Guidelines for

NITROGEN FERTILISER USE ON IRRIGATED PERENNIAL PASTURES

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Disclaimer

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CONTENTS

1. INTRODUCTION

Applications of nitrogen (N) fertiliser to increase the amount of pasture grown are an accepted management practice on many irrigated dairy farms. On these farms, perennial pastures are broadly considered to be of two types: pastures dominated with perennial ryegrass or pastures dominated by paspalum in summer. Ryegrass pastures usually contain a higher clover content than paspalum pastures and these two grasses have different patterns of growth and also physiological habits. Many of the principles of using N fertiliser are not affected by differences between pasture types. However, differences in growth patterns of these two pastures can impact on the likely effectiveness of N to increase production.

Nitrogen fertiliser is used to help fill expected feed gaps on dairy farms. Hence, dairy farmers need to establish if they require extra pasture to feed their herd before using nitrogen. They also need to know the likely increase in pasture production from applying this fertiliser.

This publication provides guidelines for using N fertiliser with irrigated pastures on dairy farms. While it is impossible to generalise on the profitability of N use across farms, the guidelines give a basis on which decisions can be made. Most of the information presented in this booklet has originated from nitrogen fertiliser research with irrigated perennial pastures conducted from the Kyabram Dairy Centre. The purpose of the booklet is to give readers an insight into the likely effects of nitrogen fertiliser on pasture and to illustrate some of the factors that should be taken into account when nitrogen is used as a management tool on dairy farms.

2. THE ROLE OF NITROGEN IN PASTURE

Nitrogen is essential for growth of pasture plants and its concentration in these plants can be as high as 4-5 % of dry matter (DM). Ryegrass-white clover pastures usually contain between 2.5-4 %N, while paspalum pastures may only contain 2-3 %N in DM.

Fertile soils contain large amounts of N in organic matter ("plant and animal residues, animal excreta and humified soil organic matter" (Whitehead 1995)); this nitrogen is not able to be taken up by pasture. However, plant available N is formed by the microbial break down of these organic compounds with the release of N in ammonium forms, a process called **mineralisation**. Some of this ammonium is converted to nitrate-N in a process called **nitrification**. Pasture plants, both grasses and clovers absorb N as ammonium and nitrate through their roots and use it to grow and make the green pigment chlorophyll and plant proteins. These processes are influenced by both soil water availability and temperature.

The amount of plant available N in soil at any one time (the ammonium and nitrate pools) is usually relatively low under irrigated perennial pasture, at 10-15 kg N/ha in the 0-30 cm horizon. The majority of this is in the ammonium form and the amount of nitrate can be as low as 1 kg N/ha. The rate of mineralisation of organic-N in soils can limit pasture growth, particularly the growth of grasses. When the available N supply is less than that required for potential grass growth, the grass will respond to N fertiliser.

Clovers are usually not as reliant on soil available N as grasses, because the nodules on their roots can absorb gaseous nitrogen (N_2) from the atmosphere. This is converted by *Rhizobium* bacteria, located in the nodules, to ammonia and subsequently other forms of plant N. This process is called **N_2 fixation**. While N_2 fixation often contributes up to 80-90 % to the N content of clover plants, they still use some soil N to meet their requirements. Clover based pastures can fix 200-300 kg N/ha each year (equivalent to about 430-650 kg urea/ha). However, in practice the amount of N_2 fixed by clover is largely dependent on the amount of clover in the pasture. The lower the clover content the lower is the amount of N_2 fixed. A schematic representation of N transformations in pastures is presented in Fig. 1. Losses of N shown in Fig. 1 are discussed later in the publication.

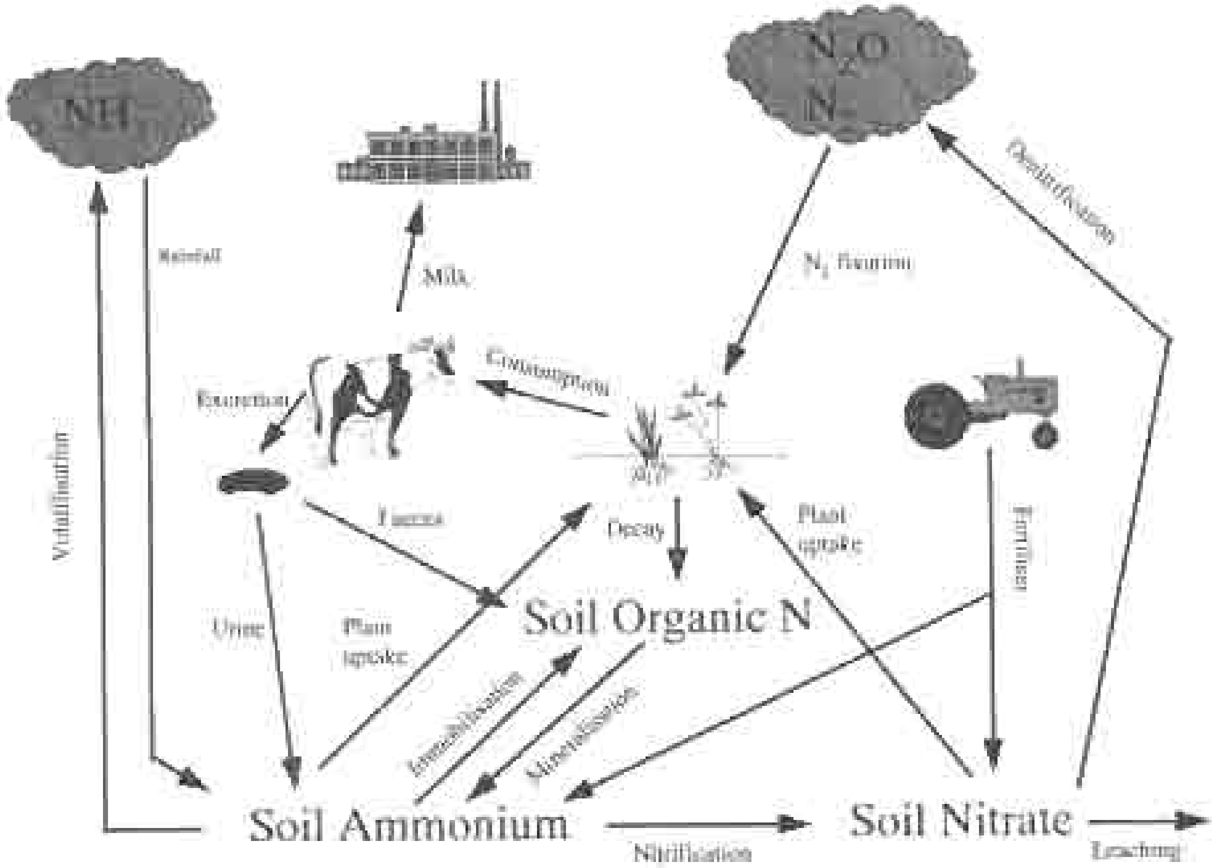

Fig. 1. Schematic representation of the nitrogen cycle in pastures.

