Chapter 12
Nitrogen and Nitrogen Fertilisers

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12 Nitrogen and Nitrogen Fertilisers

12.1 Introduction

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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.

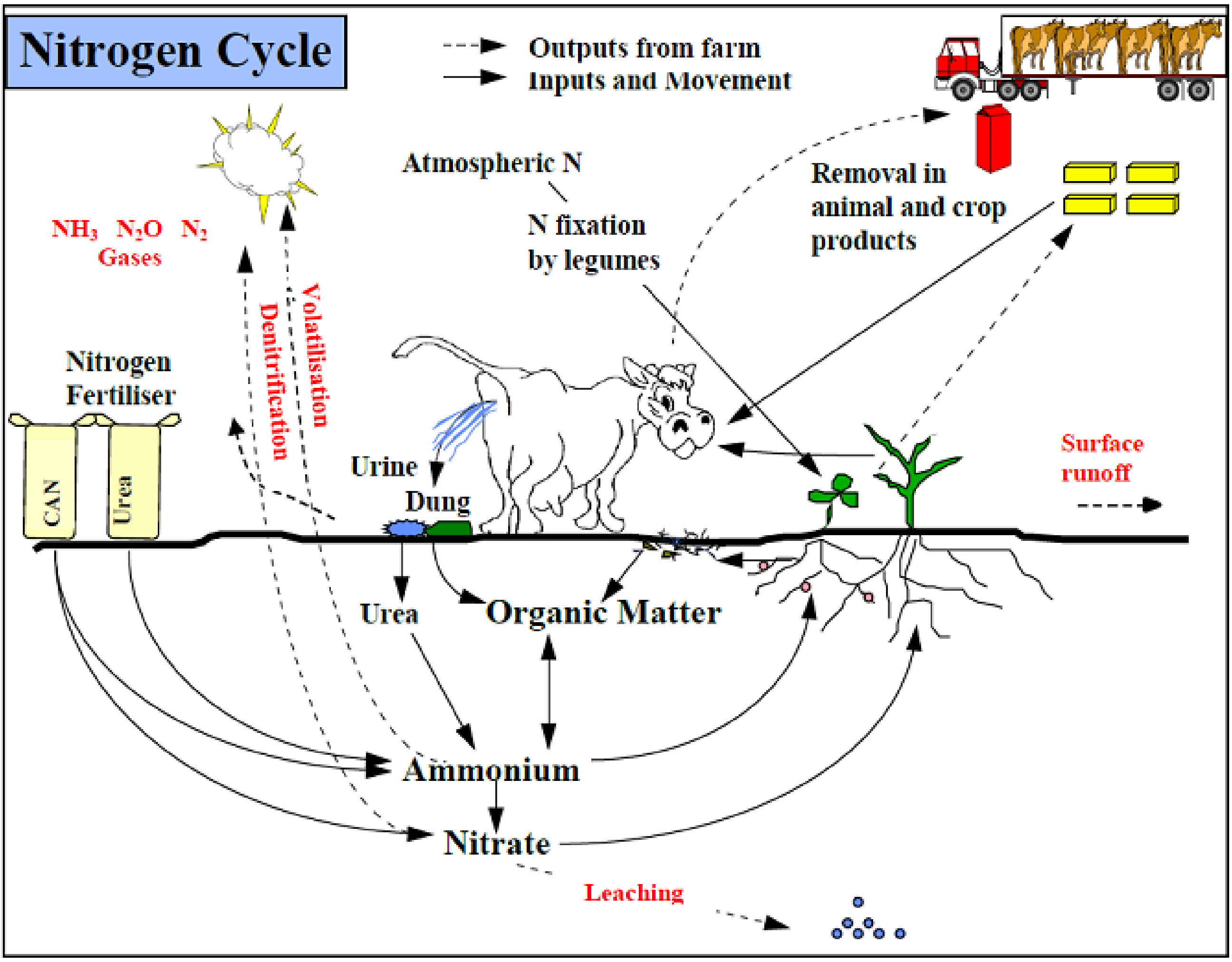

Figure 12.1 Summarised version of a nitrogen cycle in a dairy pasture system. Red labels represent N is lost to the environment.

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 is 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).

Crude protein (% DM) = total N concentration (%) x 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.

