeting to help determine nutrient application rates

Nutrient budgeting is a technique used to quantify or predict nutrient deficits or surpluses, either at a whole-farm or field scale, in an attempt to determine fertiliser requirements. It can improve nutrient use efficiency and reduce nutrient losses from agriculture. The approach discussed in this chapter is based on research led by Cameron Gourley from the Department of Environment and Primary Industries in Victoria. [Gourley et al. 2007b](#) discusses nutrient budgeting as an approach to improving nutrient management on Australian dairy farms.

Nutrients rates are always measured in kilograms of nutrients per hectare. This allows us to convert between kilograms of nutrient required/applied and the rate of fertiliser required/applied as discussed in Chapter 14. It also allows us to measure the nutrients coming and going, in a nutrient budget, on a per hectare basis.

A farm nutrient budget can be used to estimate the nutrients removed, or accumulated, for any area on the farm and this can be used to determine nutrient and therefore fertiliser requirements.

Nutrient budgets are often done on the effective milking area of the farm as it is easier to calculate the nutrients coming and going from this area. Farms with mixed production systems such as hay making, silage removal and cropping may require nutrient budgets prepared for each farm management zone.

Any imbalance between nutrient inputs (primarily as feed and fertiliser) and nutrient removals (in milk and livestock) can result in significant nutrient accumulation or depletion on dairy farms. Where there is nutrient accumulation this can represent both an opportunity cost and a threat to the environment.

15.6.1 Maintenance nutrient applications

The intent of a maintenance application is to keep the soil nutrient status at a steady level.

To determine the annual nutrient application required to meet the production goals of the farm the balance between the quantity of nutrients leaving the farm and the nutrients that are coming onto the farm must be considered. When more nutrients leave than are brought onto the farm the balance to be replaced is referred to as the **maintenance requirement**. In situations where more nutrient is coming onto an area of the farm than is being removed an excess of nutrients will develop and there is no maintenance requirement.

This method of calculating maintenance requirement is based on a nutrient budgeting approach and is currently recognised as the standard for calculating nutrient requirements on Australian dairy farms. The nutrient budgeting approach is a more accurate method across different production systems than the rules of thumb used in the past.

Nutrients enter and leave the soil and farm system via several pathways (see Figure 15.7). The question marks in the diagram indicate that the information is not readily or accurately known (such as the amount leached) or is highly variable (such as the distribution of manure and urine).

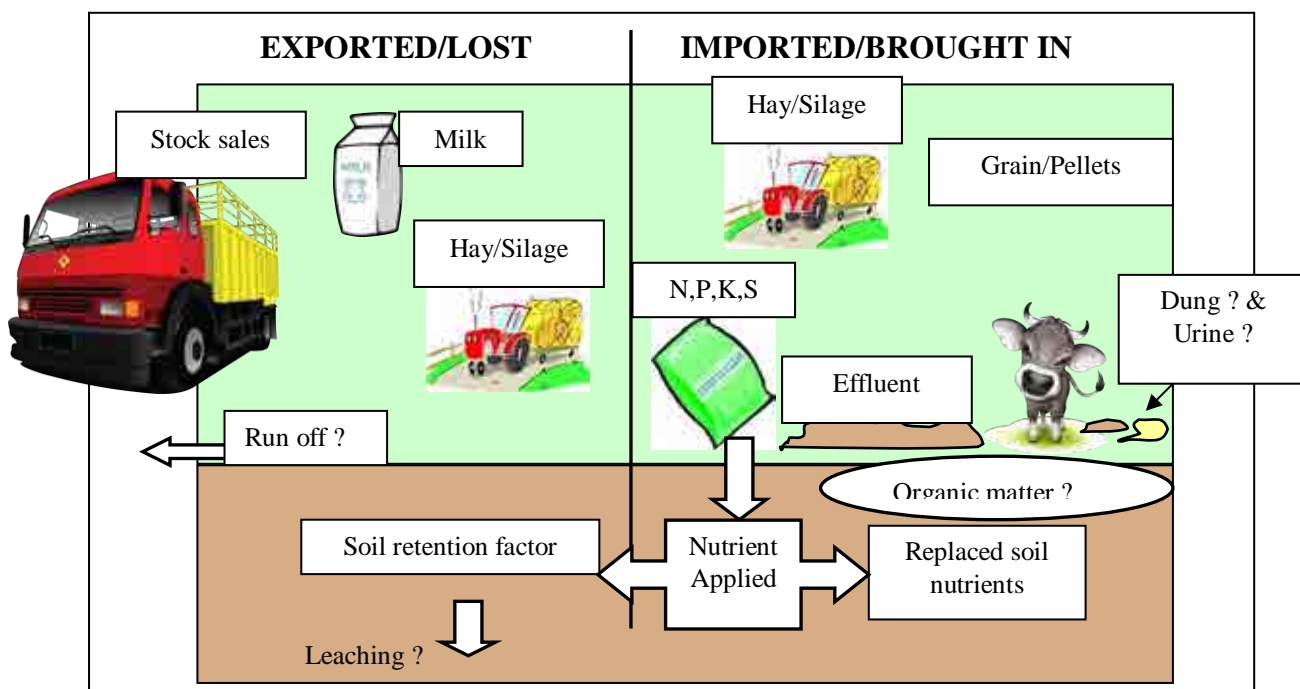


Figure 15.7 Major nutrient imports and exports in a dairy farming system

Losses include:

- Nutrients removed in milk and other animal products
- Nutrients sold or moved off farm as fodder
- Nutrients lost in dung and urine deposited on laneways and yards
- Soil losses, including leaching and nutrients held strongly or 'locked up' in the soil and its processes (commonly referred to as the **soil retention factor**)

Nutrients coming onto the farm include:

- Nutrients imported in feed (hay, silage, grain etc.)
- Nutrients returned in applied effluent

Nutrient budgeting allows you to determine the shortfall between losses and imports, which is the maintenance nutrient requirement. A simplified diagram of a nutrient budget is shown in Figure 15.8.

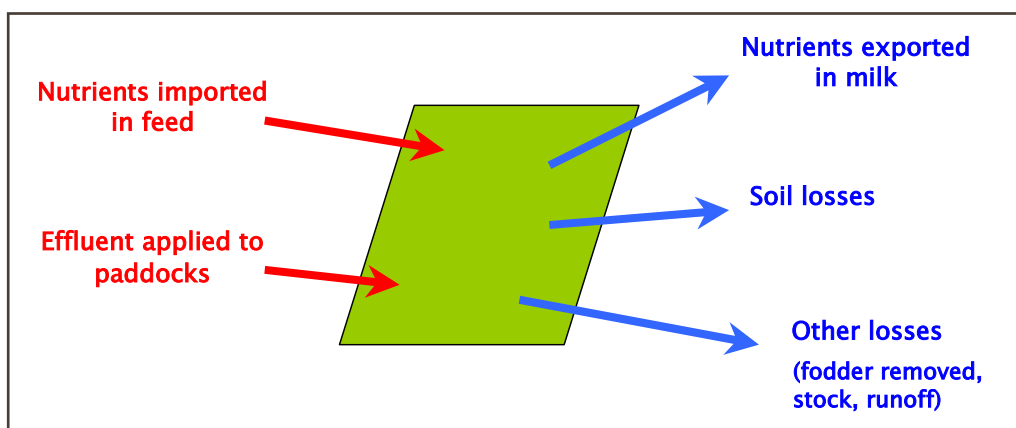


Figure 15.8 The nutrient imports and losses that determine the maintenance requirement



By calculating the amounts of imports and losses shown in Figure 15.8, the maintenance requirement of different areas of the farm can be determined as shown in the following equation:

| | | | | | | |
|----------------------------------|---|---|---|--|---|----------------------------|
| Nutrients exported in milk | + | Soil losses and other nutrient losses | - | Nutrients imported in feed and effluent | = | Maintenance requirement |
|----------------------------------|---|---|---|--|---|----------------------------|

15.7 Calculating the maintenance requirement

In this section, we will focus on calculating the maintenance requirement of P for a certain area of the farm using example figures. The major exports and imports on a dairy farm are discussed to demonstrate the nutrient budgeting approach. Nutrient budgeting can also be done automatically by entering the figures into a nutrient budgeting program. This is often done with the assistance of an advisor who will have access to a nutrient budgeting program. It is however useful to know how the budgeted is calculated and the following sections work through how a nutrient budget is calculated.

The end of this chapter also has worksheets which demonstrate how the various components of a nutrient budget are worked out.

15.7.1 Calculating nutrient exports

15.7.1.1 Nutrients exported in milk

Every litre of milk that is exported off the farm removes a certain amount of P, K and S. We know that milk contains close to 0.1% P, so we can work out how many kg of P are exported from the farm. Assuming there is equal production from all areas of the farm (you could break the farm up into different areas of production), you can work out the kg of P exported per hectare.

Example

- Farm produces 1,000,000 litres of milk from 100 ha in one year
- 1,000,000 L divided by 100 ha = 10,000 L/ha
- 10,000 L/ha x 0.1% P = 10 kg P/ha

Therefore, we are removing **10 kg P/ha** from the farm in the form of milk.

15.7.1.2 Nutrients lost from dung and urine

This is a calculation from the 'Phosphorus for Dairy Farms' project to include when working out the maintenance fertiliser requirements for the farm. It makes an allowance for the nutrients lost in dung and urine while the cows are walking up the laneways and standing in the dairy yard. These nutrients are not being redistributed around the farm, unlike dung and urine in the paddocks.

You need to know the stocking rate of the farm. This is calculated by dividing the number of cows milked by the milking area of the farm. **The P lost from dung and urine in the laneways and dairy yard is estimated by multiplying the stocking rate by 0.8.**

Example:

- Farm milks 200 cows on 100 ha
- 200 cows divided by 100 ha = 2 cows/ha (stocking rate)
- 2 cows/ha times 0.8 = 1.6 kg P/ha

Therefore, the loss from dung and urine in the laneways and dairy yard is **1.6 kg P/ha**.



15.7.1.3 Soil retention factor

The soil retention factor accounts for losses within the soil structure in the case of P and accounts for leaching from the soil in the case of K and S. The 'Phosphorus for Dairy Farms' research illustrated conclusively that the maintenance application must also include a certain amount of P just to maintain the soil Olsen P level.

Each soil type has a different soil retention factor based on its physical and chemical make-up and its origin and weathering. Soils with a high PBI will remove P from the plant available pool more quickly and will have a higher soil retention factor.

A table of recommendations of P required to satisfy the soil retention factor has been developed and is now used to assist in making nutrient decisions (see Table 15.1 for recommendations based on Olsen P soil tests and Table 15.2 for Colwell P soil tests). Both the PBI and the current soil nutrient level affect the amount of P required to satisfy the soil retention factor. Therefore, areas of the farm that have different soil nutrient statuses and PBIs can have different total maintenance fertiliser requirements.

Table 15.1 Approximate amount of phosphorus required (kg/ha/yr) to satisfy the soil retention factor for a range of PBI values and Olsen P levels.

| PBI Value | Current Olsen P Level (mg/kg) | | | | | | |
|------------|-------------------------------|--------|---------|----------|----------|----------|----------|
| | 2 to 4 | 5 to 7 | 8 to 10 | 11 to 13 | 14 to 17 | 18 to 25 | 25 to 35 |
| 0 to 50 | 0 | 3 | 6 | 8 | 9 | 10 | 10 |
| 50 to 100 | 0 | 5 | 10 | 15 | 18 | 20 | 20 |
| 100 to 200 | 0 | 6 | 13 | 20 | 23 | 25 | 25 |
| 200 to 400 | 0 | 7 | 15 | 22 | 26 | 28 | 28 |
| 400 to 600 | 0 | 8 | 16 | 24 | 28 | 30 | 30 |
| Over 600 | 0 | 10 | 18 | 26 | 31 | 35 | 35 |

(Source: Gourley and Burkitt pers. comm - Adapted from Burkitt et al. 2002)

Example:

Table 15.1 shows that a soil with a PBI of 350 and an Olsen P of 16 would require around **26 kg P/ha** to satisfy the soil retention factor.

Figure 15.2 Approximate amount of phosphorus required (kg/ha/yr) to satisfy the soil retention factor for a range of PBI values and Colwell P levels

| PBI Value | Current Colwell P Level (mg/kg) | | | | | | |
|------------|---------------------------------|----------|----------|----------|----------|-----------|-------|
| | 10 to 15 | 20 to 30 | 35 to 40 | 45 to 55 | 60 to 80 | 85 to 115 | > 115 |
| 0 to 50 | 1 | 4 | 6 | 8 | 9 | 10 | 10 |
| 50 to 100 | 2 | 7 | 10 | 14 | 18 | 20 | 20 |
| 100 to 300 | 2 | 8 | 12 | 15 | 20 | 22 | 23 |
| 300 to 400 | 2 | 9 | 14 | 18 | 22 | 25 | 25 |
| 400 to 600 | 5 | 11 | 17 | 22 | 28 | 31 | 32 |
| Over 600 | 5 | 13 | 19 | 24 | 31 | 34 | 35 |

(Adapted from Accounting for Nutrients Fertiliser Budgeting tool www.accounting4nutrients.com.au)

Note that the amount of P required to satisfy the soil retention factor increases as Olsen and Colwell P increases. This is the opposite of what one might expect in that, as more P is available, one would think that less is needed for maintenance. Why is this so?



The fate of newly added nutrients is greatly affected by soil chemical and physical properties, the soil solution, soil temperature, soil moisture content, soil pH, amount of organic matter present, current soil nutrient status and other soil related factors, as well as by the amount of new nutrients added. The soil is complex and has ever changing soil reactions and fixation rates.

The increase in the amount of P required to satisfy the soil retention factor as Olsen and Colwell P increases is due to the high level of reactivity of freshly applied P and the substantial capacity of soil minerals to transform this P into less available forms – see Chapter 3.4.2. For any soil with a particular phosphorus buffering capacity (or PBI value), there appears to be a constant proportion of the applied P that is retained by the soil. Therefore, the greater the amount added, the greater the amount retained, and therefore the greater the amount that needs to be replaced. A soil with a lower phosphorus buffering capacity (or PBI value) will retain a lower proportion of P than a higher PBI soil.

A table of recommendations for potassium and sulphur to satisfy the soil retention factor has also been developed to assist in making nutrient decisions (See Table 15.3). It is noted that there needs to be more research into this area.

Table 15.3 Approximate amount of potassium and sulphur (kg/ha/yr) required to satisfy the soil retention factor over a range of soil types

| Soil type | Amount K to maintain present soil K levels | Amount S to maintain present soil S levels |
|-----------------|--|--|
| Sand | 25 | 12 |
| Sandy loam | 20 | 12 |
| Sandy clay loam | 15 | 12 |
| Silty clay loam | 15 | 12 |
| Clay loam | 15 | 12 |
| Clay | 10 | 12 |
| Volcanic clay | 10 | 12 |
| Peat | 10 | 12 |

(Adapted from Accounting for Nutrients Fertiliser Budgeting tool www.accounting4nutrients.com.au, and C ameron Gourley, DPI, Ellinbank, pers. com.)

15.7.1.4 Other losses

Nutrients are also removed in livestock leaving the farm, nutrient runoff, and fodder conserved and taken from the farm. These nutrient losses can be significant and are discussed further in the developing a nutrient budget worksheets at the end of this chapter.

For the example being worked through, assume that no fodder is removed from the farm, that other stock (for example young stock) are not on the area, and that nutrient runoff is minimised by best management practices.