An irrigated perennial pasture producing 16 t DM/ha in a year with an average N content of 3 % requires 480 kg N/ha. This is equivalent to over 1000 kg urea/ha. This N can come from soil available ammonium or nitrate, from N_2 fixed by legumes and from fertiliser. Dairy cows excrete up to 70-80% of the N they consume and hence much of this N is returned to pasture.

3. TYPES OF NITROGEN FERTILISER

Different fertilisers have different contents and ratios of essential elements, such as N, phosphorus (P), potassium (K) and sulphur (S). Product lists show the percentage of these elements in the various fertilisers (see Table 1). There are two types of fertiliser, namely the single chemical compound (can contain more than one element) fertilisers (eg urea, ammonium nitrate and di-ammonium phosphate (DAP)) and blended fertilisers that have been formulated from more than one chemical compound (eg. nitrogen, phosphorus, potassium, and sulphur blends, nitrogen and phosphorus blends and even nitrogen and nitrogen blends).

In northern Victoria, dairy farmers have traditionally applied single compound N fertilisers, usually urea or ammonium nitrate. However, recently there has been a large increase in the use of fertilisers that also provide other nutrients, such as P, with N as in DAP. The use of high analysis and blended fertilisers may increase on dairy farms, if they are a cost effective way of applying specific amounts of more than one element. However, urea and ammonium nitrate may be the most appropriate choice where multiple applications of N are used to increase pasture growth rates over several grazing rotations.

Table 1. Commonly available nitrogen fertilisers.

Fertiliser	Form of nitrogen	Nutrient content (%)		
		Nitrogen	Phosphorus	Sulphur
Urea	urea	46		
Ammonium nitrate	ammonium & nitrate	34		
Ammonium sulphate	ammonium	21		24
DAP	ammonium	18	20	1
DAP sulphur	ammonium	16	18	12
Grass boosta Grass Booster	ammonium & urea	30		15
MAP	ammonium	10	22	

There are reports that suggest that some forms of N are more effective for pasture growth than others. Generally, the choice of fertiliser should be made on price. This refers to cost per unit of N. However, where there are conditions that will adversely affect the performance of a particular fertiliser after application, these should be taken into account. For example, nitrate-N applied to pasture which frequently becomes waterlogged may have lower than expected benefits as large losses of N by denitrification in the soil can occur. Hence, other fertilisers may be more appropriate even at a higher cost. A more detailed explanation of N loss from pasture is given in Section 6.

3.1. Costing fertilisers

Fertilisers should be compared by expressing the cost of the fertiliser per unit of N. This is because the N content of different fertilisers is not the same.

Example a: If urea costs $440 per tonne and N content is 46%
N content per tonne = 10*46 = 460 kg
Cost per unit of N = 440/460 = $0.96 /kg N.

Example b: If ammonium nitrate costs $460 per tonne and N content is 34%
N content per tonne = 10*34 = 340 kg
Cost per unit of N = 460/340 = $1.35 /kg N.

In these examples, urea is cheaper per kg N than ammonium nitrate and would generally be the best choice. The examples are based on October 1997 prices and have not taken into account differences in cartage and spreading costs.

Where fertilisers supply other nutrients, such as P, the costs should be compared taking into account whether or not P is needed.

3.2. Estimating amounts of fertiliser to be applied

It is best to start by considering the amount of N to be applied to pasture (ie. kg N/ha) rather than the amount of fertiliser per ha. This is because recommendations are given as amounts of N to be applied and different fertilisers contain different amounts of N (Table 1). After deciding on the amount of N to be applied and on the type of fertiliser to be used then the amount of fertiliser actually put out by the spreader is easily calculated as follows:

Example a: To apply 50 kg N/ha as urea which contains 46% N
Urea applied/ha = 50*100/46 = 109 kg urea/ha (approx. two bags of urea/ha)

Example b: To apply 50 kg N/ha as ammonium nitrate which contains 34% N
Ammonium nitrate applied/ha = 50*100/34 = 147 kg ammonium nitrate/ha (approx. three bags of ammonium nitrate/ha)

So as to avoid confusion between the types of N fertilisers all future reference to the rate of N applied will be the **rate of elemental N as kg N/ha.**

4. STRATEGIC USE OF NITROGEN FERTILISER

Strategic applications of N fertiliser are used on dairy farms to increase pasture production and help reduce expected feed gaps. Therefore strategic N fertiliser use is defined as a single addition of N to boost pasture growth.

Strategic use of N is justified provided that extra pasture is needed for the herd, the pasture is likely to respond to applied N, and the extra pasture grown is consumed. Nevertheless the cost of producing the extra pasture with N must be cost effective when compared to using supplements.

It is generally accepted that on average the response by pasture to N will be 10 kg DM/kg N applied. While responses can vary widely, it is best to budget increased pasture yields on the average response, unless better predictions are available.

4.1. Pasture selection

The benefits of applying N are best with responsive pastures. Unfortunately a soil test is not presently available that can predict pasture responsiveness to N fertiliser. Indicators of responsive pastures are:

- Urine patches become obvious particularly after pasture topping.

- Pasture is grass dominant and/or the grass is pale green in colour.
- Pasture contains dominant grass species that are capable of growth.

4.2. Rate of application

Growth responses in N deficient pastures increase with the rate of N applied per hectare. However, responses usually obey the law of diminishing returns, such that efficiency decreases with increasing rates of N application (Fig. 2). For moderate rates of N (up to 50 or 60 kg N/ha) pasture responses to fertiliser can be assumed to be reasonably constant in terms of extra pasture grown per unit of applied N. On the other hand, high rates of applied N (100 kg /ha) are likely to initially produce more feed than moderate application rates, but at a lower efficiency.