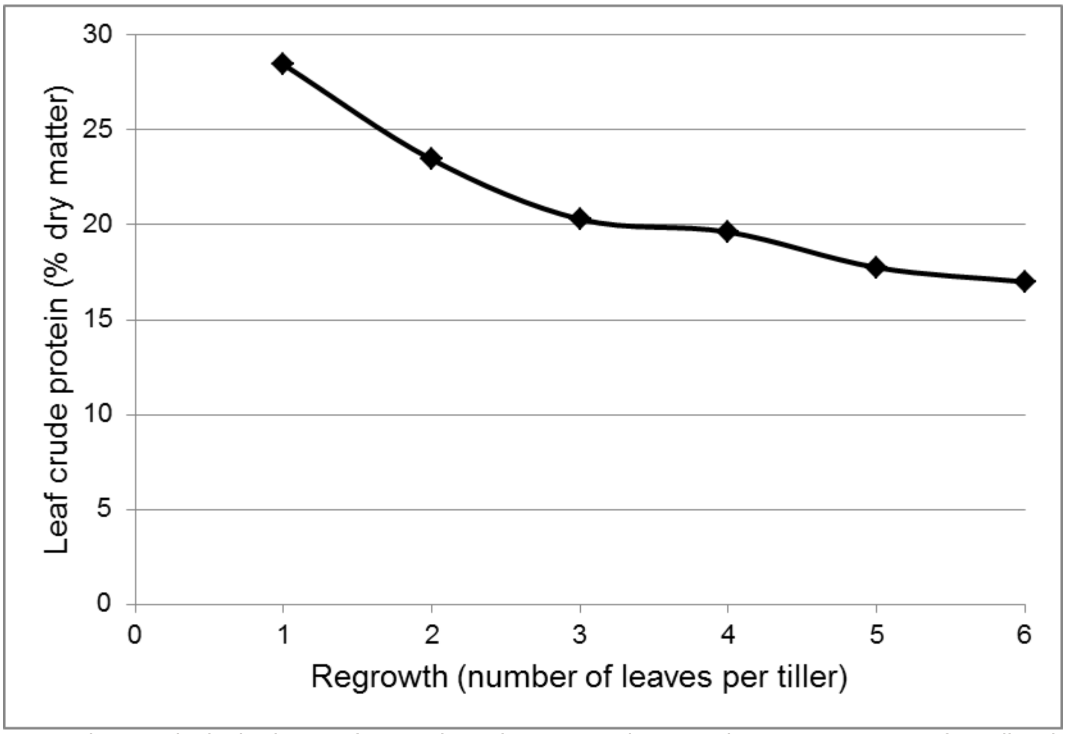

Figure 12.2 Crude protein in herbage of grass-based pastures (averaged across a range of studies investigating perennial ryegrass (Fulkerson *et al*. 1998), tall fescue (Donaghy *et al*. 2008), cocksfoot (Rawnsley *et al*. 2002), prairie grass (Turner *et al*. 2006) and kikuyu (Reeves *et al*. 1996). 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 approximately108 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, were 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.

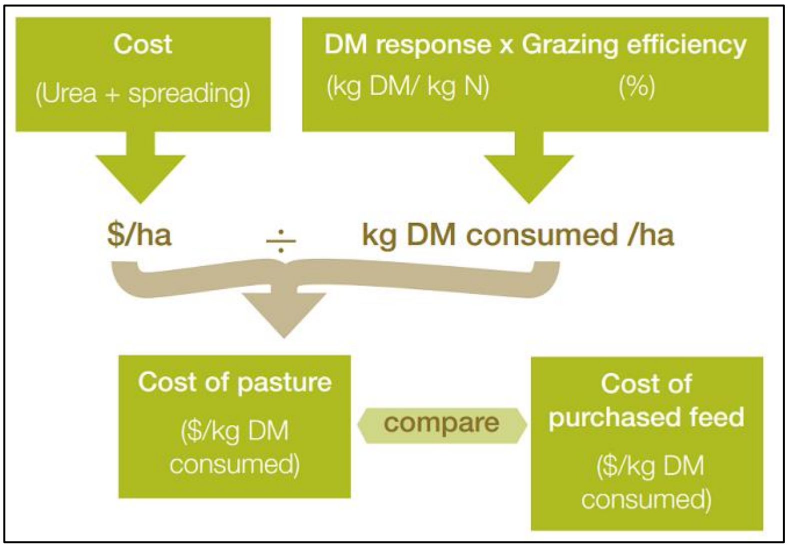

Figure 12.3 Things to consider when assessing the economics of N fertiliser application.
Source: 3030 Project (Perennial ryegrass management: V. Use of N fertiliser).

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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