15.7.2 Calculating nutrient imports

15.7.2.1 Nutrients imported in feed

Grain and fodder brought onto the farm contain a significant amount of nutrients. Both fodder and grain contain 3 kg of P per tonne of dry matter (DM). If we know how many tonnes of DM are fed over a certain area (tonnes DM/ha), we can work out the phosphorous imported onto the farm in brought in feed (see Appendix H, for nutrient contents of other feeds).

Example: 150 tonnes of grain and 100 tonnes of hay were imported and fed to animals on 100 ha

Grain: 150 tonnes divided by 100 ha = 1.5 tonne/ha
1.5 tonne/ha x 3 kg P/tonne DM = 4.5 kg P/ha

Hay: 100 tonnes divided by 100 ha = 1 tonne/ha
1 tonne/ha x 3 kg P/tonne DM = 3 kg P/ha

The total phosphorous imported in feed is therefore **7.5 kg P /ha**

It should be noted that the example above assumes the feed is spread evenly over the whole farm. In practice, there will be uneven distribution of nutrients over the farm both in terms of where the feeding out occurs and where the animals excrete the nutrients. Consider the issue of nutrient distribution when doing a nutrient budget. Regular soil testing will help identify issues associated with nutrient distribution.

15.7.2.2 Nutrients imported in effluent

The nutrients imported when effluent is applied must also be taken into account when calculating maintenance levels. Effluent is not actually imported to the farm, but is actually imported from the effluent system to the paddock. Depending on the concentration of nutrients and the rate of application, areas receiving effluent can have significant amounts of nutrients applied. If effluent has been applied to an area, the rate of nutrients can be determined using one of the worksheets in nutrient budget worksheets at the end of this chapter. (Also see Chapter 13, 'Using dairy effluent' for more information.)

For this example, assume that effluent isn't spread on the farm.

15.7.2.3 Calculating maintenance nutrient requirement

As mentioned, the nutrient budgeting approach takes into account the nutrients leaving the farm (exports and losses) and the nutrients that are coming onto the farm (imports). The shortfall between exports/losses and imports is the maintenance requirement, which is illustrated by this equation:

| | | | | | | |
|----------------------------------|---|---|---|--|---|----------------------------|
| Nutrients exported in milk | + | Soil losses and other nutrient losses | - | Nutrients imported in feed and effluent | = | Maintenance requirement |
|----------------------------------|---|---|---|--|---|----------------------------|

Using the figures from the examples above, we can work out the phosphorous requirement for this particular area of the farm.

| | | | | | | |
|----------------------|---|--|---|-----------------------------------|---|-------------|
| 10 kg P/ha (milk) | + | 26 kg P/ha (soil retention) + 1.6 kg P (dung & urine loss) | - | 7.5 kg P/ha (imported in feed) | = | 30 kg P /ha |
|----------------------|---|--|---|-----------------------------------|---|-------------|



Therefore, the maintenance requirement of **30 kg P/ha** is the amount that is required to maintain the current level of soil phosphorous. Similarly, we could calculate the maintenance requirement of K and S using the same approach.

Maintenance rates will vary between years because of farm management or production changes and climatic influences, such as wet weather (which increases nutrient leaching and runoff) or droughts (which reduce nutrient requirements). As always, monitoring soil tests over time will be important to validate P, K and S fertiliser application rates.

15.8 Capital nutrient applications

When nutrients are applied at a greater rate than that needed for maintenance, the soil fertility status of that particular nutrient rises. This is referred to as a **capital application**.

Soil type and PBI has a strong effect on the amount of applied nutrient required to lift soil fertility levels. The degree of fixation can vary. Nutrients may be strongly fixed, forming insoluble compounds, or may form more soluble compounds that can be slowly released back into the soil solution over time.

New Zealand experience has shown that it can take three to four years on some soil types before pastures fully respond to a high capital P application. Similar experience at Ellinbank on the Ferrosol soil indicates that up to two years may be required before the effects of the capital dressings are evident in terms of increased pasture growth and quality.

High P fixing soils have a high PBI, so they require large capital applications of P to raise the soil P level. Soils which contain large amounts of iron (Ferrosols) fix much of the P applied.

Sandy soil types are low P fixing and have a low PBI. In these soils, the majority of the applied P remains in the soil solution, and the remainder is held to the clay or organic matter. Sandy soils low in clay or organic matter are more susceptible to P leaching, however.

An increase in the soil nutrient status using a high capital application will occur more quickly on lighter soils, such as sands or loams, than on heavier-textured soils.

For capital P applications to be economical, pasture utilisation must be maximised. If the extra pasture grown as a result of higher P levels is not utilised, the investment in the capital application is wasted

15.8.1 The amount of capital Phosphorus required to raise the soil level by one unit

The amount of capital P required to raise the soil Olsen or Colwell P test by one unit (1 mg/kg) is variable and largely depends on the phosphorous buffering index (PBI) of the soil (see Table 15.4). Remember that this rate is in addition to the P applied to meet maintenance requirements. Soil texture can also be used as a guide for determining the amount of capital P required to raise the soil Olsen or Colwell P by one unit (where possible use the PBI figure which is more accurate).



Table 15.4 The approximate amount of capital P (kg/ha) required to raise soil Olsen or Colwell P by one unit (1 mg/kg) based on the soil type or PBI

| Soil Type | PBI | Amount of P to raise Olsen P by 1 unit (kg/ha) | Amount of P to raise Colwell P by 1 unit (kg/ha) |
|-----------------|------------|--|--|
| Sand | 0 to 50 | 6 | 2.2 |
| Sandy loam | 51 to 100 | 8 | 2.3 |
| Sandy clay loam | 101 to 300 | 9 | 2.5 |
| Silty clay loam | 101 to 300 | 9 | 2.5 |
| Clay loam | 301 to 400 | 10 | 2.8 |
| Clay | 401 to 500 | 11 | 3 |
| Volcanic clay | 501 to 600 | 13 | 3.2 |
| Peat | Over 600 | 15 | 3.6 |

(Adapted from Accounting for Nutrients Fertiliser Budgeting tool www.accounting4nutrients.com.au)

This means that a soil with a PBI of 133 would require an application rate of 9 kg of P/ha to raise the soil Olsen P by one unit. The amount of capital P (kg P/ha) required to lift the Olsen or Colwell P to your target Olsen or Colwell P level on a particular soil can be calculated using the following formula:

| | | | | | | | | |
|------------------|---|-------------------|---|-----------------------------|---|------------------------|---|--------------------------------------|
| Target Olsen P | - | Current Olsen P | = | Olsen P Units to be Added | x | Kg P/Unit of Olsen P | = | Capital P Application Rate (kg P/ha) |
| Target Colwell P | - | Current Colwell P | = | Colwell P Units to be Added | x | Kg P/Unit of Colwell P | = | Capital P Application Rate (kg P/ha) |

Example: Your soil has a PBI value of 133 and an **Olsen P** of 12, and you would like to raise the soil fertility for P to an Olsen P of 20. You would calculate the estimated amount of capital P to apply as follows:

| | | | | | | | | |
|----------------|---|-----------------|---|---------------------------|---|----------------------|---|--------------------------------------|
| Target Olsen P | - | Current Olsen P | = | Olsen P Units to be Added | x | Kg P/Unit of Olsen P | = | Capital P Application Rate (kg P/ha) |
| 20 | - | 12 | = | 8 | x | 9 | = | 72 kg P/ha† |

†Equivalent to 818 kg (about 0.82 t) of single superphosphate per ha.

Example: Your soil has a PBI value of 133 and a **Colwell P** of 20, and you would like to raise the soil fertility for P to an Colwell P of 34. You would calculate the estimated amount of capital P to apply as follows:

| | | | | | | | | |
|------------------|---|-------------------|---|-----------------------------|---|------------------------|---|--------------------------------------|
| Target Colwell P | - | Current Colwell P | = | Colwell P Units to be Added | x | Kg P/Unit of Colwell P | = | Capital P Application Rate (kg P/ha) |
| 34 | - | 20 | = | 14 | x | 2.5 | = | 35 kg P/ha |



Remember, these are capital applications. Therefore, they only become effective after the total maintenance requirement of the farming system and the soil has been satisfied. The decision would need to be made around how quickly this would be added (e.g. over one, two or three years)

15.8.2 The amount of capital Potassium and Sulphur required

Soil levels of potassium (K) and sulphur (S) can vary enormously due to factors other than soil type. Single superphosphate contains sulphur. Consequently, if single superphosphate is being applied regularly, sulphur deficiencies are less likely (although can occur on lighter soils). However, if high analysis fertilisers (e.g. triple super) or blends low in sulphur are used regularly, then extra sulphur may be required.

Potassium is fairly mobile in most soils. It is leached readily, particularly from lighter soil types and in extremely wet conditions. It is also removed in large amounts in hay, silage and fodder crops.

Table 15.5 The estimated amount of capital potassium (kg/ha) required to raise the soil level by one unit (1 mg/kg)

| Soil Type | Potassium (kg K/Unit of K) |
|----------------|-------------------------------|
| All soil types | 2 |

(Adapted from Accounting for Nutrients Fertiliser Budgeting tool www.accounting4nutrients.com.au, and Cameron Gourley, DPI, Ellinbank, Pers. Com. 2013)

For example, to raise the level of potassium (K) by 30 units in a clay loam soil, approximately 60 kg/ha of K above that required for maintenance must be applied.

Research into yield responses to K have not been as extensive as for P, however the more commonly used K tests have a greater degree of field calibration. Because of the K buffering capacity of soils and many other influences on K concentration in the soil, K levels can vary throughout the year, and substantially from year to year. It is therefore important to monitor K regularly – See Chapter 9.2.6.1, 'Tests for Available Potassium'.

Table 15.6 Estimated amount of capital sulphur (kg/ha) required based on soil test result

| Sulphur soil test level (KCl 40 Test) (mg/kg) | Sulphur Required (kg/ha) |
|---|--------------------------|
| 0 – 4 | 30 |
| 4 – 9 | 15 |
| 9 – 13 | 7 |
| > 13 | 1 |

(Adapted from Accounting for Nutrients Fertiliser Budgeting tool www.accounting4nutrients.com.au, and Cameron Gourley, DPI, Ellinbank, Pers. Com. 2013)

For example, if soil testing indicates that the sulphur level is 5 mg/kg, then 15 kg/ha of sulphur should be applied in addition to maintenance.

Field-calibrated trials for sulphur are limited and there is insufficient research to quantify the amount of sulphur required to raise the sulphur levels by one unit. In addition to this, sulphur becomes less available in cold, wet conditions, and in these conditions responses to applied nitrogen are sometimes improved if some sulphur is applied at the same time (M. Bolland, Pers. Com. April 2013) – See Chapter 9.2.7.



15.9 Prioritising nutrient applications on farm

Whether the nutrient requirements of the farm will be fulfilled depends largely on the availability of money and the cost of nutrients. Sometimes these constraints mean that only part of the ideal nutrient plan can be implemented.

In that case, choices have to be made as to which part to implement now and which to implement later. Similarly, the choice may be between fertilising only part of the farm at the desired nutrient application rate and allowing the remainder to be unfertilised, or fertilising the entire farm at a lower rate.

If areas of the farm have recently been renovated, it is important to maintain nutrient application to these paddocks to ensure they do not become run down, as considerable dollars have already been invested in them.

Areas of the farm that have been cut for hay or silage also need special consideration. These paddocks will quickly deplete their stores of potassium in particular and may become infested with low producing grasses and flat weeds if potassium is not applied.

Part of the farms effluent management may be to pump out the ponds onto several paddocks throughout the year. These paddocks may not need additional applications of nutrients due to the high loads that may be being applied via the effluent.

It is up to the farm owner to decide on the nutrient level targets for the different Farm Management Zones on the farm. Once targets are reached, capital applications are no longer required and maintenance rates will be the most economic rate to apply. Soils with lower P levels should, under good management, reap larger economic benefits per unit of phosphorus applied compared to farms with higher P levels (see Figure 15.9).

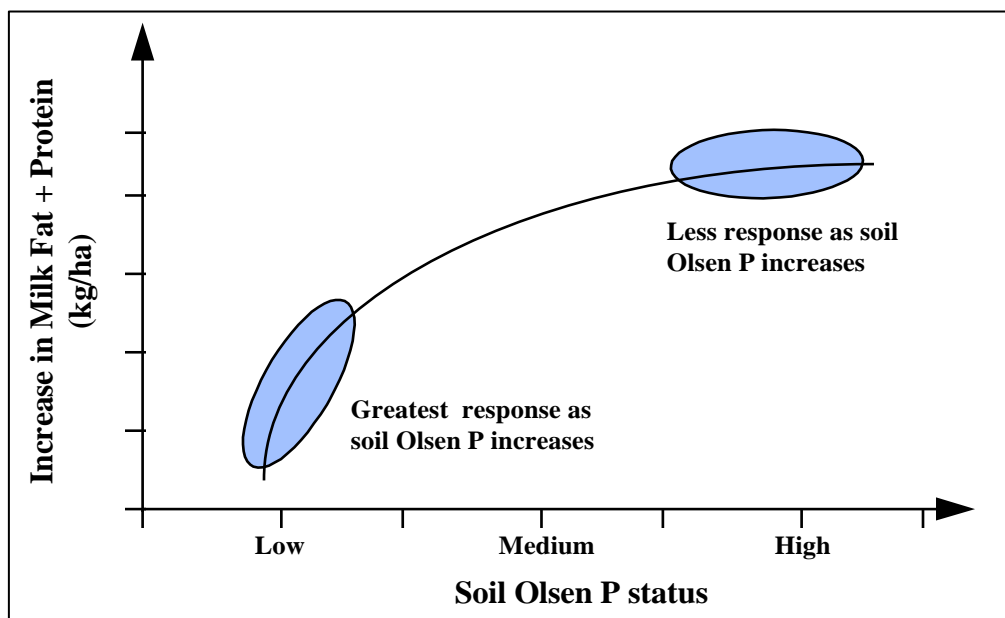


Figure 15.9 Relationship between soil Olsen P level and milk fat and protein responses to capital P applications

Figure 15.9 illustrates the principle of diminishing returns. This shows that fertiliser applied to increase the soil Olsen P level by one unit when the soil Olsen P levels are low will give a greater increase in production and financial return than fertiliser applied when the soil Olsen P levels are high. This same principle applies to all the nutrients required by plants.



In years where milk returns are high, capital applications may be applied to the paddocks with low P levels to prepare them for the sowing of improved pasture species or to improve the growth of existing improved species.

Factors affecting the nutrient requirements are constantly changing, and the soil fertility levels should be regularly monitored to make more informed, cost effective nutrient decisions.

Ideally, every paddock on the farm would be soil tested to determine the spatial distribution of each nutrient over the entire farm. This is very expensive, but research has shown that the cost is several times less than the savings that can be made.

15.10 Monitoring of soil nutrient status

An effective way to determine whether sufficient fertiliser is being applied to meet capital and maintenance requirements is to monitor soil fertility. Regular soil testing of Farm Management Zones, using correct sampling procedure, is vital to monitor your fertiliser program's effect on soil fertility.

Two useful tools that can help to record results, monitor soil fertility trends, and make much more efficient fertiliser decisions are:

- [Fertiliser monitor charts](#)
- [Computer software](#)

15.10.1 Fertiliser monitor charts

Recording soil test results in the form of a graph (referred to as a **fertiliser monitor chart**) allows farmers to more easily identify or monitor the trend of the soil fertility in nominated areas on their farm over time. If fertiliser applications exceed the maintenance requirements, then the soil nutrient levels will increase. If applications are below the maintenance requirement, then the soil nutrient levels will decline. A sharp rise or fall in nutrient level may be the result of incorrect soil sampling, and may be ignored if the soil fertility trend has been steady and cow numbers and fertiliser applications have not altered substantially in that soil test period.