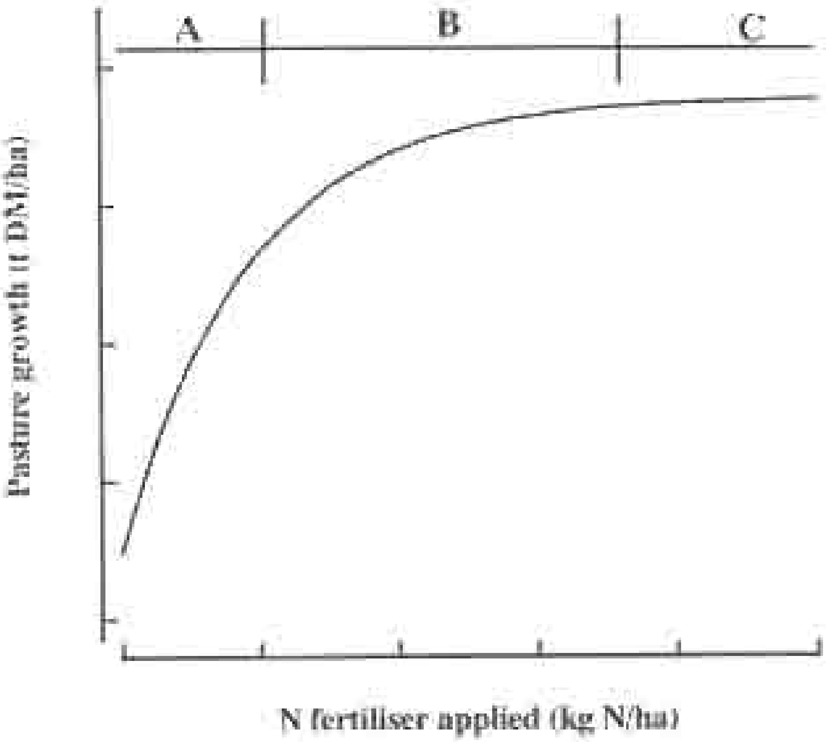

Fig. 2. Schematic representation of pasture growth responses (t DM/ha) to increasing amounts of N fertiliser applied. Initially (represented by A) the amount of pasture grown per unit of N applied is relatively constant. As N application increases beyond this phase (represented by B), the amount of pasture grown per unit of N applied decreases although actual growth rates still increase. Finally, there is essentially no further increase in actual pasture growth rate (represented by C).

The effect of N rate is illustrated with the comparison of pasture production after 50 kg or 100 kg N/ha were applied to perennial ryegrass-white clover pasture (Fig. 3 1). In the first 3 weeks after application, both application rates increased pasture growth. The efficiency when 50 kg N/ha was applied was 10 kg DM/kg N applied, while when 100 kg N/ha was applied the efficiency was 8 kg DM/kg N applied. In this study, the carryover effects on pasture after the first 3 weeks for 50 kg N/ha treatment were small as indicated by the parallel lines for this treatment and the control (0 kg N/ha).

Too much N applied, can adversely affect clover growth in mixed pastures. There was no adverse effect with 50 kg N/ha applied (Fig. 3.2), but when 100 kg N/ha was applied to the perennial ryegrass-white clover pasture, clover growth was depressed. This depressed clover growth explains the decline in cumulative DM production for the 100 compared to the 50 kg N/ha applications over the five harvests as shown in Fig. 3.1. The effect of the high N rate was not always large at each harvest, but the cumulative adverse effect over five harvests was significant.

These findings and those from other experiments indicate that low to moderate rates of N can be used to strategically increase pasture production without longer term adverse effects, especially on clover persistence and N_2 fixation.

In addition to increasing pasture growth, N fertiliser usually increases the N content of grass. However, the overall N content (%N) of the grass-clover pasture can often remain about the same as the unfertilised pasture, because after a N response, the pasture has a higher grass DM content.

Generally, 75% of a DM response to N occurs at the next grazing after the N is applied. Only when pastures are grossly deficient in N, could a relatively large carryover response be expected at the second grazing after N application.

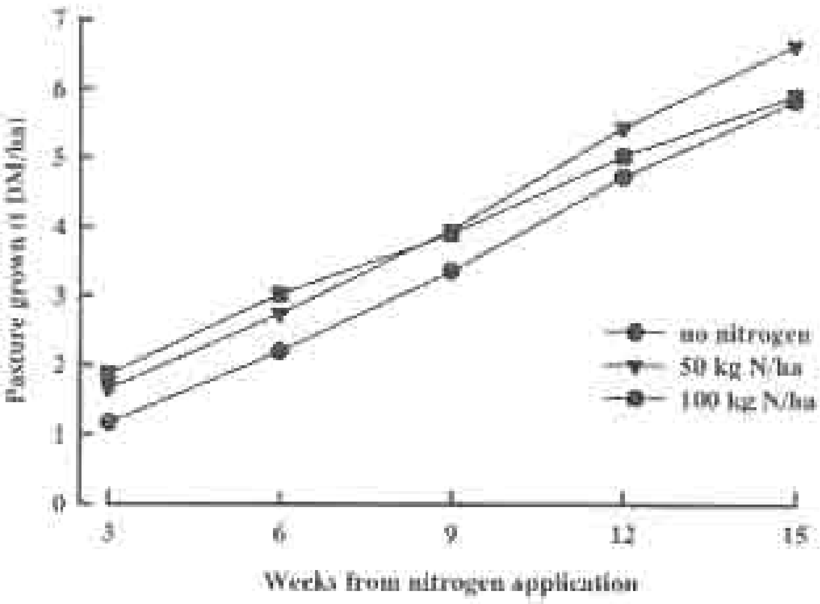

Fig. 3.1. Cumulative production of ryegrass-white clover pasture over 15 weeks following a strategic one off N application

The clover component of pasture is important to the N nutrition of pasture and also is a valuable component for milk production. N fertiliser can adversely affect clover in mixed pastures and any decision on N fertiliser use on pasture should aim to maintain clover persistence.

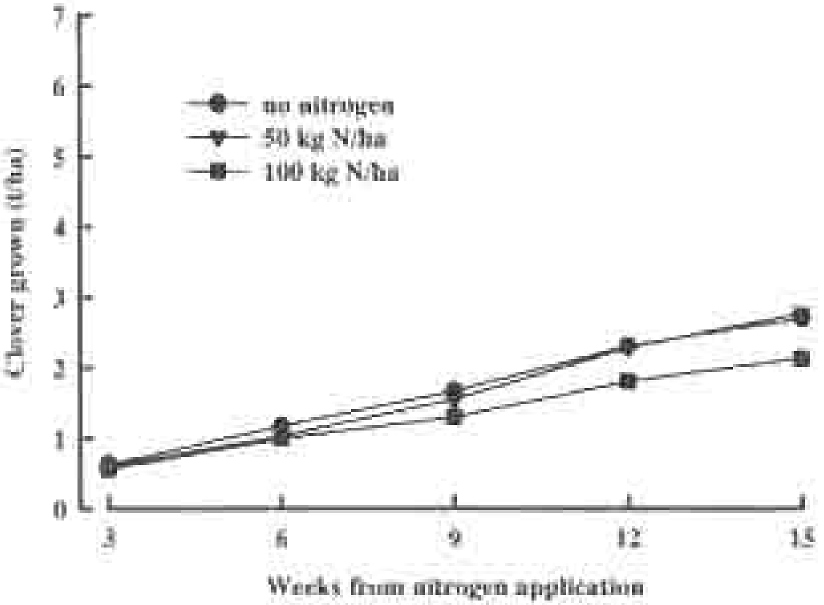

Fig. 3.2. Cumulative production of clover in a ryegrass-white clover pasture over 15 weeks following a one off strategic N application

4.3. Seasonal effects on pasture response

The two basic types of irrigated pastures (ryegrass-white clover and paspalum-white clover) have different seasonal growth patterns and therefore are likely to respond differently to N when it is applied at different times of the year.

a). Paspalum based pasture

Paspalum dominant pastures are most responsive to N during the late spring and summer months. During this period responses vary from 10 to 20 kg DM/kg N (Table 2). Nevertheless, economic responses to N can be obtained following application in late winter, providing there are sufficient other grass species (eg. perennial ryegrass) in the pasture that can grow well at that time of year.

The least likely effective time to apply N to paspalum is in the autumn/early winter period when pasture growth has slowed with the onset of cooler temperatures and shorter day lengths. During this period responses may only be 4 to 10 kg DM/kg N applied or less as winter approaches (Table 2).

Avoid using N on paspalum dominant pasture from March until late winter. At these times, N is better applied to ryegrass dominant pasture.

b). Perennial ryegrass based pasture

Although ryegrass pastures have seasonal growth patterns, these pastures will respond to N throughout the year. However, growth responses on these pastures can vary, both within and between seasons (Table 2). The density of the ryegrass can be a factor affecting the response. Typical responses by ryegrass are up to 15 kg DM/kg N in late winter and spring, whereas in summer and autumn responses of 10 kg DM/kg N can be achieved. Late autumn and early winter can be difficult times in which to apply N. This is because growth rates are much lower and so the time taken for a response to occur increases. Also, when the irrigation season finishes the incidence of rainfall influences when to apply the N, and the adequacy of soil water for plant growth which can affect the effectiveness of N to increase pasture growth.

As a general rule pastures respond best to N when N limits their potential to grow and the level of response will depend largely on the N deficiency at that time. Although most pasture will give a 10 to 1 response to N, more responsive pasture can achieve 20 or more to 1. Conversely, uneconomic responses can also occur as with paspalum dominant pastures in autumn-early winter. N fertiliser will change the botanical composition of pasture. Lower N application rates reduce potential changes in composition of pasture because the grasses are stimulated less than with heavier applications.

Table 2. A range of pasture responses (kg DM/kg N) obtained when a single application of 50 kg N/ha was applied to two pastures at different times of the year.

	Pasture type	
Season response required	**Ryegrass-white clover**	**Paspalum-white clover**
Winter	2-10	1-5
Spring	5-15	10-17
Summer	1-13	8-21
Autumn	2-10	4-10

The variable responses obtained within seasons occur for a range of reasons some of which are considered below.

4.4. Rotation Length

Rotational grazing of pastures is widely practised on irrigated dairy farms. The use of N is well suited to this form of pasture management because resting the pasture between grazings gives pasture time to respond to the applied fertiliser before it is grazed again.

The length of a pasture rotation affects the quantity of pasture grown within each rotation, but also can change the relative response to N. The effects of four defoliation intervals of paspalum pasture without N fertiliser, and with two rates of a single application of N as urea, on the total yield of pasture harvested over 60 days in summer are shown in Fig. 4.1.

In Fig. 4.1, there were 6 harvests for the 10 day rotation length and only 2 harvests for the 30 day rotation length. Clearly, the longer the interval between defoliations resulted in more pasture grown with or without N applied. The response to N for each rotation length (10, 15, 20 and 30 days) was 13, 17, 20 and 26 kg DM/kg N applied, respectively. The high response rates are because the study was conducted with paspalum pasture in summer.

When a pasture rotation is short, some loss of response to N fertiliser is likely and with marginally responsive pastures this could affect the economics of fertiliser use.

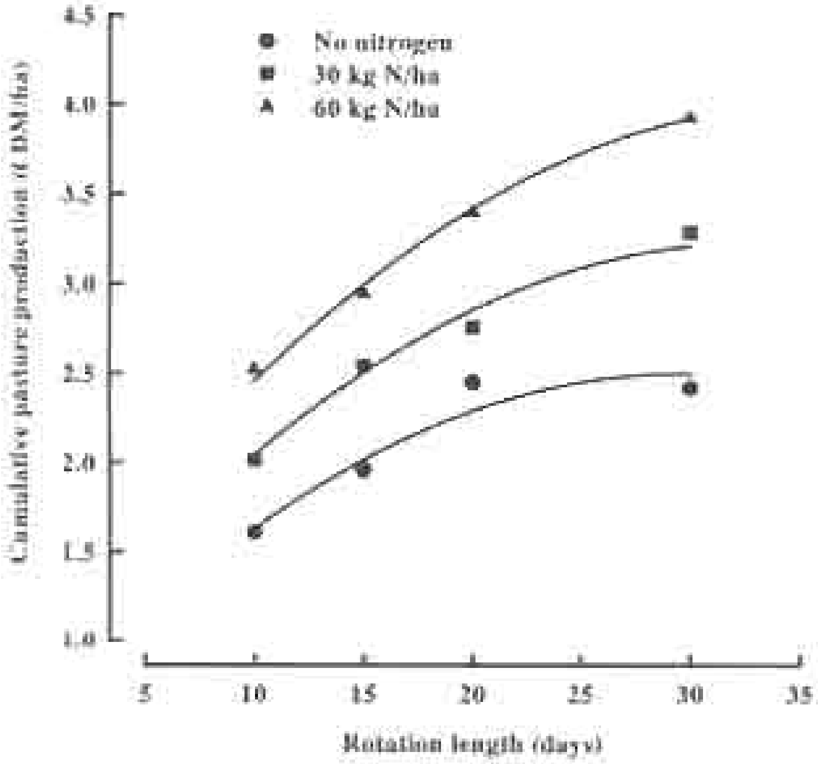

Fig. 4.1. The effect of N and rotation length on cumulative DM yield of pasture after 60 days for a one off application of N fertiliser.