Figures 15.10a, b, c, and d show some examples of how to interpret soil Olsen P monitor charts. When trends on the fertiliser monitor chart are not what you expect, consider whether this is the result of management or environmental factors, such as the effect of applying effluent, feeding out in a sacrifice paddock rather than over a larger portion of the farm, or the effect of a very wet year on K and S.

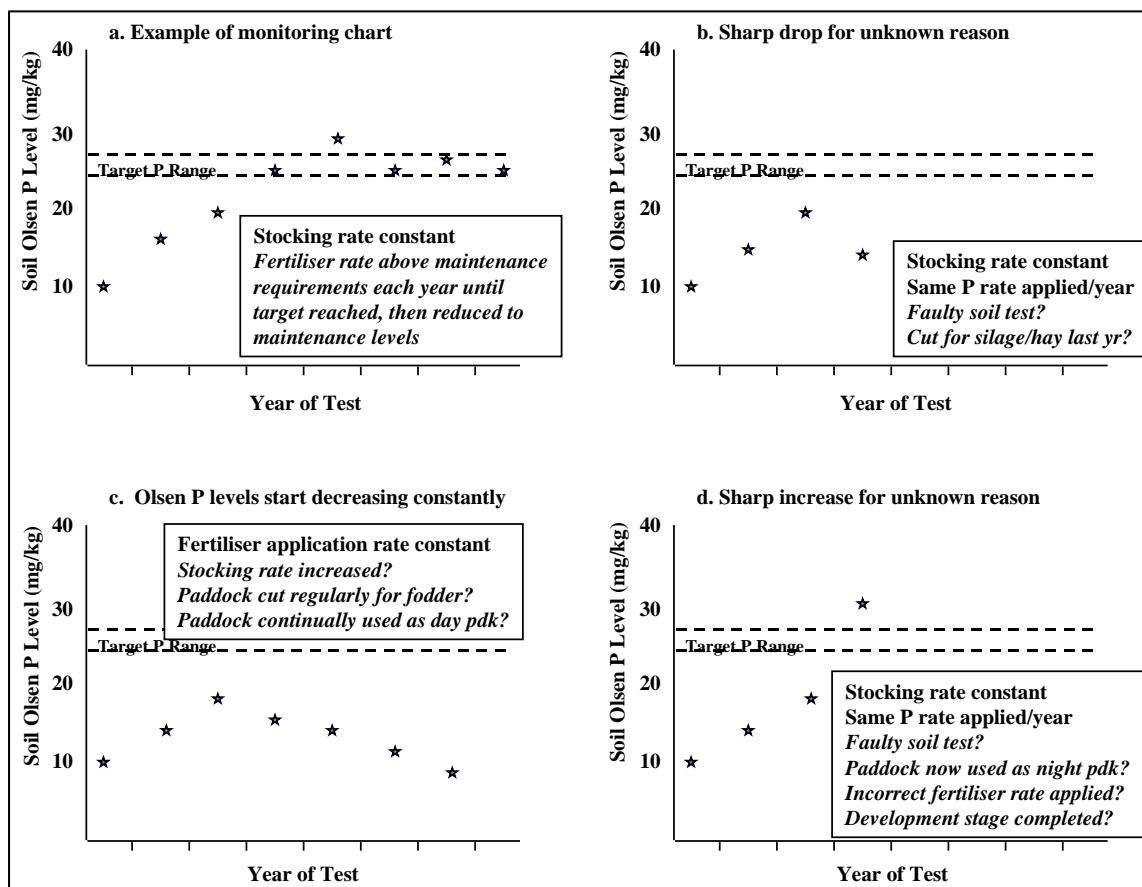


Figure 15.10 Example fertiliser monitoring charts recording phosphorus levels and showing possible reasons for the interpretations

Figure 15.10a shows the soil Olsen P level rising steadily as capital applications above maintenance are applied and then levelling off when the target soil Olsen P level has been reached and maintenance application rates only are applied.

Figure 15.10b shows a sudden drop in the soil Olsen P level, even though the stocking rate and fertiliser application rates remained unchanged. It is unlikely that the soil Olsen P level would suddenly decline, and the drop may be due to a soil sampling or testing error. Sampling soon after a fodder crop has been removed and before the new season’s fertiliser is applied may result in a slight drop but not a drastic decrease in one year.

Figure 15.10c shows the soil Olsen P level steadily rising and then declining, even though the fertiliser application rates remained the same. The change in the soil fertility trend may be due to an increase in stocking rate, regular cutting of hay or silage, or nutrient transfer to elsewhere on the farm if the paddock is routinely used as a day paddock.

Figure 15.10d shows a steady rise in the soil Olsen P level towards the target P range and then a sharp rise. Again, this may be due to a soil sampling or testing error, paddock management changes, or application of an incorrect rate of fertiliser.

Make a graph for each nutrient or soil condition indicator you want to monitor, such as P, K, S, pH, and aluminium. You will need a set of these graphs for each area to be monitored on the farm.



15.10.2 Computer software

Many farm or herd management computer programs have sections which allow pasture and nutrient records to be kept. Alternatively fertiliser monitor charts can quickly be designed using spreadsheet software found on most computers.

15.11 Developing a nutrient budget for a dairy farm

15.11.1 Nutrient budgeting worksheets

The nutrient budgeting worksheets provide a guide to working through the process of calculating a whole farm nutrient budget. The worksheets take a whole-farm approach to nutrient management. Nutrient imports and exports are calculated over the entire milking area. Areas with different soil types and fertility levels should be treated differently; and where nutrient distribution is an issue, this should be taken into account.

Many advisors will be able to assist farmers with calculating nutrient budgets for the farm as a part of the fertiliser planning process. Often advisors will have spreadsheets or programs that will help process the numbers, and these spreadsheets and tools are based on information discussed in this chapter and on the following worksheets.

[Nutrient Budget Worksheets](#)



15.12 References

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Chapter 16

Developing a Fertiliser Management Plan

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16 Developing a Fertiliser Management Plan

16.1 Introduction

The purpose of a fertiliser management plan is to guide soil and fertiliser management decisions across the farm throughout the coming season or year. Fertiliser management plans are used by dairy farmers and farm managers for the following purposes:

- Budgeting for fertiliser expenditure.
- Ordering fertilisers; types/blends, quantities, and delivery dates.
- Applying fertilisers; types/blends, the rates in each paddock/farm management zone (FMZ), and the frequency/timing of applications.
- Targeting use of dairy effluent as a fertiliser.
- Maintaining healthy and productive soils and implementing management recommendations specific to the farm.
- Managing risks to humans, animals and the environment.
- Monitoring, record keeping and reviewing management decisions.
- A communication tool for the management team, farm staff and contractors.

16.2 Components of a Fertiliser Management Plan

There are a number of important components in a Fertiliser Management Plan including the following:

[Farm map](#)

[Soil characteristics and soil constraints](#)

[Soil fertility and trends](#)

[Soil health assessment](#)

[Crop and pasture condition](#)

[Utilising on-farm nutrients](#)

[Fertiliser program](#)

[Nutrient Budget](#)

[Managing risks](#)

16.2.1 Farm Map

Soil and fertiliser management recommendations are specific to individual paddocks, or groups of paddocks known as Farm Management Zones (FMZs). A farm map is used to identify the FMZs, and to discuss soil and fertiliser management decisions with farm staff and contractors. FMZs can be shown by simply highlighting the area directly onto the farm map (See Figure 16.1), using a clear plastic overlay, or by creating a digital shape file using mapping software. Paddocks or FMZs are labelled on the farm map and referred to in the fertiliser program.

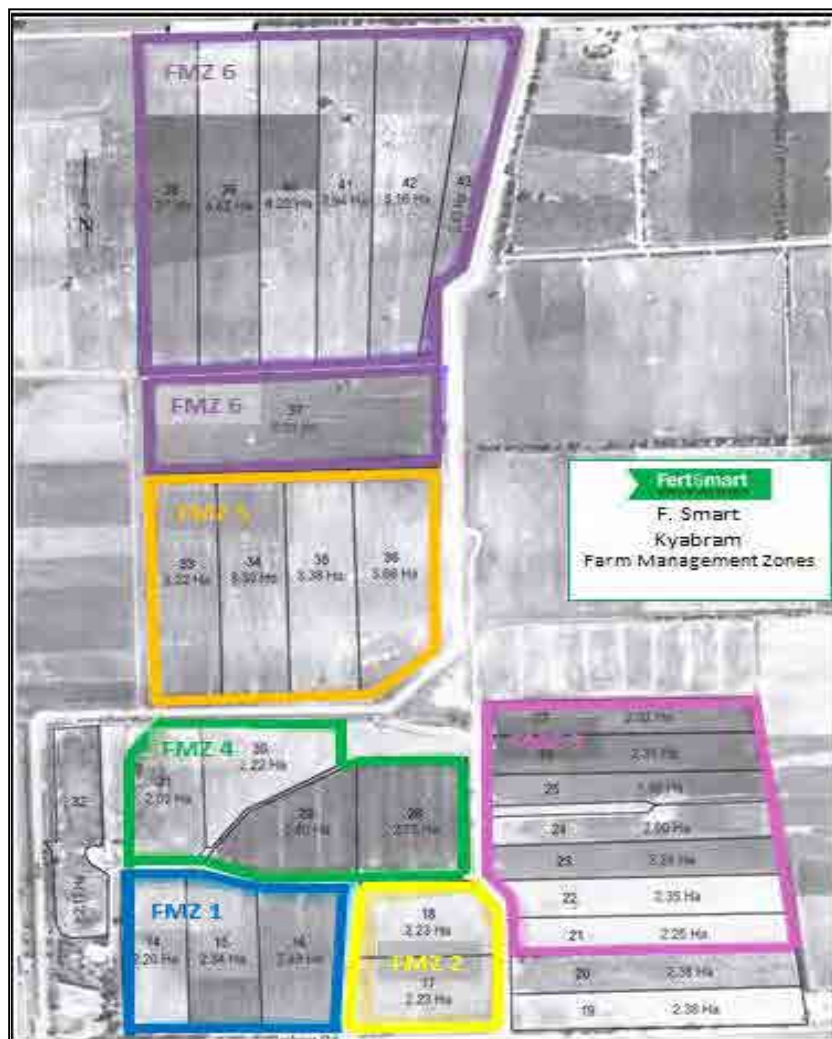


Figure 16.1 Farm map showing farm management zones.
Source: FertSmart Planning Pilot

Aerial photographs and satellite imagery make ideal bases for additional information including; soil types, fence lines, paddocks and farm infrastructure. Farm maps can be used to calculate paddock areas, and hence the fertiliser quantities required across different parts of the farm. Soil nutrient levels can be represented spatially on farm maps using what is known as nutrient mapping (See Chapter 15.4.2). Nutrient maps provide a snapshot of nutrient levels across the farm and are growing in popularity with farmers and advisors as a nutrient management tool.

16.2.2 Soil Characteristics and Constraints

An important part of nutrient planning is to manage physical and chemical limitations of the soil, also known as soil constraints (See Chapter 7). Soil constraints are present due to the inherent soil characteristics, or as a result of soil and fertiliser management. Management strategies to address limiting soil factors or to improve soil condition should be considered and included in the fertiliser management plan. The following factors have the potential to limit production even when plant nutrients are adequate:

- pH
- Salinity
- Water logging



- Slaking and dispersion
- Soil surface condition
- Soil structure

For more information on soil characteristics and constraints, refer to Chapters 4 to 7.

16.2.3 Soil Fertility and Trends

Current soil fertility levels across the farm are essential to include in a fertiliser management plan. If soil testing records are available, it is also very useful to include soil fertility trends. The key information to include in the plan is as follows:

- Soil test results for each FMZ.
- A visual comparison of the soil fertility status (P, K, S, pH and OC) in each farm management zone, with the optimum level for the specific soils and production system (Figure 16.2). The soil fertility guidelines for the relevant dairy region are used to compare current fertility levels with the optimum levels (generally 95% to 98% of potential production for dairy pastures).

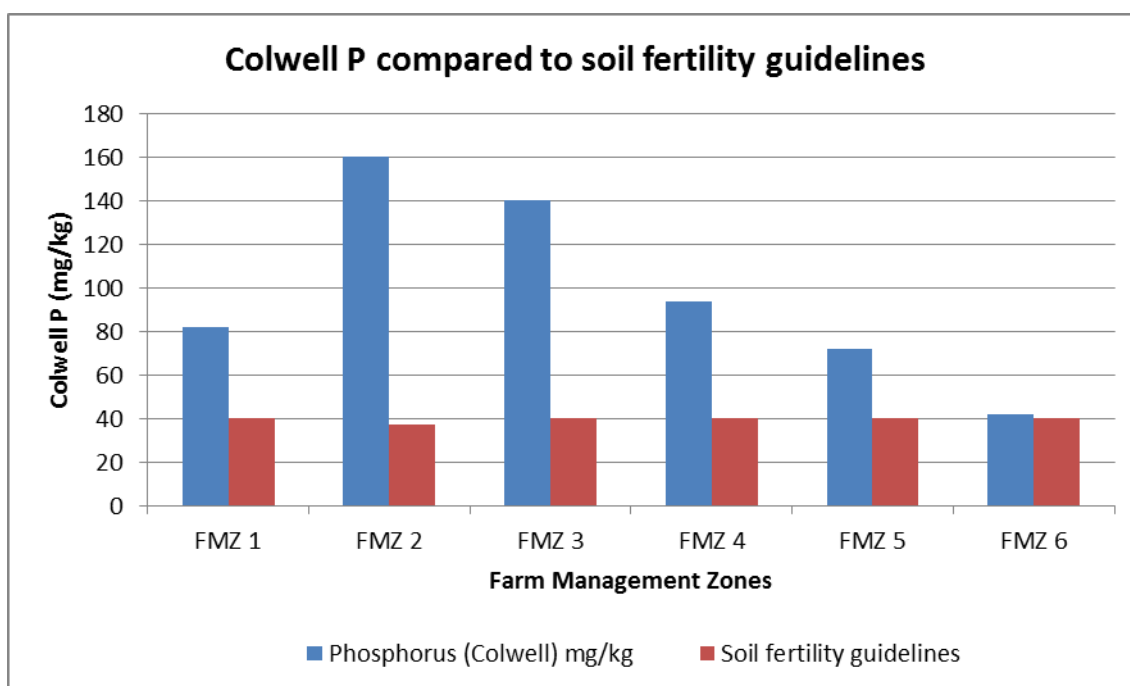


Figure 16.2 A comparison between current Colwell P levels in each FMZ with the soil fertility guidelines for specific soil types (Note: Optimum Colwell P values vary with soil type and PBI).

- Look for trends in the soil fertility status (P, K, S, pH and OC) over time for each FMZ and make comparisons with the optimum level for these soils and the farm production system (e.g. Figure 16.3). Soil fertility trends provide useful feedback on the effectiveness of previous fertiliser management decisions in maintaining soil fertility at the optimum levels and help to refine the fertiliser program. This feedback loop is like having on-farm research to find the optimum fertiliser program for the farm soils and production system.