By delaying grazing for 20 to 30 days after N has been applied, most of the growth response to N should have occurred. Whereas, with more frequently grazed pasture, the total response will be spread over a number of grazings as the carryover effect of N on pasture growth was generally higher when pasture was defoliated more frequently.

The N content of especially grass in pasture can also be affected by rotation length and rate of N applied. By increasing defoliation intervals progressively from 10 to 30 days the average N content of the pasture declined, thereby reducing the protein content of the pasture from about 16% CP to 13% CP (Table 3). Although N rate increased the N content of the pasture, the effectiveness of the fertiliser in achieving this declined with increased rotation length.

Table 3. Effect of N rate and rotation length on pasture N content (%N).

N rate	Rotation length (days)			
(kg N/ha)	10	15	20	30
0	2.5	2.5	2.3	2.1
30	2.6	2.5	2.4	2.1
60	2.8	2.6	2.4	2.2

As a general rule of thumb, when weather conditions are favourable for growth, pasture takes about three weeks from the time of application to the next grazing, to respond adequately to N. Under less suitable conditions for growth, it will take longer for most of the response to occur. Therefore the rotation needs to be extended by an appropriate amount. For instance, ryegrass growth is retarded by temperatures above 30°C, and ideally a rotation may need to be extended from three to around four weeks to optimise growth response in ryegrass dominant pastures when high temperatures persist. In cold conditions in winter at least five or six weeks may be needed for pasture to respond most effectively to N fertiliser.

4.5. Time of application in relation to grazing

Pastures are often grazed towards the end of an irrigation cycle and ideally are irrigated fairly soon after, avoiding water stress of the pasture. However, it is not always possible to arrange grazing and irrigating to occur at the most appropriate times. This situation is complicated further if topping and/or N fertiliser application are also involved. Consequently, in practice, N is applied to pasture at various times after grazing.

It has been found that an optimum time to apply N is with an irrigation, within a few days after defoliation of pasture. Applying N at this time, means the pasture has more time to utilise the fertiliser before the next grazing than when N is applied mid-way through a rotation. Experiments have indicated that pasture responses could be 8-15% greater when N is applied within the first week after grazing (Table 4). The timing of the application of N is possibly more critical with lower rates of fertiliser applied.

The least efficient time to apply N is towards the middle of a rotation. When N is applied about 3 days before grazing there was no reduction in response. In this situation the response occurs by the second grazing after the N was applied. It should be noted that applying ammonium nitrate at that time could run the risk of elevated nitrate concentrations in the pasture. Also, it would be good practice not to apply heavy rates of urea (>60 kg N/ha) at that time, so as to avoid the possibility of higher than normal ammonium concentrations in the herbage.

Table 4. Pasture DM response (kg DM/kg N applied) to a single application of N when applied at different times during a (a) 24 day rotation of paspalum dominant pasture and (b) 27 day rotation of ryegrass dominant pasture.

(a). cumulative response after three harvests

N rate (kg N/ha)	Day of application in first rotation 0	7	14	21
30	31	18	15	28
60	21	21	15	23

(b). cumulative response after three harvests

N rate (kg N/ha)	Day of application in first rotation 0	8	15	23
30	32	24	19	26
60	23	19	12	26

Consumption by stock of relatively small amounts of N fertiliser granules can be toxic to the stock. Dissolving the N fertiliser granules by irrigation or rainfall before allowing stock access to the pasture should reduce any potential problems with stock consuming fertiliser on the pasture or from spillage from a spreader.

4.6. Pasture management

Good pasture management is essential for the effective use of N on pastures.

For pasture to respond well to N, other soil nutrients such as phosphorus, should not be limiting. For strategic use of N, the normal recommended rate of phosphorus (45 kg P/ha) is adequate. However, when repeated applications of N are being used over an extended period some consideration could be given to slightly increasing the recommended rate of P because more pasture is being produced and the P requirement may be higher than normal.

Irrigation management is vital to the success with N. Water stress of the pasture can lower the response if N uptake is reduced because soil water is limiting. Ryegrass pastures are more sensitive to water stress than paspalum. Irrigation scheduling every 7 days in summer is important for pastures with high ryegrass and white clover contents. Although poorly drained pastures will respond to N, waterlogging assists weeds to invade the pasture and therefore overall pasture quality is reduced. Good drainage does help pasture to grow better by reducing the stress on the root systems of pasture plants and therefore should aid with N responses. Pasture responses to N can also be limited by low soil water conditions outside the irrigation season.

This highlights the care needed with ryegrass pastures on landformed soils but also on the better class of soils to provide adequate time for the response and to maintain soil water so the pasture is not water stressed. In addition pasture growth responses per unit of N applied will be greater if other essential nutrients are not limiting for plant growth.

5. REPEATED USE OF N FERTILISER ON PASTURES

Repeated or recurrent use of N fertiliser is the application of fertiliser to a pasture a number of times over a year. Farmers may consider the use of multiple applications of this fertiliser on their farm when grazing pressure limits feed availability for prolonged periods during the lactation period. Repeated use of N is used to fill expected feed gaps over longer periods. In this case, the purpose of using N is to maintain a higher rate of pasture growth than can be achieved without added N. Importantly, the consequences of repeated applications of N on pasture need to be understood if its use is to remain economical.

5.1 Rate of application

Similar, low to moderate rates (up to 50 or 60 kg N/ha) of N fertiliser, as were recommended for strategic use, are also suggested for repeated applications of N. Pasture responses can be hard to see when low rates (25 kg N/ha or less) of N are applied, and a change in the colour of grass to a darker green could be the only indication of the effect of the fertiliser on pasture growth.

In a study where two rates of N were applied four times after the pasture was defoliated, the response to N (kg DM/kg N applied) was not different between the four application times (Fig 5.1).

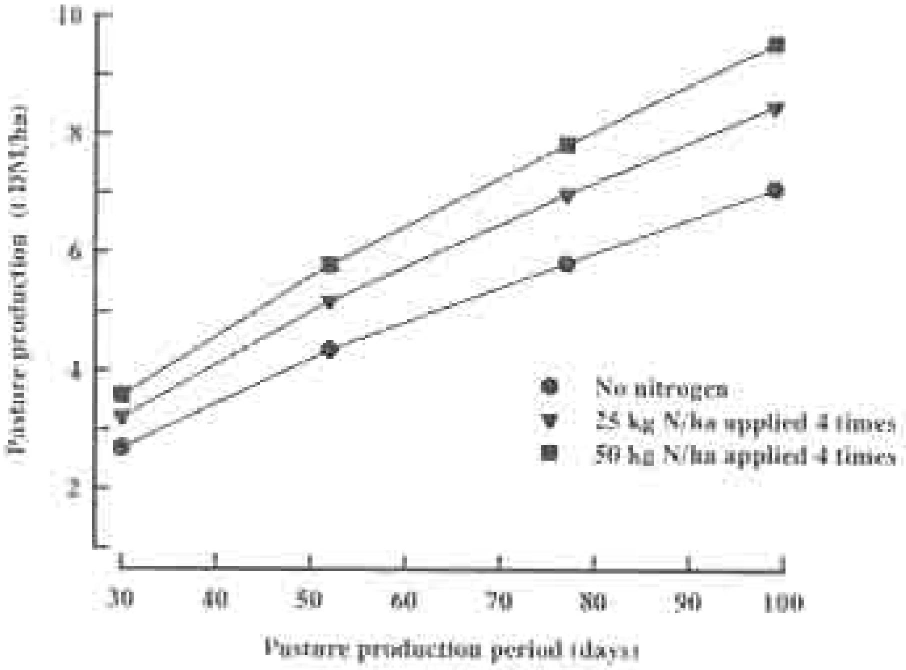

Fig. 5.1. Cumulative DM production when two N application rates (kg N/ha) were applied four times to a paspalum based pasture.

5.2 Frequency of N applications

Providing moderate rates of N are being applied, the response in growth of irrigated pastures is not affected by frequency of application. Consequently the amount of N applied to a pasture over time is the major factor controlling the level of production.

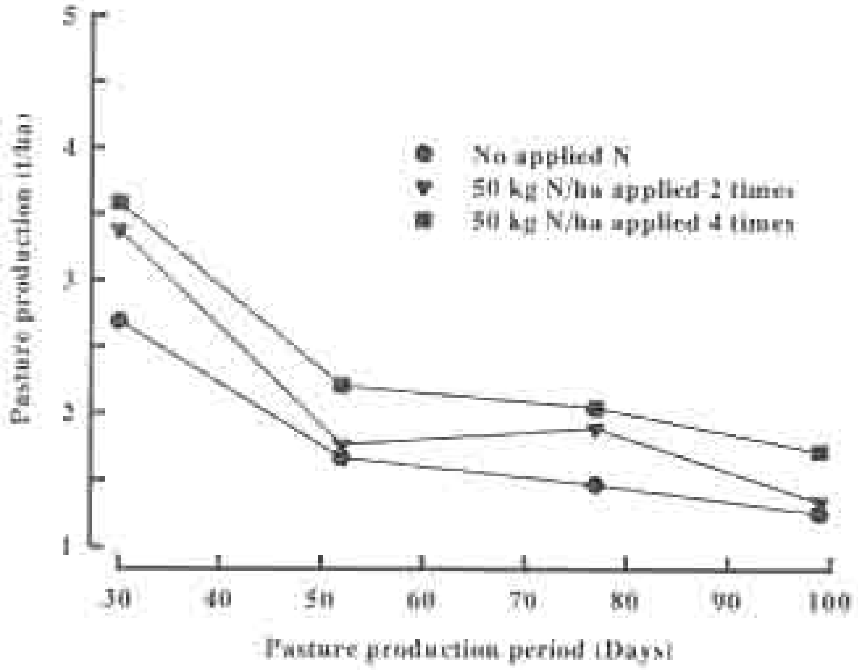

Fig. 5.2. Pasture production with frequent and less frequent applications of N applied at the same rate.

This conclusion has been reached from a study where N was applied to a pasture after each defoliation, or less frequently (fertiliser applied after every two grazings) (see Fig. 5.2). The more frequent addition of N maintains pasture growth at a reasonably constant level above that of pasture receiving no fertiliser N. The application of N after every two defoliations increased pasture growth only with fertiliser addition. Prior to the next application of N, pasture growth was similar to unfertilised pasture. This figure shows that the frequency of N application to pasture has a large influence on the pattern of pasture production, but not the response (kg DM/kg N applied).

The purpose of applying N frequently to pasture is to sustain pasture growth at an elevated level for the term of the strategy. Pasture responses with less frequent applications will fluctuate depending on each application of N. Pasture growth varies from day to day and week to week throughout the season. However, the responses to N from the two strategies examined was comparable at 10 kg DM/kg N applied. Any residual effects of the fertiliser on pasture growth are often small in comparison with the initial response obtained after application.

5.3 Clover persistence in pasture with repeated N use

High rates and continual use of N fertiliser is known to adversely affect clover by reducing its growth in mixed pastures and the amount of N_2 fixed by the clover. Applications of N to pasture can reduce the clover content of pasture simply because the growth of grass has increased. This change in botanical composition of the pasture does not necessarily affect the quantity of clover per ha.

Table 5. Total clover production (kg DM/ha) in two pastures with 0, 100, and 200 kg N/ha applied over four applications in a season. Separate areas of pasture were treated with N in each of the seasons.

(a). Ryegrass-white clover

Fertiliser applied kg N/ha	Spring	Summer	Autumn
0	3820	2478	1803
100	3876	2389	1876
200	3253	2113	1419

(b). Paspalum-white clover

Fertiliser applied kg N/ha	Spring	Summer	Autumn
0	2177	1618	610
100	2259	1433	530
200	2015	1468	608

However, the repeated use of N to boost feed production over several months can reduce clover growth, unless the amount of N applied over that time span is restricted. As an example Table 5 illustrates the effect of four N applications at two N rates on total clover growth over four harvests in spring, summer and autumn. For the ryegrass-white clover pasture, 100 kg N/ha applied over a season (25 kg N/ha/application) had no effect on clover production but at the higher amount of applied N (200 kg N/ha) total clover production was significantly reduced by 15 to 20%. The application of 100 and 200 kg N/ha over a season to paspalum-white clover pasture had no significant effect on total clover production over each season (Table 5). However, clover growth was less after the fourth application of N to the pasture in summer.

To minimise the detrimental effects on clover growth with repeated N applications to ryegrass or paspalum based pastures, the total amount of N applied over a year should be less than 200 kg N/ha. Applications of N approaching the suggested upper limit of 200 kg N/ha may cause some loss of clover DM production.