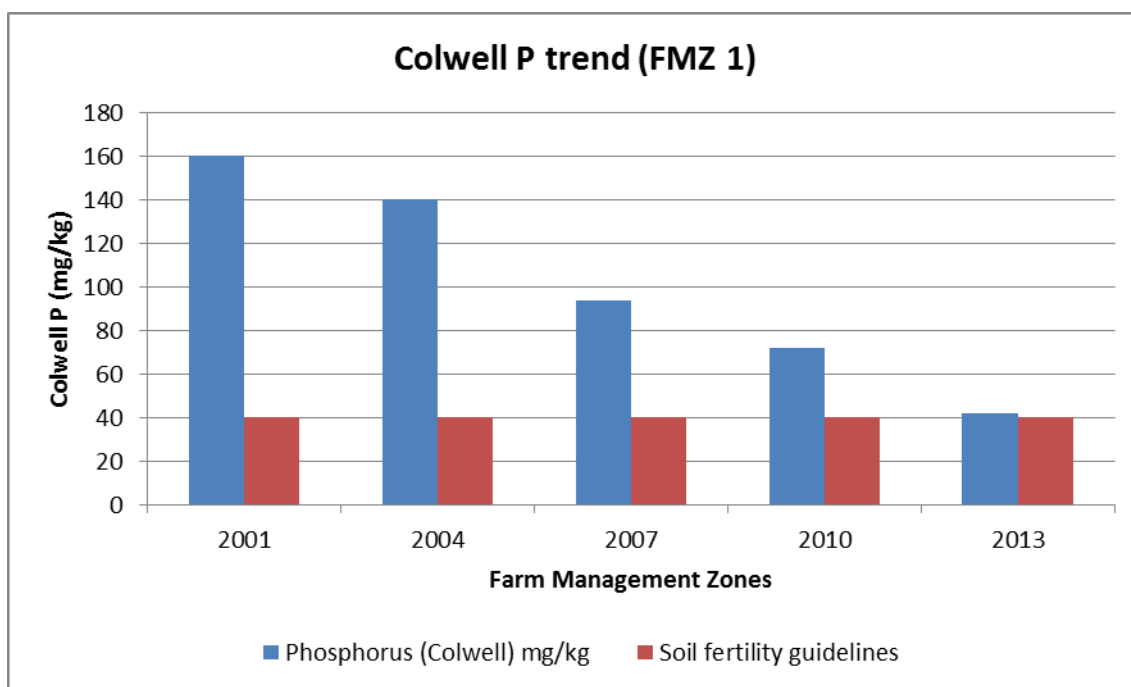


Figure 16.3 Example of Colwell P trends in FMZ 1 between years 2001 and 2013 compared to the soil fertility guidelines for this soil type.

16.2.4 Soil Health

Include a report on the soil health status and how to manage soil health in each FMZ. A soil health assessment is based on field observations and soil test results. Some basic indicators to include are as follows:

- Percentage ground cover or bare ground
- Depth of thatch layer/root mat layer.
- Organic carbon as shown on the soil tests (Walkley and Black test method)
- Fine root development and depth (top 30cm).
- Soil organisms (e.g. earthworms, beetles, fungi).
- Nodule development on legumes.

There are many more indicators that can be used to assess and monitor soil health. For more information refer to Chapter 5.

16.2.5 Crop and pasture condition

Production can be limited by crop and pasture condition (e.g. species, plant population, diseases, pests and weeds). Crops and pastures in good condition and suited for the purpose will use soil nutrients more efficiently than unhealthy and weedy stands. Provide management recommendations to maintain productive crops and pastures. See Chapter 1.1.8 for information on how to assess and manage crop and pasture condition.

16.2.6 Making the most of on-farm nutrients

Appraise the current use of organic fertilisers (including on-farm manure, effluent and compost) and consider cost effective management options to use effluent more strategically in the fertiliser program. To assist with management decisions it is worthwhile discussing the costs and benefits of infrastructure upgrades that result in more efficient use of effluent as a fertiliser. Effluent calculations



can be used to approximate the quantity of nutrients available as a fertiliser, and hence the estimated value of effluent. For more information on using dairy effluent as a fertiliser - See Chapter 13.3.

16.2.7 Fertiliser Program

The fertiliser program is the key guide for fertiliser management decisions in each FMZ throughout the year. The fertiliser program is developed by adhering to the following steps:

1. Identify and briefly state the production system for the farm, then pasture and crop yield targets and pasture consumption targets for each FMZ.
2. Consider the soil fertility and trends in soil fertility (see [Section 16.2.3](#)).
3. Use a nutrient budget to determine nutrient removal and accumulation (see [Section 16.2.8](#)).
4. Work out the fertiliser program for each farm management zone. At this stage you might start to identify the FMZs with similar requirements.

The fertiliser program follows the 4Rs principles (Right fertiliser source, Right rate, Right place, and Right time) and includes the following detail (see the example in Figure 16.4):

- Fertiliser types (product names and analysis)
- Application rates (kg/ha)
- Application areas (FMZs/ paddocks)
- Timing and frequency of applications (including split applications)
- How the products are applied (e.g. broadcast, banded)

The following links provide information to help in developing a fertiliser program:

[Introducing fertilisers \(Chapter 11\)](#)

[Nitrogen fertilisers \(Chapter 12\)](#)

[Calculating rates and costs \(Chapter 14\)](#)

[Nutrient planning \(Chapter 15\)](#)



Fertiliser Program 2012/2013

Fertiliser products top-dressed unless otherwise indicated using DairySAT BMP (best management practices). Products are based on past use. Discuss all aspects fully with your Fertcare C accredited advisor.

| FMZ | Area | Fertiliser kg/ha | | | | 2012 / 2013 | | Fertiliser Program |
|-----|-------------------|------------------|-----|----|----|-------------|--|---------------------------------------|
| | | N | P | K | S | Spring | Summer | |
| 1 | No 14-16 (Perm't) | 7.4 | 193 | 13 | 0 | 16 | Spring | 2 x 70 kg/ha Urea NPKS 46:0:0:0 |
| | | | | | | Summer | Nil | |
| | | | | | | Autumn | 1 x 150 kg/ha Single Super NPKS 0:9:0:11 | |
| | | | | | | Autumn | 2 x 70 kg/ha Urea NPKS 46:0:0:0 | |
| | | | | | | Winter | 2 x 70 kg/ha Urea NPKS 46:0:0:0 | |
| 2 | No 17-18 (Perm't) | 4.6 | 161 | 13 | 0 | 16 | Spring | 2 x 70 kg/ha Urea NPKS 46:0:0:0 |
| | | | | | | Summer | Nil | |
| | | | | | | Autumn | Gypsum required. Refer FMZ 2 notes | |
| | | | | | | Autumn | 1 x 150 kg/ha Single Super NPKS 0:9:0:11 | |
| | | | | | | Autumn | 2 x 70 kg/ha Urea NPKS 46:0:0:0 | |
| | | | | | | Winter | 1 x 70 kg/ha Urea NPKS 46:0:0:0 | |
| 3 | No 21-27 (Perm't) | 16.0 | 161 | 0 | 0 | 0 | Spring | 2 x 70 kg/ha Urea NPKS 46:0:0:0 |
| | | | | | | Summer | Nil | |
| | | | | | | Autumn | Gypsum required. Refer FMZ 3 notes | |
| | | | | | | Autumn | 2 x 70 kg/ha Urea NPKS 46:0:0:0 | |
| | | | | | | Winter | 1 x 70 kg/ha Urea NPKS 46:0:0:0 | |
| 4 | No 28-31 (Perm't) | 10.1 | 129 | 0 | 0 | 0 | Spring | Irrigated with effluent pond liquid * |
| | | | | | | Summer | Irrigated with effluent pond liquid * | |
| | | | | | | Autumn | 2 x 70 kg/ha Urea NPKS 46:0:0:0 | |
| | | | | | | Winter | 2 x 70 kg/ha Urea NPKS 46:0:0:0 | |
| 5 | No 33-36 (Perm't) | 13.5 | 129 | 21 | 24 | 27 | Spring | 1 x 70 kg/ha Urea NPKS 46:0:0:0 |
| | | | | | | Summer | Slurry likely to be applied | |
| | | | | | | Autumn | Gypsum required. Refer FMZ 5 notes | |
| | | | | | | Autumn | 1 x 300 kg/ha Super Potash 5:1 NPKS 0:7:8:9 | |
| | | | | | | Autumn | 2 x 70 kg/ha Urea NPKS 46:0:0:0 | |
| | | | | | | Winter | 1 x 70 kg/ha Urea NPKS 46:0:0:0 | |
| 6 | No 37-43 (Annual) | 32.0 | 97 | 35 | 40 | 45 | Spring | 1 x 70 kg/ha Urea NPKS 46:0:0:0 |
| | | | | | | Summer | Nil | |
| | | | | | | Autumn | Agricultural lime required. Refer FMZ 6 notes. | |
| | | | | | | Autumn | 1 x 500 kg/ha Super Potash 5:1 NPKS 0:7:8:9 | |
| | | | | | | Autumn | 1 x 70 kg/ha Urea NPKS 46:0:0:0 | |
| | | | | | | Winter | 1 x 70 kg/ha Urea NPKS 46:0:0:0 | |

* Effluent pond liquid is applied to FMZ 4, but slurry will be pumped out onto FMZ 6 in summer 2013.

Figure 16.4 Example Fertiliser Program for a dairy farm (Source: Fert\$mart Planning Pilot)

16.2.8 Nutrient Budget

It is worthwhile including a farm nutrient budget and discussing what this means to farm nutrients and fertiliser management. The farm nutrient budget is used to work out the total quantities of nutrients that need to be brought onto the farm to replace nutrients exported from the farm in saleable products. The nutrient budget alerts decision makers to situations of soil nutrient rundown or nutrient build-up which can be managed effectively through the fertiliser program (Refer to the farm nutrient budget example in Figure 16.5).



FARM GATE NUTRIENT BUDGET

Milking area is 83.0 ha and stocking rate is 3.3 cows /ha.

As background any pasture silage cut is fed back out on the milking area.

Calculations based on DPI Nutrient Planning guidelines being updated for Fertsmart website.

Stock movements have been relatively constant between years.

| 2011/12 | | | |
|---------------------------|---|------------------------------------|--------------------------------------|
| Milk production (litres) | 1644672 | 19815 | litres per milking ha (6097 x 3.25) |
| Total Butterfat (kg) | 72703 | | |
| Total Protein (kg) | 56398 | | |
| Total MS (kg) | 129101 | 1555 | MS kg per milking ha (479 x 3.25) |
| Nutrient removal * | 42 kg N, 10 kg P, & 14 kg K removed per 10,000 litres milk. | | |
| Phosphorus soil factor ** | 25 | Moderate PBI with Olsen > 25 mg/kg | |
| Potassium soil factor *** | 15 | Clay loam soil type | |

PHOSPHORUS CALCULATIONS

| INPUTS: | Per cow | DM % | t DM/cow | SR cows/ha | DM/ha tonne | P kg/tonne | P/ kg/ha |
|---|-----------|-----------|----------|---------------|------------------|---------------|-------------|
| Pellets (484 tonne/DM) | | | 1.79 | | | | |
| Hay (684 tonne/DM) | | | 2.53 | | | | |
| | | | 4.32 | 3.25 | 14.04 | 3.0 | 42.1 |
| Fertilizer phosphorus inputs (average kg actual P/ha based on milking area) | | | | | | | Nil |
| Sub total | | | | | | | 42.1 |
| OUTPUTS: | | | | P | | | |
| | litres/ha | kg/1000 l | P kg/ha | | | | |
| Milk * | 19815 | 1.0 | 19.8 | | | | |
| Soil factor ** | | | 25.0 | | | | |
| Dung losses 0.8 x SR | | | 2.6 | | Sub total | | 47.4 |
| Negative P balance | | | | | | | 5.3 |

POTASSIUM CALCULATIONS

| INPUTS: | Per cow | DM % | t/ha | SR | DM/ha tonne | K kg/tonne | K/ kg/ha |
|--|-----------|-----------|---------|------|------------------|---------------|--------------|
| Pellets (484 tonne/DM) | | | 1.79 | 3.25 | 5.8 | 4 | 23.2 |
| Hay (684 tonne/DM) | | | 2.53 | 3.25 | 8.2 | 17 | 139.4 |
| Fertilizer potassium inputs (average kg actual K/ha based on milking area) | | | | | | | Nil |
| Sub total | | | | | | | 162.6 |
| OUTPUTS: | | | | K | | | |
| | litres/ha | kg/1000 l | K kg/ha | | | | |
| Milk * | 19815 | 1.4 | 27.7 | | | | |
| Soil factor *** | | | 15.0 | | | | |
| Dung losses 0.8 x SR | | | 2.6 | | Sub total | | 45.3 |
| Positive K balance | | | | | | | 117.3 |

Figure 16.5 Example farm nutrient budget (Source: Fert\$mart Planning Pilot).



16.2.8.1 Nutrient Budget Tool

The [Ellinbank Nutrient Budgetor](#) is a decision support tool developed to assist farmers and advisers make better fertiliser decisions within different areas of a dairy farm. The Budgetor is primarily designed to generate a report that covers up to 9 different areas within the farm (FMZs). It determines the results of on-farm nutrient movements caused by the practices of forage harvesting and effluent applications, and takes into account nutrients that are imported onto the farm in brought-in forages. It uses specific information such as soil type, stock numbers, grazing area, production, and the frequency of paddocks being visited, so as to determine a fertiliser report for up to 9 different areas of the farm (FMZs). The Budgetor can also be used to explore the results of altering different farm practices.

[More on nutrient budgets \(Chapter 15.6\)](#)

16.2.9 Managing Risks

Consider the risks and include recommendations to manage and reduce unacceptable risks associated with fertiliser management. The risk of nutrient loss can be assessed using tools such as the '[Farm Nutrient Loss Index](#)' (FNLI) or '[Cracking the Nutrient Code](#)'. These tools help to identify which farm areas and activities contribute to the highest risk of nutrient loss, and suggest management actions to reduce the potential risk of nutrient loss. Fertilizer Australia also coordinates training courses in managing environmental risks – See the [Fertcare Program](#).

It is also important to include strategies to manage risks to human and animal health associated with fertiliser and effluent use. For more information on managing risks see the following Chapters:

[More on minimising losses \(Chapter 10.5\)](#)

[More on using dairy effluent \(Chapter 13\)](#)

16.3 Documenting the Fertiliser Management Plan

There are many suitable formats for documenting a fertiliser management plan ranging from a printed hard copy to a digital report created by fertiliser planning software. The most important sections for farm management purposes are the fertiliser program and the key farm recommendations.

Dairy farmers involved in the Fert\$mart planning pilots said they preferred a concise plan with the farm fertiliser program and key farm management recommendations condensed into the first few pages, followed by more detailed management information for each FMZ. A template, including the components described in [Section 16.2](#), was developed to meet the specific needs of farmers involved in the Fert\$mart Pilots and included the following sections:

1. Fertiliser Program
2. Key farm recommendations
3. Farm details
4. Farm management zones
5. Farm nutrient budget
6. Appendix

Examples of fertiliser management plans can be found on the following links:

[Fert\\$mart Soil and Fertiliser Management Plan Example \(PDF\)](#)

[Fert\\$mart 'Soil and Fertiliser Management Plan' template \(Word\)](#)



Glossary

4Rs: a nutrient stewardship framework: the right fertiliser source, at the right rate, at the right time, and in the right place.