5.4 Long term intensive N strategy

When N is used to increase pasture growth throughout the year, pastures could receive a total annual application of 300 - 600 kg N/ha spread over a dozen or so grazing rotations. In many European countries, similar amounts of N are used on grass swards to optimise DM production over their growing season (Whitehead 1995). Intensive N use on mixed pastures can lift annual DM production by several tonnes per ha (Table .6).

The level of increased pasture production with repeated N strategies can be affected by a decline in clover persistence. Some pastures (particularly ryegrass-white clover) may become less responsive to N with continued use of repeated N applications. A decline in clover growth can reduce the apparent pasture response to N unless the increase in grass growth compensates for any loss of clover production.

Table 6 shows total pasture and clover DM production of two pastures over two years where the total amount of N applied at three rates was 0, 300 and 600 kg N/ha/yr.

For the ryegrass pasture, N increased DM production, at least initially, but it was apparent that the response to N declined from year 1 to year 2. This occurred even though the average response by the non-clover (total pasture DM-clover DM) component of the pasture was at least 10 kg DM/kg N applied over the two years. The main reason for the decline in the overall pasture production response was the marked affect of the repeated N applications on clover production. The average clover content of the pasture after two years of intensive N applications was 43, 33 and 25 % clover, where 0, 600 and 1200 kg N/ha had been applied. In ryegrass pasture with lower clover content (10-20%), the loss of clover may not adversely affect the pasture response to the same extent, as the ryegrass response may compensate for the relatively smaller loss of clover production.

In the paspalum pasture, the repeated application of 25 and 50 kg N/ha/defoliation increased DM production on average by 10 and 9 kg DM/kg N across harvests 1 to 12 and by 9 and 8 kg DM/kg N in the second year. It was evident that repeated N applications to paspalum pastures gave a more sustained response than for ryegrass pastures. This occurred even though cumulative clover DM production was markedly reduced by repeated applications to paspalum pastures (Table 6). The sustainability of the paspalum pasture under intensive N use was due to an increased grass DM response to N, which negated the loss of clover DM production. However, after 24 defoliations the clover content (%) of the pasture was 27%, 10% and 3% for 0, 600 and 1200 kg N/ha applied over the two years. This effect of intensive N use on paspalum-white clover has implications for pasture quality and possibly milk production from relatively low digestible paspalum dominant pasture.

Table 6. Pasture and clover production of two pastures that received 0 or 25 or 50 kg N/ha after each of 24 defoliations over two years.

(a). Ryegrass-white clover pasture

Nitrogen rate (kg N/ha)	Pasture DM total production (t/ha)		Clover DM total production (t/ha)	
	Harvest 1-12	Harvest 13-24	Harvest 1-12	Harvest 13-24
0	15.8	15.5	8.5	8.5
25	17.1	15.7	6.9	5.8
50	20.5	18.4	4.7	4.2

Harvest 1-12 = 393 days production and harvest 13-24 was 332 days production

(b). Paspalum-white clover pasture

Nitrogen rate (kg N/ha)	Pasture DM total production (t/ha)		Clover DM total production (t/ha)	
	Harvest 1-12	Harvest 13-24	Harvest 1-12	Harvest 13-24
0	17.5	13.3	5.2	4.7
25	20.5	16.0	4.8	2.9
50	22.7	17.8	3.9	1.6

Harvest 1-12 = 377 days production and harvest 13-24 was 321 days production

Continual applications of N to clover based pastures at annual rates of 300 kg N/ha/yr or more are probably not economically or ecologically sustainable. Pastures (especially paspalum based) fertilised with large amounts of N annually will eventually contain essentially no clover and the pasture will become fully reliant on fertiliser N for DM production to be maintained.

6. NITROGEN LOSSES

Significant amounts of N from fertiliser may be lost from pastures under certain conditions. There are four main processes that can occur in duplex soils of irrigated dairy farms in northern Victoria. These processes are denitrification, ammonia volatilisation, losses in runoff from irrigation bays and leaching losses. Leaching is generally not considered as a major cause of N loss in duplex soils because of low water flow through the subsoil. However, on well drained soils N losses through leaching may be important.

6.1 Denitrification losses of N

Denitrification in soils occurs mainly when soil oxygen concentrations become very low following heavy rainfall or flood irrigation. Under these conditions micro-organisms convert soil nitrate into gaseous forms of N (nitrous oxide and N_2) which can diffuse into the atmosphere.

Losses of up to 35% of applied N from ammonium nitrate have been measured under waterlogged soil conditions in northern Victoria. Under the same waterlogged conditions, losses of N from urea were less than 14%. As urea does not contain nitrate, it is initially protected from loss by denitrification. This difference in loss of N between ammonium nitrate and urea indicates that ammonium nitrate can be a less efficient form of N than urea for application to flood irrigated pastures in spring, summer and autumn. Consequently nitrate forms of fertiliser (eg. ammonium nitrate) are often not recommended when pastures are flood irrigated in the warmer months.

Under wet saturated soil conditions, up to 35% of the N, from ammonium nitrate may be lost to the atmosphere by denitrification.

6.2 Ammonia volatilisation

In acid soils, urea is the form of N fertiliser most susceptible to loss via ammonia volatilisation. Urea is widely used in irrigated dairying and on application to soil it is, in the presence of water and the enzyme urease, converted to ammonium carbonate. Ammonium carbonate breaks down to ammonia and carbon dioxide. The formation of ammonia can lead to ammonia volatilisation into the atmosphere.

With the formation of ammonium carbonate soil pH in the vicinity of the urea granule can be greatly increased. This favours ammonia formation and hence ammonia volatilisation. Temperature, soil water content and other factors have some controlling influence on the potential loss of urea-N by this process.

In order to minimise the risk of N loss by volatilisation, it is recommended that the pasture should be irrigated within 24 hours after the urea has been applied. It has been shown that irrigation will protect urea from ammonia volatilisation. Alternatively, urea could be applied to pasture after irrigation when runoff has stopped but the soil is still very wet.

At other times of the year when irrigation is not possible urea can be applied to moist soil providing temperatures and evaporation rates are not high, so water loss from the soil after urea has been hydrolysed (1 to 3 days after application) is low. In late winter, when the soil may be very wet N losses from urea may be small, but it could be impractical to spread the fertiliser.

As an example, recovery of urea applied to pasture in late autumn was determined for different initial soil water contents and compared with standard flood irrigation of dry soil (Table 7). Four weeks after application more than 90% of N from urea was recovered from initially moist and wet soils. The lowest recovery 79% occurred when the soil was initially quite dry. However, 10 mm of rainfall was sufficient to improve the recovery comparable with the other treatments.