A

accessions: water that moves through the soil profile and into the water table

acid mat: a partially decomposed layer of plant material, often in association with fog grass or bent grass.

actinomycete: a member of a group of micro-organisms commonly regarded as filamentous bacteria.

adsorb: the attachment of a substance or ion to the surface of a solid or liquid.

adsorption: the electrostatic attraction of ions (cations and anions) onto the surfaces of clay minerals and organic colloids

aeolian soils: are carried and deposited by wind.

aeration: refers to the process of using mechanised equipment to loosen the soil.

aerobic: active only in the presence of oxygen.

aggregates: groups of soil particles held together by organic matter or chemical forces.

agistment: the pasturage or feeding of livestock in return for payment.

agronomically: relates to soil and crop management

Al: symbol for the element aluminium.

aluminosilicate: a salt that is both an aluminate and a silicate.

aluminate: 1. *Chem.* a salt of the acid form of aluminium hydroxide. 2. *Mineral.* a metallic oxide combined with alumina.

alluvial soils: soils moved and deposited by flowing water.

ameliorants; substances added to soil to improve the growing conditions for plant roots, e.g. organic matter to improve soil structure, coarse grit to improve drainage, fertilisers for improved plant growth.

anaerobic: active only when oxygen is absent.

anecdotal: not necessarily true or reliable, because based on personal accounts rather than facts or research.

anion: negatively charged ion.

aquifer: an underground layer of permeable rock, sediment (usually sand or gravel), or soil that yields water.

arbuscular mycorrhizal fungi: is a type of mycorrhiza in which the fungus penetrates the cortical cells of the roots of a vascular plant

As: symbol for the element arsenic.

ASPAC: Australasian Soil and Plant Analysis Council.

atoms: the smallest quantity of an element that can take part in a chemical reaction.

autotrophic: plants that can build their own food by, for example, photosynthesis.

B

B: symbol for the element boron.

banded: fertilizer is placed in bands which may be continuous or discontinuous to the side of a seed or plant.

basalt: an dark, dense igneous (volcanic) rock, composed mostly of plagioclase and pyroxene.

Base: a substance that can accept hydrogen cations (protons) or more generally, donate a pair of valence electrons. A soluble base is referred to as an alkali if it contains and releases hydroxide ions (OH⁻) quantitatively.

base cations: positively charged ions such as magnesium, sodium, potassium, and calcium that increase pH of water (make it less acidic) when released to solution through mineral weathering and exchange reactions.

irrigation bay: an area of land which is confined for flood irrigation.

beneficial insects: any of a number of species of insects that perform valued services like pollination and pest control.

benign: tending to exert a neutral or beneficial influence; not harmful.

biochemical: involving chemical processes in living organisms.



Glossary

biocide: a chemical substance which can deter, render harmless, or exert a controlling effect on any harmful organism.

biosolids: the residual, semi-solid material left from industrial wastewater, or sewage treatment processes.

biota: the total collection of living organisms

bioturbation: the mixing of soils through the action of the 'ecosystem engineers'.

border check irrigation: border check or bay irrigation could be considered as a hybrid of level basin and furrow irrigation. The field is divided into a number of bays or strips, each bay is separated by raised earth check banks (borders).

botanical composition: The proportion of pasture made up by different botanical species.

broadcast: process of spreading fertiliser products onto the soil surface.

buckshot: describes generally rounded, hard (small to medium sized) ferruginous concretions.

buffer / buffering: processes that constrain or resist change or reduce the shift in pH when acids or bases are added. More generally processes that constrain shifts in the dissolved concentration of any ion, when it is added or removed from the system (i.e. Resist change in concentration).

buffering capacity: the soil's ability to resist change in pH. Soils with a high clay and organic content show a higher buffering capacity. The amount of lime or dolomite required to reverse a pH effect will vary from soil to soil depending on the buffering capacity.

bulk density: the ratio of dry soil mass to bulk soil volume (including pore spaces).

C

C4 grasses: a grass having an alternative photosynthetic system to C3, in which the initial fixing of CO₂ is via a four-carbon chain compound. At C4 photosynthesis is more efficient at higher light intensities and higher temperatures, hence its prominence amongst grasses (and other plant species) in the warmer, summer-rainfall regions.

C: symbol for the element carbon.

Ca: symbol for the element calcium.

CaCl₂: calcium chloride.

Ca(H₂PO₄)₂: primary phosphate, or superphosphate, consisting of about 31% phosphates, 50% gypsum and 19% impurities of various kinds.

CaCO₃: calcium carbonate or the mineral calcite.

calcarosol: a calcareous soil (at the A horizon or within 0.2 m of the A horizon) without a clear or abrupt textural change at the B horizon.

calcareous: a soil that has sufficient calcium carbonate to cause effervescence when a few drops of hydrochloric acid are applied to it.

calcium carbonate: a crystalline compound (CaCO₃) occurring in nature as the mineral calcite. It is the neutralising component of lime.

calcium chloride: a white powdery compound (CaCl₂) that becomes liquid by absorbing moisture from the air, used as a drying agent, preservative, etc.

calcium sulphate: one of the salts of sulphuric acid. Unlike most sulphates, calcium sulphate is not water soluble.

CAN: calcium ammonium nitrate, a fertiliser.

capillary action: forces between water and soil surfaces in the small (capillary) pores.

capillary movement: the raising or lowering of water in the small pore spaces (micropores) caused by surface tension, attraction between the water molecules and the soil particles, etc.

capillary zone: the area above the watertable that is affected by capillary rise

capital applications: nutrients applied to increase soil fertility to a target level, and are in excess of nutrients required to maintain production.

capital requirements: amount of fertiliser required to lift soil nutrient levels to the target levels.

carbohydrates: plant sugars



Glossary

carbonate: a salt of the anion CO_3^{2-} , typically formed by reaction of carbon dioxide with bases

carbonation: reaction with carbon dioxide to remove lime.

catalyst: a substance that increases the rate of a chemical reaction without itself undergoing any permanent chemical change

cation: positively charged ion.

cation exchange capacity: the total sum of exchangeable cations that the soil can adsorb at a specific pH.

Cd: symbol for the element cadmium.

cellulose: an important structural component of the primary cell wall of green plants, many forms of algae and the oomycetes.

chelates, and chelating agents: a soluble organo-metal complex. The leaching of immobile Al^{3+} and Fe^{2+} cations can be enhanced by formation of chelates, which are metal complexes with the carboxyl group of humified organic matter. Certain micronutrients are supplied as chelates, often complexed with synthetic chelating agents such as ethylene tetra-acetic acid.

chlorosis: the yellowing or whitening of normally green plant tissue because of a decreased amount of chlorophyll, often as a result of disease or nutrient deficiency.

clay-pan: a layer of stiff impervious clay situated just below the surface of the ground

Co: symbol for the element cobalt.

coffee rock: a compacted, cemented or indurated layer within the profile that is comprised of humus and iron oxides

colwell P: A measure of the phosphorus that is available for plant uptake.

cohesion: the capability of a soil's particles to hold together.

compaction: the process whereby soil density is increased as a result of tillage, stock trampling and/or vehicle traffic. Compaction can lead to lower soil permeability. Deep ripping and conservation tillage can alleviate the condition.

connectivity: nutrient-carrying water flows from a critical source area directly to a water body.

conservation tillage: an agricultural method used to prevent soil erosion and nutrient loss. This is accomplished by leaving crop residue on the surface of the soil after harvest.

contour banks: earthen structures constructed at intervals down the slope to slow the flow of runoff and to reduce soil erosion.

critical habitat: a habitat area essential to the conservation of a listed species, though the area need not actually be occupied by the species at the time it is designated.

critical source areas, or hot spots: Critical source areas of a nutrient result from the co-location of areas with high levels of that nutrient availability (source areas) with areas with high potential for nutrient movement (transport areas).

critical value: target soil test level for optimum pasture yield, generally 95% - 98% of maximum pasture dry matter yield.

Cu: symbol for the element copper.

cultural control: the deliberate alteration of the production system, either the cropping system itself or specific crop production practices, to reduce pest populations or avoid pest injury to crops

cutical: a protective film covering the epidermis of leaves, young shoots and other aerial plant organs without periderm.

D

DairySAT: an Australian self-assessment tool to improve productivity and environmental outcomes on a dairy farm.

DAP: di-ammonium phosphate, a fertiliser.

day-degrees: the number of accumulated heat units required to reach each stage of growth.

decomposers: organisms that break down dead or decaying organisms, and in doing so carry out the natural process of decomposition.

debris: remains of something.

decompose: to break down or decay



Glossary

denitrification: breakdown of nitrogen compounds to forms that are less available to plants.

development phase: phase in nutrient management when nutrient levels are raised to adequate levels for pasture production.

desludging: the process of removing sludge (sediments) from an effluent pond or tank.

desorption: a phenomenon whereby a substance is released from or through a surface. The process is the opposite of sorption (that is, either adsorption or absorption).

dieback: a condition of plants that starts at the tips of the shoots and works downwards, causing progressive lifelessness.

diffusion: the process by which molecules spread out and intermingle as a result of their kinetic energy of random motion.

diminishing returns: in all productive processes, adding more of one factor of production, while holding all others constant will at some point yield lower per-unit returns.

disperse: when the clay particles form a cloud around an aggregate placed in water.

dispersible soils: soils that are structurally unstable and disperse in water into basic particles (sand, silt and clay). Dispersible soils tend to be highly erodible and present problems for earthworks. (See also sodicity.)

dispersion: when the clay particles form a cloud around an aggregate placed in water.

DM: (dry matter). A measurement of the mass of something when completely dried.

DNA: Deoxyribonucleic acid (DNA) is a molecule that encodes the genetic instructions used in the development and functioning of all known living organisms and many viruses.

dolomite: a carbonate mineral composed of calcium magnesium carbonate $\text{CaMg}(\text{CO}_3)_2$.

dry matter: a measurement of the mass of something when completely dried.

duplex profile: a soil in which a marked difference in soil texture occurs at a particular layer. Two or more distinct bands of soil type occur within the profile.

dynamic: constantly changing to different states or forms.

ecological niches: the status of an organism within its environment and community (affecting its survival as a species).

E

ecology: the scientific study of the relationships that living organisms have with each other and with their abiotic environment.

ecosystem engineers: soil fauna that alter the physical structure of soil by moving through it.

ecosystem services: the resources and processes supplied by natural ecosystems that benefit humans.

effective cation exchange capacity: the sum of the five most abundant cations present in soil. Includes cations of calcium, magnesium, potassium, sodium and aluminium. Under alkaline conditions the sum of these exchangeable cations is approximately equivalent to the CEC.

effective milking area: total farm area less that area that cannot be grazed

effective neutralising value: the value that a certain mass of lime has to change soil pH; considering the neutralising value (calcium carbonate content), particle size and solubility.

effluent calculator: a calculator used to estimate the quantity of effluent produced on a dairy farm.

element: simple substance that can not be broken down into simpler substances by normal chemical means.

electrical conductivity: a measure of the conduction of electricity through water. The value reflects the amount of soluble salts in an extract and therefore provides an indication of soil salinity.

electron transport system: a sequence of biochemical reduction-oxidation reactions that effects the transfer of electrons



Glossary

enmeshment: the state of being enmeshed; entanglement.

ENV: effective neutralising value (of lime).

environmental asset: a naturally occurring entity that provides environmental “functions” or services.

enzymes: large biological molecules responsible for the thousands of chemical interconversions that sustain life.

essential element: see major element.

eutrophication: the process by which a body of water becomes enriched in dissolved nutrients that stimulate the growth of aquatic plant life usually resulting in the depletion of dissolved oxygen.

extracellularly: situated or occurring outside a cell or cells.

extractant: a liquid used to remove a solute from a solution.

exudates: extracellular material produced by organisms for the purposes of protection or communication.

F

fallow: a rest period during a cropping cycle.

farm management zones; farm areas (or paddocks) with similar physical features and management.

Farm Nutrient Loss Index: an index for assessing the risk of nitrogen and phosphorus loss for the Australian grazing industries.

fate: end point - where nutrients end up.

Fertiliser Risk Assessment Matrix: a tool developed by Fertiliser Australia to help individual industries, regions and farms to develop their own specific Nutrient Management Codes of Practice.

Fe: symbol for the element iron.

feed budget: a farm assessment to identify feed requirements based on the number and class of livestock to be fed and the production levels that are targeted.

feldspar: any of a group of minerals, principally aluminosilicates of potassium, sodium, and calcium. They are among the most important constituents of igneous rocks.

ferrosol: soils with B2 horizons which are high in free iron oxide, and which lack strong texture contrast between A and B horizons.

fertigation: the application of fertilizers, soil amendments, or other water-soluble products through an irrigation system.

fertiliser: (as used in this manual) any nutrient or substance that, when added to the soil, promotes plant growth. This definition includes both inorganic and organic fertilisers and also soil conditioners, such as lime and gypsum, which may promote plant growth by increasing the availability of nutrients that are already in the soil or by changing the soil's physical structure.

fertiliser management plan: a documented plan that describes the use of fertiliser (including effluent and manures) to effectively provide needed crop nutrients while reducing the potential adverse impacts of fertiliser to the environment.

fertiliser monitor charts: recording soil test results in the form of a graph

fertiliser program: the key guide for fertiliser management decisions in each farm management zone throughout the year. It describes the right fertiliser source, the right rate, the right placement and the right time.

fertiliser use efficiency: the proportion of fertiliser nutrients converted to the targeted product, e.g. pasture or milk.

field capacity: the percentage of moisture remaining in soil horizon 2 to 3 days after being saturated (by rainfall or irrigation) and after free drainage has ceased.

fixation: the rendering insoluble or making unavailable, by elements or organisms within a soil, of a plant nutrient: Phosphorous is fixated by iron and aluminium oxides; nitrogen is fixated by bacteria in the nodules on legumes for use by the host plant.

flocculation: a process in which individual particles of a suspension form aggregates

FNLI: an abbreviation for Farm Nutrient Loss Index; an index for assessing the risk of nitrogen and phosphorus loss for the Australian grazing industries.

free-board: the elevation difference between the full pond and the crest of the bank.



Glossary

fulvic acids: humic acids of lower molecular weight and higher oxygen content than other humic acids - see humic acids.

G

gate valve: a valve in a pipeline consisting essentially of a flat or wedge-shaped gate that can be lowered into a seat to seal off the line.

genomics: the study of the genomes of organisms. The field includes intensive efforts to determine the entire DNA sequence of organisms and fine-scale genetic mapping.

glacial soil: soil composed of boulder clays, and moraines which were formed by the action of ice during the Pleistocene age.

GPS: global positioning system.

gradational profile: a soil in which there is a slight increase in clay content with depth.

grass tetany: a condition where cattle cannot store magnesium.

green manure: a growing crop, such as clover or grass, that is ploughed under the soil to improve fertility.

gridline: a system of referencing points using intersecting parallel lines at right angles to each other (similar to using mapping coordinates).

growing day degrees: a measure of heat accumulation used by horticulturists, gardeners, and farmers to predict plant and pest development rates such as the date that a flower will bloom or a crop reach maturity.

gully erosion: steep-sided watercourses and one of the most visible and severe forms of water erosion.

gypsum: a naturally occurring soft crystalline material (hydrous calcium sulphate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). Deposits occur naturally in inland Australia. It contains approximately 23% calcium and 18% sulphur. It is used to improve soil structure and reduce crusting in hardsetting clay soils.

H

half-life: the time for concentrations to halve.

hard pan: a general term for a dense layer of soil

Hardsetting: soils that collapse on wetting and set to a hard, featureless mass on drying.

heavy metal: metals with a density greater than 5 g per cubic centimetre; includes copper, iron, molybdenum, cobalt, zinc, cadmium, mercury, nickel, and lead but does not include arsenic or selenium.

Hg: symbol for the element mercury.

heterotrophic: incapable of building (synthesising) their own food. *Compare with autotrophic.*

high-analysis fertiliser: a more concentrated fertiliser product with a higher percentage of nutrients in the analysis.

homogeneous: having a uniform composition or structure.

horizon: a layer or band within a soil profile.

humic acid: a principal component of humic substances produced by the biodegradation of dead organic matter.

humic substances: an organic residue of decaying organic matter.

humins: the fraction of humic substances which are not soluble in alkali or acid.

hump and hollow drainage: the practice of forming the ground surface into parallel humps separated by hollows. The humped shape sheds excess moisture relatively quickly while the hollows act as shallow surface drains.

humus: soil organic matter that has decomposed into a dark-coloured mass without trace of the original plant tissue.

hydration: process of combining chemically with water; hydrated means chemically combined with water in its molecular form (H_2O).

hydrolysis: chemical decomposition by which a compound is resolved into other compounds by taking up the elements of water (hydrogen and oxygen).

hygroscopic: readily taking up and retaining water.

hydrous: containing water or its elements in some kind of union, as in hydrates or in hydroxides.



Glossary

hyphae: long, branching filamentous structure of a fungus, and also of unrelated Actinobacteria.

I

immobilisation: tie-up of nutrients

immobilised: the absorption of decomposed organic matter by micro-organisms.

Improved pasture: a pasture sown with more productive species.

interveinal: between the veins.

Inoculant: agricultural amendments that use beneficial microbes to promote plant health.

inoculation: mixing seed (usually clover seed) with the appropriate rhizobia bacteria.

ion: an atom in water that is either positively or negatively charged.

ion exchange: the interchange between an ion in solution and another ion on the surface of any surface-active material such as clay or humus.

inert: having little or no ability to react with other elements.

infiltration: the movement of water through the soil surface.

infrastructure: physical structures needed for the operation of the enterprise.

inorganic: compounds of inanimate, not biological, origin.

inversely related: means that one variable is directly proportional to the inverse, or reciprocal, of the other.

insoluble: not soluble (the property of a solid, liquid, or gaseous chemical substance called solute to dissolve in a solid, liquid, or gaseous solvent to form a homogeneous solution).

inundation: to cover with water.

K

K: symbol for the element Potassium.

K-Line: K-Line is a flexible hose line sprinkler system originally designed for irrigation. However, the low application rate makes the K-Line system well suited to effluent distribution. At the heart of the system is a series of tough plastic pods protecting a

sprinkler, firmly attached to special K-Line low density polyethylene pipe.

KCl: potassium chloride.

krasnozem: typically a red, deep, well-structured, acid and porous soil of volcanic origin; they have a high clay content that increases with depth.

kurosol: a soil with a clear or abrupt textural change at the B horizon, which is strongly acidic in the upper B2 horizon.

L

labile: readily plant available

lacustrine soils: lacustrine material is well sorted and fine-textured, having finer silts and clays.

lasered: the process of levelling the soil surface using a laser beam

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

leaf margin: the border or edge of a leaf

legume: a member of the Leguminosae family. Characterised by their pea-shaped flowers. Legumes have a symbiotic association with the nitrogen-fixing species of the bacterial genus *Rhizobium*. (See symbiotic fixation.)

lenticular: describing soil particles arranged around an elliptical or circular plane and bounded by curved (lens-shaped) faces; often occurs in subsoils of vertosols and can be associated with slickenside development.

lignin: an indigestible part of plant fibre, which, together with cellulose, forms the woody cell walls of plants and the material that cements the cells together.

lime: a naturally occurring calcareous material used to raise the pH of an acidic soil.

limestone: sedimentary rock consisting of CaCO₃. Parent material for lime products.

litter transformers: organisms which are capable of shredding and 'pre-digesting' organic materials.

logarithmic: is a scale of measurement that displays the value of a physical quantity using intervals corresponding to orders of magnitude, rather than a standard linear



Glossary

scale. For example, a chart whose axis has equally spaced increments that are labelled 1, 10, 100, 1000, instead of 1, 2, 3, 4.

low-analysis fertiliser: a less concentrated fertiliser product with a lower percentage of nutrients in the analysis.

lower extractable limit: the amount of water remaining in the soil when a plant wilts and does not respond to added water.

lunette: a crescent or half-moon shaped sand dune.

M

macro-aggregate: a relatively large aggregated particle, a soil crumb.

macrofauna: soil organisms which are retained on a 0.5mm sieve.

macropores: soil cavities that are larger than 75 μm

macronutrients: the essential plant nutrients required in the largest proportions by plants, namely nitrogen, phosphorus, potassium, sulphur, calcium and magnesium.

maintenance applications: nutrient applications that keep the soil nutrient status at the same level while supporting pasture production.

maintenance requirement: the balance to keep nutrients at the same level when more nutrients leave the farm than are brought onto it.

major element: an essential element that is present or required by organisms in relatively large amounts.

MAP: mono-ammonium phosphate, a fertiliser.

marine soils: deposition of sediments in the marine environment.

marl. 1. a soil or earthy deposit of marine origin consisting of clay and calcium carbonate, used esp. as a fertiliser. 2. compact, impure limestones.

massive: without layers or cleavage; of uniform structure. (*Compare with vesicular.*)

mediate: assist; make happen

megalitre: one million litres, or 1000 cubic metres, of a liquid.

mesofauna: invertebrates between 0.1mm and 2mm in size, which live in the soil or in a leaf litter layer on the soil surface.

metabolic products: products within the cells of living organisms required to sustain life e.g. products required to harvest energy in cellular respiration.

metabolic problems: diseases related to the disturbance of one or more metabolic processes, the root cause being diet.

metabolism: the chemical processes that occur within a living organism in order to maintain life

meq/100 g: milliequivalent(s) per 100 grams; a measure of cation exchange capacity.

mg/L: milligram(s) per litre.

microaggregates: aggregates less than 250 μm in size; play a key role in protecting soil organic carbon (SOC) from microbial decomposition

microbe: a microscopic organism

microbial stimulant: natural additive to enhance microbial activity in the soil

microfauna: protozoa and nematodes

microflora: actinomycetes, archaea, bacteria, fungi, viruses and algae.

micropores: smaller pores within the aggregates or between soil particles that hold water against gravity.

micronutrients: nutrients essential to plants but only required in small amounts.

milliequivalent: one milligram of hydrogen or the amount of any other ion that will combine with or displace it.

mineral soils: soils that contains less than 20% organic carbon.

mineralisation: the release of plant-available compounds during decomposition.

mineralogy: the minerals that make up the soil

minimum tillage: a crop production system that uses minimum soil disturbance.

minor element: see trace element.

ML: see megalitre.

mobile: (of a nutrient in the plant) moves to the actively growing tissue, such as root tips and growing points in the tops of



Glossary

plants; (of a nutrient in the soil) readily leached.

moderator: reduces fluctuations

mole drain: underground channel or drain formed by a mole plough, which consists of a sharp blade with a bullet-shaped cylinder attached to the bottom.

MOP: muriate of potash

mycelium: consists of elongated, branched, microscopic filaments termed hyphae.

N

N: symbol for the element nitrogen.

NaCl: sodium chloride.

NATA: National Association of Testing Authorities.

necrotic: process pertaining to the death of tissue in response to disease, disorders or injury.

nematodes: round worms.

neutralising value: provides an indication of how much acidity can be neutralised with a product reflecting its calcium carbonate content only; its purity. Neutralising value does not consider solubility or particle size.

Ni: symbol for the element nickel.

nitrification: the breakdown of nitrous acid (nitrite, HNO_2) to nitric acid (nitrate, HNO_3) by nitrifiers or nitrifying organisms.

nitrification inhibitors: chemical products which can reduce the conversion of ammonium to nitrate.

nitrifying bacteria: soil bacteria that change ammonia or ammonium into nitrite or change nitrite into nitrate as part of the nitrogen cycle.

nitrogen fixation: any process (either chemical or bacterial) that describes the transformation of N_2 gas from the atmosphere to nitrogenous compounds.

Nodule: a knob like growth occurring on the roots of plants (primarily legumes) that associate with symbiotic nitrogen-fixing bacteria.

non-labile: not readily plant available, but slowly released over time.

Nucleic acids: Nucleic acids are large biological molecules essential for all known

forms of life. They include DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). Together with proteins, nucleic acids are the most important biological macromolecules; each is found in abundance in all living things, where they function in encoding, transmitting and expressing genetic information.

nutrient analysis: the NPKS system states the percentage of nitrogen, phosphorus, potassium and sulphur contained in a fertiliser product.

nutrient budget: the process involves balancing nutrients coming into the farming system with those leaving.

nutrient conversion efficiency: the proportion of nutrient entering the farm that is converted into saleable product such as milk or meat.

nutrient maps: a visual representation of soil fertility across the farm.

nutrient mapping: a process of visual representation of soil fertility across the farm.

nutrient plan: a management plan outlining the efficient use of nutrients and fertilisers for production.

nutrient rundown: situation occurring when soil nutrients are removed in agricultural products and are not replaced.

nutrient use efficiency: the proportion of nutrient entering the farm that is converted into saleable product such as milk or meat.

O

O: symbol for the element oxygen.

OC: Symbol for Organic Carbon.

on-off grazing: where cows are taken off the paddock for part of the day through to cows being held off pasture for a number of weeks.

opportunity cost: the benefits you could have received by taking an alternative action

optimum nutrient status: nutrient status where production is at 95% to 98% of potential.

Organic: has come from a once-living organism, is capable of decay or the product of decay, or is composed of organic compound.



Glossary

organic carbon: carbon held within the soil, primarily in association with its organic content.

organic matter: anything that is either living or the remains of a living thing; organic matter in the soil refers to the remains of living things, namely, decayed animal and plant matter.

organic soils: soils that contains more than 20% organic carbon.

osmosis: movement of solvent molecules through a partially permeable membrane into a region of higher solute concentration

oxidation: the loss of an electron by a substance, therefore gaining a positive charge.

oxides: chemical compounds that contain at least one oxygen atom and one other element in its chemical formula.

P

P-sorption: the process by which soluble P becomes adsorbed to clay minerals and/or precipitated in soil.

P: symbol for the element phosphorus.

parasitising: to live on or in a host as a parasite

parent material: the underlying geological material (generally bedrock or a superficial or drift deposit) in which soil horizons form.

particulate: formed of minute separate particles

pasture meter: device for measuring the amount of feed remaining; based on a design in which a flat metal plate traverses up a central spindle when the spindle is inserted through the plants so that it reaches the ground, the plate floating on top of the plants.

pathogen: a microorganism in the widest sense, such as a virus, bacterium, prion, or fungus that causes disease in its host.

Pb: symbol for the element lead.

PBI: Phosphorus Buffering Index. The amount of P absorbed or desorbed per unit change in solution.

P concentration

peat: a heterogeneous mixture of more or less decomposed plant (humus) material that has accumulated in a water-saturated environment and in the absence of oxygen.

Peat soil: soil with an accumulation of partially decayed vegetation

permeable: allows liquids or gases to pass through it

petiole: the stalk of a leaf, attaching the blade to the stem

peer reviewed: the evaluation of work by one or more people of similar competence to the producers of the work (peers).

permanent wilting point: If moisture decreases to this or any lower point, a plant wilts and can no longer recover its turgidity when placed in a saturated atmosphere for 12 hours.

pH: a measure of soil acidity or alkalinity on a scale of 0 (extremely acidic) to 14 (extremely alkaline) with a pH of 7 being neutral. It gives an indication of the availability of plant nutrients.

pH buffering test: a soil laboratory test to determine lime recommendations for target soil pH of 5.5, 6.0 or 6.5.

pH buffering capacity: the soil's ability to resist a change in its pH level, and is largely determined by the soil texture

phospholipids: a class of lipids that are a major component of all cell membranes.

Phosphorus Buffering Index: The amount of P absorbed or desorbed per unit change in solution.

Phosphorus Environmental Risk Index: Ratio of Colwell P / PBI, an indicator of risk to possible leaching in to waterways and environmental damage. The number should be < 0.65 to be safe for production.

photosynthesis: a process used by plants and other autotrophic organisms to convert light energy into chemical energy that can be used to fuel the organisms' activities. Carbohydrates, such as sugars, are synthesized from carbon dioxide and water.

peds: groups of soil particles held together by organic matter or chemical forces.



Glossary

permanent pastures: pasture of perennial or self-seeding annual plants maintained through several years of grazing.

plagioclase: any of the feldspar minerals, varying in composition from $\text{NaAlSi}_3\text{O}_8$ to $\text{CaAl}_2\text{Si}_2\text{O}_8$.

plant tissue tests: an assessment of the nutrient content of a plant by testing a sample of tissue from that plant.

plastic limit: The plastic limit is the soil water content at which the soil becomes 'plastic' and capable of being deformed when external force is applied. Soil compaction due to deformation results in a reduction in porosity and pore size, and when dry, the compacted soil presents a barrier to root penetration.

plasticity: the property of a soil that allows you to mould the soil when it is moist into various forms by applying pressure; when the pressure is released, the material will retain its moulded form.

podosol: an infertile, difficult-to-cultivate, acidic forest soil, with a grey-white upper layer leached of colloids and iron and aluminium compounds and a brownish lower layer where the colloids and iron and aluminium compounds have accumulated. It is a common soil in eastern Australia.

point source: a single identifiable localised source of pollution

pores: the spaces in the soil.

porosity: the amount of pore space (air gaps) in a soil. The percentage of the total space between solid particles.

primary salinity: salinity occurring naturally in soil or water.

precipitation: the formation of a suspension of an insoluble compound by mixing two solutions

predator: an organism that lives by preying on other organisms

profile: a vertical slice through the soil from the soil surface down through the horizons to or including the parent material.

proliferation: to grow or multiply by rapidly producing new tissue, parts, cells, or offspring.

Pugging: structural damage to soils caused by penetration of animal hooves in wet conditions.

R

Ramsar Convention: an international treaty for the conservation and sustainable utilisation of wetlands.

readily available water (RAW): the water that plants can easily extract from the soil.

recalcitrant carbon: biologically stable carbon; typically in the form of charcoal.

recent: pertaining to the later division of the Quaternary period, succeeding the Pleistocene, and regarded as the present or existing geological division.

relief, or terrain: the vertical and horizontal dimension of land surface usually expressed in terms of the elevation, slope, and orientation of terrain features.

replicated trial: repetition of a research trial plots.

refill point: The water content of the soil below which the plant exhibits some form of stress, and a drop in yield.

residual soils: soils that develop from their underlying parent rocks and have the same general chemistry as those rocks.

respiration: the transport of oxygen from the outside air to the cells within tissues, and the transport of carbon dioxide in the opposite direction.

rhizobacteria: root-colonising bacteria that form a symbiotic relationship with legumes.

rhizobia: soil bacteria that fix nitrogen after becoming established inside root nodules of legumes

rhizosphere: root zone

riparian buffer / buffer strip: a vegetated area near a stream which helps to protect a stream from the impact of adjacent land uses.

riparian zone: a riparian zone or riparian area is the interface between land and a river or stream.

root mat layer: similarly defined as the thatch layer except it is generally in a more decomposed state because of the inclusion of soil or a mineral component.