Therefore urea should only be applied to dry soil when substantial rainfall is expected or irrigation is possible. It is not sensible to apply N fertiliser to dry soil without irrigation or follow up rainfall because the pasture will not respond to the N due to the lack of soil water.

Nitrogen from other ammonium fertilisers, particularly ammonium sulphate and DAP can be lost from alkaline or heavily limed acid soils. Ammonium nitrate and MAP are more suitable alternatives for that type of soil because they are less likely to form the unstable ammonium carbonate, from which ammonia is lost. Experiments conducted in New Zealand on acid soils have shown that losses of N by ammonia volatilisation can also occur from DAP. However, the losses are only 40% of the expected loss from urea-N under comparable conditions.

Table 7. Total N recovery (% of applied N) from urea in pasture and soil as affected by initial soil water content and post N application of water.

Water applied (mm)	Initial soil water status		
	Dry[1]	Moist[2]	Wet[3]
0	79	90	98
10	91	96	
50	94		

[1]Evaporation(E)-Rainfall(R) 50 mm, [2]E-R 25 mm and [3] E-R 0 mm

When urea is applied in the cooler months, up to 20% of the N applied may be lost to the atmosphere by ammonia volatilisation. Overnight dews are possibly sufficient to dissolve urea but are not sufficient to wash urea into the soil

6.3 Nutrient runoff after irrigation

Most forms of N and phosphorus fertilisers are readily soluble and dissolve in irrigation water. Nutrient runoff in water from pasture after irrigation is a potential loss of fertiliser and can lead to elevated nutrient concentrations in drainage water. These nutrients may lead to nutrient enrichment of rivers and streams.

Experiments have shown that the loss of N from urea in runoff may be 2 to 5% of that applied. Whatever the loss, concentrations of N in runoff are much higher after fertiliser is applied and so care should be taken to minimise runoff.

Fertiliser and irrigation practices which minimise N losses in runoff water should be used.

Some suggestions for minimising N losses in runoff are:

- Do not spread the fertiliser near the bottom end of the irrigation bay; that is, leave an unfertilised strip at the drainage end of the bay.
- The volume of water as runoff has a big influence on the amount of nutrient in drainage. Therefore try to minimise runoff volumes by stopping irrigation so that the water does not reach the drain.
- Where possible re-use drainage water.
- Where practical, spread the fertiliser after runoff has stopped. To dissolve the fertiliser particles and allow the diffusion of the applied N into the soil, there needs to be some free water on the soil surface.

7. RECOMMENDED BEST PRACTICES

The recommended best practices for nitrogen fertiliser use on irrigated pastures are given below.

7.1 For pasture growth responses

a. Estimate feed shortages

This is an important decision. It involves estimating the amount of extra pasture DM (kg) needed per paddock to over come the foreseen feed shortage and determining the duration of any expected pasture deficit (as the number of grazings or rotations).

Feed budgets are a useful means for estimating likely pasture shortages and so play a role in developing a suitable strategy for N fertiliser use and/or supplementary feeding.

A plan of strategic or repeated use of N fertiliser can be developed to meet a particular situation.

b. Pasture selection

It is important to select pasture paddocks that are likely to respond well to applied N. This decision may influence the success of overcoming expected feed shortages.
Choose dense and grass dominant pastures.
Identify the dominant grass species to ensure it is a grass capable of responding at that time of the year (eg. paspalum is not responsive in autumn).
Inspect pastures to see whether the urine patches indicate that the pasture will respond to N ie. darker green than surrounding areas and an obvious DM response.
Ensure that other nutrients do not limit pasture growth (eg. P level of soil).

c. Rate of N to apply

Calculate the rate of N to apply per ha knowing the amount of extra DM required.
Use 1 kg N = 10 kg extra pasture DM as an average response unless a better prediction available.
For example:
25 kg N/ha = an extra 250 kg DM/ha
50 kg N/ha = an extra 500 kg DM/ha.

d. Amount of fertiliser to apply per ha

Choose the appropriate fertiliser depending on cost per unit of elemental N and whether other nutrients are being applied. It may be cost effective to use DAP instead of urea and another P fertiliser.

Fertiliser rate (kg/ha) = N rate x 100 /N content of fertiliser
(N rate = kg N/ha, N content of fertiliser =%N on bag)

e. Timing N applications

Apply the N fertiliser as soon as possible after grazing particularly when rotations are 3 weeks or less. The aim is to maximise the time available for the pasture to respond by the next grazing.

f. Grazing the pasture.

Pasture responses to N are dependent on air and soil temperatures and hence responses may decline over the autumn/winter period. A DM response should occur in about 3-4 weeks in the warmer months and 4-6 weeks in the colder months.
Grazing a pasture too early may lower the expected response.

Effective use of N involves grazing the pasture well to utilise the extra feed grown. This improves the economics of applying N to pastures as a way of filling feed gaps.

7.2 To minimise effects on white clover growth and persistence

a. Single application rate
A maximum application rate of 50-60 kg N/ha as a single application should minimise loss of clover growth in mixed pastures.

b. Repeated applications of N
On farms where repeated N applications are used, the total amount of N applied to a pasture should be less than 200 kg N/ha/yr. In some pastures clover production can begin to decline after 100 kg N/ha has been applied. A greater number of applications of a low rate of N than a higher rate may be an appropriate tactic with prolonged feed shortages.

7.3 To minimise losses of applied N prior to its uptake by pasture

a. Denitrification losses
It is recommended that ammonium nitrate or other nitrate fertilisers should not be applied to pastures that will be flood irrigated to avoid possible losses by denitrification.
Urea and DAP do not contain nitrate and denitrification loss can only occur when some of the fertiliser is eventually converted to nitrate in the soil.

b. Volatilisation losses
Irrigate pastures within 24 hours when urea or urea blends are applied, to minimise potential losses. DAP should be watered in as soon as practicable as some volatilisation can occur from DAP after it has dissolved. Under similar conditions, volatilisation from DAP is about 40% of that from urea.
About 10 mm of rainfall can help to reduce volatilisation loss from urea applied to pasture without an irrigation.
Ammonium nitrate is not subject to volatilisation loss in acid soils.

c. Runoff losses
Take care to avoid spreading fertilisers close to the drains at the end of pasture bays to reduce the loss of fertiliser in drainage water.

8. Reference

Whitehead, D.C. (1995). Grassland Nitrogen. CAB International, Wallingford, Oxon, UK.