Glossary

S

S: symbol for the element sulphur.

saline soils: soils that have a salt concentration in the surface soil that is sufficient to interfere seriously with the growth of plants.

salinity: a measure of the total soluble salts in a soil or in water. Salinity levels of a soil or water can be measured using electrical conductivity.

Salt: Any of a large class of chemical compounds formed when a positively charged ion (a cation) bonds with a negatively charged ion (an anion), as when a halogen bonds with a metal. Salts are water soluble; when dissolved, the ions are freed from each other, and the electrical conductivity of the water is increased.

saprophytic: live on dead organic matter.

Se: symbol for the element selenium.

secondary salinity: salinity resulting from human activities, usually land development and agriculture.

sedentary: native to the site

seedset: fertilised ovules that mature into viable seeds.

settleable: the tendency of suspended solids to settle

sequential: occurring in a consecutive order.

shandied: mixed

sheet erosion: occurs when a relatively uniform layer of topsoil is removed by raindrop splash or water run-off

shelter belt: a plantation usually made up of one or more rows of trees or shrubs planted in such a manner as to provide shelter from the wind and to protect soil from erosion. They are commonly planted around the edges of fields on farms.

silicate: any salt derived from the silicic acids or from silica.

slake: the breaking down of soil aggregates when immersed in water.

slaking: the breaking down of soil aggregates when immersed in water.

slickensides: a subsoil structural feature that develops as a result of two masses moving

past each other, polishing and smoothing the surfaces; common in vertosols.

sludge: the semisolid sediment precipitated from dairy effluent

SOC: soil organic carbon

sodicity: a measure of exchangeable sodium in relation to other exchangeable cations. It is expressed as the exchangeable sodium percentage (ESP). A soil with an ESP greater than 6 is considered to be sodic, and this level may interfere with plant growth.

sodic soil: sodic soils are characterised by a disproportionately high concentration of Sodium (Na) in their cation exchange complex.

sodosol: a soil with a clear or abrupt change between the A and B horizon; the B horizon is sodic; the B2 horizon is not subplastic.

soil amendment: a material added to soil to improve soil condition and /or plant growth.

soil characteristics: physical chemical and biological properties pertaining to a particular soil.

soil constraints: soil properties that negatively influence both soil function and productivity.

soil creep: slow movement of soil down a slope due largely to gravitational forces or stock movements

soil fertility targets: the concentration of soil nutrients required for targeted pasture yields.

soil fertility trends: the change in soil fertility levels over a period of time..

soil properties: physical chemical and biological properties pertaining to a particular soil.

soil retention factor: nutrients held strongly or 'locked up' in the soil and its processes

soil solution: the soil water together with its dissolved salts (cations and anions). The soil solution is the medium by which most soil nutrients are supplied to growing plants. It also has a role in salinity and pH.

soil structure: describes the arrangement of the solid parts of the soil and of the pore space located between them



Glossary

soil test: the analysis of soil sample to determine nutrient content, composition and other characteristics, such as acidity or pH level.

soil texture: the relative proportions of various sized particles making up the soil. These particles include sand, silt and clay all which vary in size through a particular range.

soil types: the classification of a soil due to its formation which is influenced by parent material, climate, topography, organic activity and age.

soil water: the water (H₂O) held within the soil pores.

soil water budget: tracks the inputs and outputs of water in soil. At its simplest form it tracks actual evapotranspiration, potential evapotranspiration and precipitation across a year for a given location.

soluble: the property of a solid, liquid, or gaseous chemical substance called solute to dissolve in a solid, liquid, or gaseous solvent to form a homogeneous solution.

SOM: soil organic matter

sorb: fix to the soil

spinner cuts: drains that are used to help get water onto a flood irrigation bay, or to facilitate drainage off the bay

split applications: when fertiliser is applied in more than one application to match the nutrient demands of a growing crop or pasture.

Stand-off areas: alternate land areas which allow cows to be removed from wet paddocks when unacceptable damage is likely to occur from pugging.

stomata: a pore, found in the epidermis of leaves, stems and other organs that is used to control gas exchange.

sump: a low-lying place, such as a pit, that receives drainage

superphosphate: the most common form of phosphate fertiliser used in Australia: Ca(H₂PO₄)₂.

suspensions: mixture of two chemicals with the property that one does not rapidly settle out.

symbiosis: a relationship of mutual benefit or dependence.

symbiotic fixation: the taking in of nitrogen by the bacteria in the nodules of legumes for use by the host plant. Symbiotic means both the plant and bacteria benefit from the association.

T

Tertiary: pertaining to a geological period or system of rocks that precedes the Quaternary and constitutes the earliest principal division of the Cainozoic era.

test strip: a strip of fertiliser spread in an otherwise unfertilised paddock.

thatch layer: a tightly intermingled layer of living and dead stems, leaves and roots which accumulates between the layer of actively-growing grass and the soil underneath.

tile drain: a drain constructed of perforated plastic or ceramic pipes layed underground.

tillering: refers to the production of side shoots and is a property possessed by many species in the family Poaceae (grasses).

topdressing: a covering of fertiliser or manure spread on soil without being ploughed under.

transpiration: the evaporation of water from aerial parts of plants, especially from leaves but also from stems and flowers.

triple-super: a widely used phosphate fertiliser: CaHPO₄.

Topdressing:

topography: the recording of relief or terrain representing the three-dimensional quality of the surface and identifies landforms.

total mixed ration: the practice of weighing and blending all feedstuffs into a complete ration which provides adequate nourishment to meet the needs of dairy cows.

total soluble salts: a measure of the soluble salts in the soil (mainly sodium, chloride, sulphate and carbonate) (See also electrical conductivity or salinity.)

transpire: to give off water vapour through the stomata (leaf pores)

TSS: see total soluble salts.



Glossary

tunnel erosion: occurs when water scouring or seeping through dispersive subsoils forms underground tunnels

turgor: the distension of the protoplasmic layer and wall of a plant cell by the fluid contents.

Tying: where the sub-soil is loosened using a ripper tyne

U

uniform profile: a soil with little, if any, texture change down the profile.

Unimproved pasture: a native pasture with no introduced productive pasture species.

V

vascular system: the tissue that carries sap through the plant.

venation: distribution or arrangement of a system of veins, as in a leaf blade.

vertosol: a clay soil with shrinking and swelling properties, which displays strong cracks when dry and has slickensides or lenticular structural aggregates at depth.

vesicular: a small, usually spherical cavity in a rock or mineral caused by gas or vapour. (*Compare with massive.*)

volatilisation: conversion of nitrogen to gaseous forms, which are lost to the atmosphere.

VS: volatile solids

W

Walkley and Black test: used for the determination of the percentage by dry mass of organic matter in a soil sample

water holding capacity: the specific ability of a particular type of soil to hold water against the force of gravity.

water logging: a condition where the soil is so wet that there is insufficient oxygen in the pore space for plant roots to be able to adequately respire.

watertable: the level below which the ground is saturated with water.

whoa boys: low profile, trafficable earth banks that intercept runoff flowing down roads and tracks, carrying it safely to a stable outlet.

whole-farm plan: a plan for farm design and management based on natural resources and economic factors.

wilting point: the amount of water remaining in the soil when a plant wilts and does not respond to added water.

Z

Zn: symbol for the element zinc.



Appendix A – Conversion Tables

Appendix A contains conversion tables for fertiliser application rates, weights, and areas.

Table A.1 Fertiliser application rate conversions

| kg/ha | kg/acre | cwt/acre | Small bag/ha | Small bag/acre |
|----------------|---------|----------|--------------|----------------|
| 50 | 20 | | 1 | 0.4 |
| 100 | 40 | | 2 | 0.8 |
| 125 | 50 | 1 | 2.5 | 1 |
| 150 | 60 | | 3 | 1.2 |
| 175 | 70 | | 3.5 | 1.4 |
| 200 | 81 | | 4 | 1.6 |
| 225 | 90 | | 4.5 | 1.8 |
| 250 | 100 | 2 | 5 | 2 |
| 275 | 110 | | 5.5 | 2.2 |
| 300 | 120 | | 6 | 2.4 |
| 350 | 140 | | 7 | 2.8 |
| 375 | 150 | 3 | 7.5 | 3 |
| 400 | 160 | | 8.5 | 3.2 |
| 450 | 180 | | 9 | 3.6 |
| 500 | 200 | 4 | 10 | 4 |
| 550 | 220 | | 11 | 4.4 |
| 600 | 240 | | 12 | 4.8 |
| 625 | 250 | 5 | 12.5 | 5 |
| 650 | 260 | | 13 | 5.2 |
| 700 | 280 | | 14 | 5.6 |
| 800 | 320 | | 16 | 6.4 |
| 900 | 360 | | 19 | 7.2 |
| 1000 (1 tonne) | 400 | 8 | 20 | 8 |

**Table A.2** Weight conversions

| This Weight | Equals This Weight |
|---------------|------------------------------|
| 1 kg | 2.2 lbs |
| 1 lb | 0.45 kg |
| 1000 kg | 1 metric tonne or 2200 lbs |
| 1 cwt | 50 kg or 112 lbs |
| 1 large bag | 84.3 kg or 186 lbs |
| 1 small bag | 50 kg or 112 lbs |
| 20 small bags | 1 tonne, 1000 kg or 2200 lbs |
| 10 lbs/acre | 11 kg/ha |

Table A.3 Area conversions

| This Area | Equals This Area |
|-----------|----------------------|
| 1 hectare | 2.47 acres |
| 1 acre | 0.4 hectares |
| 1 hectare | 10,000 square metres |

Online metric conversions: <http://www.measurement.gov.au/Pages/MetricConversion.aspx>



Appendix B – Explanatory Notes on the Metric System

Often people do not realise the connections between the units in the metric system. The meaning of the prefixes centi and milli, which should make the system easy to use, are lost on many adults who have never had the opportunity to learn about or discuss the new system. Many people will buy 600 mL of milk without ever realising that mL is an abbreviation of millilitre or that it is in any way connected to a litre measure.

A prefix at the start of a word often gives a clue to the meaning of the word. The prefix is a short descriptive word or abbreviation at the beginning of a word that adds to or qualifies its meaning.

A word like cent means one hundred, for example:

| | |
|------------|--|
| Cent: | 100 cents in a dollar |
| Century: | 100 years in a century 100 runs in a century in cricket |
| Centipede: | 100 legs on a centipede. |

Once this use of the prefix is understood the use of milli, as a thousandth part (1/1000) is easier to comprehend. Words like millimetre, millilitre and milligram all suddenly start to make sense.

| | |
|--------------|---|
| Millimetre : | one thousandth of a metre. There are 1000 millimetres in one metre. |
| Millilitre : | one thousandth of a litre. There are 1000 millilitres in one litre. |
| Milligram: | one thousandth of a gram. There are 1000 milligrams in one gram. |

Another common prefix is kilo. This is a prefix for one thousand. So therefore a:

| | |
|------------|-----------------|
| Kilometre: | is 1000 metres. |
| Kilogram: | is 1000 grams. |
| Kilolitre: | is 1000 litres. |

Other common prefixes to describe other measurements that farmers use are:

| | |
|--------|---|
| Mega: | one million. A megalitre is a million litres or a megajoule is one million joules. |
| Hecto: | Ten thousand (10,000). A hectare is 10,000 square metres, or a 100-metre by 100-metre square. |



Some common conversions from Imperial to metric are:

- 2.47 acres = 1 hectare.
- 1 acre = 0.405 hectare.
- 0.39 inches = 1 centimetre.
- 1 inch = 2.54 centimetres.
- 39.37 inches = 1 metre.
- 1.09 yards = 1 metre.
- 1 yard = 0.914 metres.
- 0.621 miles = 1 kilometre.
- 1 mile = 1.61 kilometres.

Thinking Metric

For farmers who have grown up with the Imperial system one of the most important things to concentrate on is the ability to **think metric**. It is far less confusing if you can try to think in metric terms, the prefixes help you with how big or small the measurement is and you don't have to continually convert from one system to another. One of the most effective ways to think metric is to think of objects you know well as a reference point. For example, the length of your road might be close to 1 kilometre or you can visualise a milk carton as 1 litre or a plastic chemical drum as 25 litres. If you can begin to visualise other measures in the same way, and try to use them as often as you can then you're well on your way to thinking metric.



Appendix C – Chemical Symbols

| | |
|--|---|
| Al | symbol for the element aluminium |
| As | symbol for the element arsenic |
| B | symbol for the element boron |
| C | symbol for the element carbon |
| Ca | symbol for the element calcium |
| Ca(H₂PO₄)₂ | primary phosphate, or superphosphate, consisting of about 31% phosphates, 50% gypsum and 19% impurities of various kinds. |
| CaCl₂ | calcium chloride |
| CaCO₃ | calcium carbonate or the mineral calcite. |
| CAN | calcium ammonium nitrate, a fertiliser |
| Cd | symbol for the element cadmium |
| Co | symbol for the element cobalt |
| Cu | symbol for the element copper. |
| DAP | di-ammonium phosphate, a fertiliser |
| Fe | symbol for the element iron |
| Hg | symbol for the element mercury |
| K | symbol for the element Potassium |
| N | symbol for the element nitrogen |
| NaCl | sodium chloride |
| Ni | symbol for the element nickel |
| O | symbol for the element oxygen |
| OC | Symbol for Organic Carbon |
| P | symbol for the element phosphorus |
| Pb | symbol for the element lead |
| S | symbol for the element sulphur |
| Se | symbol for the element selenium |
| Zn | symbol for the element zinc |



Appendix D – Nutrient Level Tables

Table D.1 Desirable plant tissue levels in a dairy pasture for adequate production

| Nutrient | For Plant Growth(White Clover) | For Animal Health(Mixed Pasture) |
|------------------|--------------------------------|----------------------------------|
| Boron mg/kg | 20 – 40 | 15 – 25 |
| Calcium % | 0.4 – 0.5 | 0.8 – 1.2 |
| Chloride % | Up to 2 | Up to 2 |
| Cobalt mg/kg | 0.5 | 0.1 – 0.15 |
| Copper mg/kg | 6 – 12 | 10 – 12 |
| Iron mg/kg | 50 – 65 | 100 – 200 |
| Magnesium % | 0.18 – 0.2 | 0.2 – 0.3 |
| Manganese mg/kg | 24 – 30 | 40 – 50 |
| Molybdenum mg/kg | 0.15 – 1 | 1 |
| Nitrogen % | 3.3 – 5.5 | 4 – 5 |
| Phosphorus | 0.3 – 0.4 | 0.4 – 0.5 |
| Potassium | 1.9 – 2.4 | 2.5 – 3 |
| Sodium % | Up to 0.8 | 0.2 – 0.3 |
| Selenium mg/kg | Not Applicable | 0.1 – 0.15 |
| Sulphur % | 0.23 – 0.3 | 0.25 – 0.4 |
| Zinc mg/kg | 15 – 20 | 40 – 50 |



Table D.2 Seasonal Mineral Levels in Pasture and Dairy Cow Lactational Requirements (per day)

| Minerals | Plant Level | Cow Req. | Plant Level | Cow Req. | Plant Level | Cow Req. | Plant Level | Cow Req. |
|----------|-------------|-------------|-------------|-----------|-------------|------------|-------------|----------|
| | Spring | Early Lact. | Summer | Mid Lact. | Autumn | Late Lact. | Winter | Dry Cow |
| P % DM | 0.41 | 0.48 | 0.41 | 0.37 | 0.40 | 0.28 | 0.38 | 0.19 |
| K % DM | 2.27 | 1.00 | 2.73 | 0.90 | 2.61 | 0.90 | 2.38 | 0.65 |
| Ca % DM | 0.55 | 0.77 | 0.50 | 0.58 | 0.43 | 0.43 | 0.44 | 0.30 |
| Mg % DM | 0.32 | 0.25 | 0.32 | 0.20 | 0.28 | 0.20 | 0.30 | 0.16 |
| Na % DM | 0.47 | 0.18 | 0.18 | 0.18 | 0.24 | 0.18 | 0.34 | 0.10 |
| Cl % DM | 1.45 | 0.25 | 1.33 | 0.25 | 1.23 | 1.33 | 1.30 | 0.20 |
| S % DM | 0.24 | 0.25 | 0.34 | 0.20 | 0.30 | 0.20 | 0.26 | 0.16 |
| Mn ppm | 234 | 40 | 250 | 40 | 265 | 40 | 254 | 40 |
| Fe ppm | 545 | 50 | 339 | 50 | 440 | 50 | 541 | 50 |
| Cu ppm | 13 | 10 | 20 | 10 | 14 | 10 | 12 | 10 |
| Zn ppm | | 40 | 41 | 40 | 44 | 40 | 39 | 40 |
| Se ppm | | 0.3 | | 0.3 | | 0.3 | | 0.3 |
| I ppm | | 0.6 | | 0.6 | | 0.6 | | 0.6 |
| Co ppm | | 0.1 | | 0.1 | | 0.1 | | 0.1 |



Appendix F - Fertiliser Product Lists (Examples)

CSBP:

<http://www.csbp-fertilisers.com.au/fertiliser-products>

Growforce:

<http://www.growforce.com.au/>

Impact Fertilisers product list:

<http://www.impactfert.com.au/products/index.html>

Incitec Pivot Fertilisers:

<http://www.incitecpivotfertilisers.com.au/Products%20%20%20Services/Product%20by%20Location>

Summit Fertilisers:

http://www.summitfertz.com.au/product_analyses.html

Superfert Dongbu:

<http://www.superfert.com.au/fertiliser-products/product-range/>

Viterra Fertiliser product lists:

http://cdn-l.viterra.com/static/au/agri_products/fertiliser/pdf/Product_List.pdf

Wengfu Australia:

<http://www.wengfuaustralia.com/fertilisers.html>

Whitfert Pty Ltd:

<http://www.whitfert.com.au/products.aspx?MenuID=23>

Yara Nipro Liquid Product List:

<http://www.yaranipro.com.au/yara-nipro-product-list.pdf>



Appendix G – General Fertiliser Products

Table G1 Composition of Fertilisers and Soil Amendments (Australian Soil Fertility Manual, FIFA and CSIRO 2006)

| Fertilizer | Approximate percentage of principal elements | | | | |
|---|--|-------|-------|-------|-------|
| | N | P | K | S | Ca |
| Anhydrous ammonia | 82 | – | – | – | – |
| Aqua ammonia | 20.5 | – | – | – | – |
| Urea | 46 | – | – | – | – |
| Ammonium nitrate | 34 | – | – | – | – |
| Calcium ammonium nitrate | 21–27 | – | – | – | 8–14 |
| Calcium nitrate | 15.5 | – | – | – | 19 |
| Ammonium sulfate | 20–21 | – | – | 24 | – |
| Ammonium phosphate sulfate | 14–18 | 7–12 | – | 12–17 | – |
| Mono-ammonium phosphate (MAP) | 10–12 | 22 | – | 1–2 | – |
| Sulfur-coated MAP | 9 | 19 | – | 12 | 1.7 |
| Di-ammonium phosphate (DAP) | 18 | 20 | – | 1–3 | – |
| Sulfur-coated DAP | 16 | 18 | – | 12 | 0.6 |
| Sodium nitrate | 16 | – | – | – | – |
| Ground phosphate rock/reactive phosphate rock | – | 11–16 | – | – | 30–37 |
| Single superphosphate | – | 8.9 | – | 11 | 18–20 |
| Sulfur-fortified single superphosphate | – | 5–8 | – | 25–45 | 12–17 |
| Double/triple superphosphate | – | 17–20 | – | 1–4 | 15–16 |
| Sulfur-coated triple superphosphate | – | 16 | – | 20 | 11.8 |
| Powdered sulfur | – | – | – | 100 | – |
| Gypsum | – | – | – | 10–18 | 12–20 |
| Lime | – | – | – | – | 35–40 |
| Dolomite (8–13% magnesium) | – | – | – | – | 16–21 |
| Potassium chloride (muriate of potash) | – | – | 48–51 | – | – |
| Potassium nitrate | 13 | – | 37–38 | – | – |
| Potassium sulfate (sulfate of potash) | – | – | 40–42 | 16 | – |
| Blood and bone | 4–7 | 3–9 | – | – | 8–15 |



Appendix H – Feed nutrient contents

Table H.1 Feed nutrient contents (adapted from DPIV Ellinbank Nutrient Budgetor, 2011).

| Feed Type | DM% | ME | CP% Mean | N% Mean | P% Mean | K% Mean | S% Mean | Ca% Mean | Mg% Mean |
|----------------------------|------|-------|-------------|------------|------------|------------|------------|-------------|-------------|
| Canola silage | 24 | 9.45 | 17.2 | 2.75 | 0.3 | 2.88 | 0.51 | 0.97 | 0.36 |
| Average grain | 90 | 12.27 | 14.92 | 2.39 | 0.36 | 0.55 | 0.16 | 0.12 | 0.17 |
| Grain + Minerals | 90 | 12.58 | 16.93 | 2.71 | 0.58 | 0.58 | 0.23 | 0.75 | 0.36 |
| Average hay | 86 | 8.43 | 13.63 | 2.18 | 0.29 | 2 | 0.22 | 0.69 | 0.32 |
| Average silage | 46.5 | 9.096 | 13.234 | 2.117 | 0.324 | 2.046 | 0.215 | 0.664 | 0.251 |
| Almond shells | 78 | 9.4 | 5.45 | 0.87 | 0.2 | 2.96 | 0.03 | 0.29 | 0.11 |
| Annual pasture (Rye grass) | | 10.34 | 23.35 | 3.74 | 0.55 | 2.33 | 0.28 | 0.79 | 0.24 |
| Barley grain | 90 | 12.33 | 11.98 | 1.92 | 0.36 | 0.53 | 0.13 | 0.05 | 0.13 |
| Brassica crop | 22 | 10.79 | 19 | 3.04 | 0.29 | 3.05 | 0.62 | 1.49 | 0.52 |
| Bread | 60 | 13.19 | 17.93 | 2.87 | 0.29 | 0.31 | 0.2 | 0.23 | 0.07 |
| Brewers grain | 58 | 11.29 | 23.63 | 3.78 | 0.68 | 0.42 | 0.28 | 0.16 | 0.23 |
| Canola hay | 83 | 9.06 | 16.63 | 2.66 | 0.31 | 2.41 | 0.53 | 0.81 | 0.38 |
| Canola meal | 90 | 12.97 | 38.48 | 6.16 | 1.14 | 1.34 | 0.7 | 0.62 | 0.55 |
| Cereal hay | 85 | 8.69 | 10.38 | 1.66 | 0.2 | 1.73 | 0.16 | 0.23 | 0.14 |
| Cereal pasture | 17 | 12.92 | | | 0.52 | 4.47 | 0.43 | 0.28 | 0.2 |
| Cereal silage | 45 | 9.07 | 11.01 | 1.76 | 0.32 | 1.9 | 0.18 | 0.28 | 0.19 |
| Cereal straw | 86 | 5.97 | 4.04 | 0.65 | 0.1 | 1.2 | 0.09 | 0.22 | 0.11 |
| Citrus pulp | 16 | 10.11 | 8.47 | 1.36 | 0.23 | 1.13 | 0.11 | 0.91 | 0.14 |
| Clover hay | 90 | 9.12 | 18.35 | 2.94 | 0.39 | 2.62 | 0.18 | 1.35 | 0.24 |
| Corn grain | 90 | 12.87 | 9.67 | 1.55 | 0.31 | 0.37 | 0.11 | 0.01 | 0.12 |
| Cotton seed meal | 89 | 11.64 | 50.4 | 8.06 | 1.41 | 1.61 | 0.53 | 0.27 | 0.75 |
| Forage blend | 87 | 8.82 | 12.06 | 1.93 | 0.35 | 1.75 | 0.2 | 0.56 | 0.2 |
| Fruit | 4 | 11.6 | 17.85 | 2.86 | 0.49 | 4.34 | 0.22 | 0.15 | 0.22 |
| Grain husks | 89 | 13 | 19.4 | 3.1 | 1.24 | 1.38 | 0.21 | 0.1 | 0.48 |
| Kikuyu pasture | 30 | 9.82 | 20.37 | 3.26 | 0.42 | 2.99 | 0.27 | 0.53 | 0.33 |
| Kikuyu silage | 58 | 10.16 | 10.6 | 1.7 | 0.39 | 1.85 | 0.13 | 0.19 | 0.16 |
| Legume pasture | | 11.88 | 28.7 | 4.59 | 0.67 | 2.47 | 0.21 | 2.22 | 0.29 |
| Linseed meal | 91 | 10.75 | 0.93 | 0.15 | 0.54 | 0.85 | 0.29 | 0.2 | 0.41 |
| Lucerne hay | 86 | 9.63 | 21.4 | 3.42 | 0.36 | 2.08 | 0.28 | 1.25 | 0.39 |
| Lucerne pasture | 24 | 10.8 | 27.4 | 4.38 | 0.46 | 1.72 | 0.38 | 1.45 | 0.45 |
| Lucerne silage | 56 | 9.33 | 19.77 | 3.16 | 0.42 | 2.15 | 0.28 | 0.98 | 0.52 |
| Lucerne&orghum pasture | | 10.88 | 26.25 | 4.2 | 0.38 | 2.34 | 0.36 | 0.87 | 0.47 |
| Lupins grain | 89 | 13.55 | 26.69 | 4.27 | 0.38 | 0.82 | 0.2 | 0.25 | 0.17 |
| Maize silage | 37 | 9.76 | 7.56 | 1.21 | 0.26 | 0.99 | 0.1 | 0.19 | 0.19 |
| Milk Vat | | 5.5 | 3.305 | 0.522 | 0.091 | 0.142 | 0.038 | 0.113 | 0.011 |
| Millet crop | | 9.76 | 18.65 | 2.98 | 0.29 | 3.58 | 0.44 | 0.53 | 0.6 |
| Mineral additive | 91 | 9.77 | 16.47 | 2.64 | 1.67 | 0.55 | 1.03 | 7.74 | 2.96 |
| Mix Beef | 74 | 12.59 | 17.75 | 2.84 | 0.72 | 0.64 | 0.27 | 1.05 | 0.64 |



| | | | | | | | | | |
|-----------------------|----|-------|-------|------|-------|--------|--------|--------|--------|
| Mix Calf | 89 | 12.22 | 19.07 | 2.84 | 0.59 | 0.78 | 0.24 | 0.95 | 0.34 |
| Mixed grain | 89 | 12.46 | 14.65 | 2.34 | 0.38 | 0.55 | 0.17 | 0.2 | 0.19 |
| Molasses | 72 | 12.7 | 4 | 0.64 | 0.23 | 4.68 | 0.5 | 1 | 0.37 |
| Oat Hay | 86 | 8.41 | 8.61 | 1.38 | 0.2 | 1.72 | 0.14 | 0.24 | 0.15 |
| Oats & peas silage | 48 | 9.16 | 14.1 | 2.26 | 0.39 | 2.43 | 0.2 | 1.88 | 0.18 |
| Oats grain | 91 | 12.64 | 10.7 | 1.71 | 0.35 | 0.54 | 0.15 | 0.04 | 0.13 |
| Oats pasture | | 11.53 | 33.1 | 5.3 | 0.95 | 5.94 | 0.35 | 0.53 | 0.31 |
| Palm kernels | 89 | 7.92 | 16.2 | 2.59 | 0.65 | 0.69 | 0.21 | 0.41 | 0.32 |
| Paspalum silage | 53 | 8.21 | 11.93 | 1.91 | 0.32 | 2.06 | 0.18 | 0.71 | 0.25 |
| Pasture hay | 84 | 8.06 | 10.41 | 1.67 | 0.25 | 1.7 | 0.21 | 0.48 | 0.2 |
| Pasture silage | 44 | 9.22 | 16.37 | 2.62 | 0.38 | 2.74 | 0.28 | 0.59 | 0.24 |
| Pea pollard | 90 | 9.87 | 13.2 | 2.11 | 0.25 | 0.96 | 0.1 | 0.34 | 0.26 |
| Pellets Calf | 88 | 12.88 | 19.52 | 3.12 | 0.63 | 0.81 | 0.26 | 1.43 | 0.33 |
| Pellets Dairy | 89 | 12.37 | 15.31 | 2.39 | 0.59 | 0.63 | 0.21 | 1.49 | 0.5 |
| Pellets Springer | 87 | 12.62 | 16.03 | 2.56 | 0.58 | 0.65 | 1.08 | 1.16 | 0.7 |
| Pellets Weaner | 89 | 12.9 | 16.84 | 2.69 | 0.77 | 0.76 | 0.35 | 1.68 | 0.33 |
| Prairie grass silage | 64 | 8.51 | 11.9 | 1.9 | 0.19 | 1.3 | 0.14 | 0.69 | 0.27 |
| Ryegrass pasture | 20 | 10.47 | 23.28 | 3.71 | 0.45 | 2.8 | 0.34 | 0.55 | 0.29 |
| Safflower grain | 91 | 9 | 16.8 | 2.69 | 0.47 | 0.69 | 0.15 | 0.24 | 0.24 |
| Setaria silage | 36 | 8.09 | 11.9 | 1.9 | 0.27 | 2.16 | 0.15 | 0.16 | 0.15 |
| Sorghum crop | 24 | 8.97 | 14.48 | 2.32 | 0.4 | 2.56 | 0.15 | 0.45 | 0.62 |
| Sorghum grain | 87 | 12.63 | 11.05 | 1.77 | 0.32 | 0.33 | 0.17 | 0.08 | 0.2 |
| Sorghum hay | 88 | 7.74 | 12.37 | 1.98 | 0.35 | 1.9 | 0.13 | 0.57 | 0.76 |
| Sorghum/millet hay | 84 | 7.84 | 9.55 | 1.53 | 0.39 | 2 | 0.22 | 0.38 | 0.39 |
| Sorghum/millet silage | 24 | 7.53 | 7.8 | 1.25 | 0.32 | 2.3 | 0.24 | 0.38 | 0.35 |
| Soybean meal | 92 | 14.65 | 46.12 | 7.38 | 0.78 | 2.37 | 0.39 | 0.28 | 0.31 |
| Sugar | 96 | 12.5 | 0 | 0 | 0.107 | 0.0366 | 0.0214 | 0.0412 | 0.0038 |
| Triticale grain | 90 | 12.69 | 13.49 | 2.16 | 0.3 | 0.48 | 0.16 | 0.04 | 0.13 |
| Turnips crop | | 10.81 | 13.1 | 2.1 | 0.27 | 2.91 | 0.55 | 0.95 | 0.3 |
| Vetch hay | 84 | 10.03 | 21.34 | 3.41 | 0.28 | 2.41 | 0.23 | 0.91 | 0.27 |
| Wheat grain | 89 | 12.87 | 14.03 | 2.24 | 0.34 | 0.43 | 0.16 | 0.05 | 0.13 |