



Nitrogen And The Environment

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Summary

- Nitrate leaching to groundwater is of environmental concern.
- Ad hoc surveys indicate highest groundwater nitrate levels are in the dairying regions of Taranaki and Waikato, with about 20% of wells having nitrate levels exceeding recommended limits for drinking water set by WHO and NZ Department of Health.
- Under grazing, most N losses are from cow urine patches.
- N fertiliser use indirectly increases N losses by increasing N cycling through the grazing animal.
- Studies with high N inputs as dairy factory effluent showed greatly increased nitrate concentrations in groundwater and in adjacent streams.
- Responsible use of N fertiliser is desirable to minimise environmental impacts and avoid the need for "EEC-type" regulations by Regional Councils.

Introduction

Nitrogen (N) is the nutrient required in the largest amount for growth of pastures. Annually, total N uptake by dairy pastures is about 700-1000 kg N/ha, of which about 100-300 kg N/ha is typically fixed from the atmosphere by clover (Ledgard and Steele 1992). Intensive grazing by dairy cows results in consumption of much of the pasture N, of which only 10-20% is retained in milk and meat proteins. The remaining 80-90% is returned in excreta. Thus, in grazed pastures, N undergoes considerable cycling within the soil/plant/animal system and is prone to significant loss.

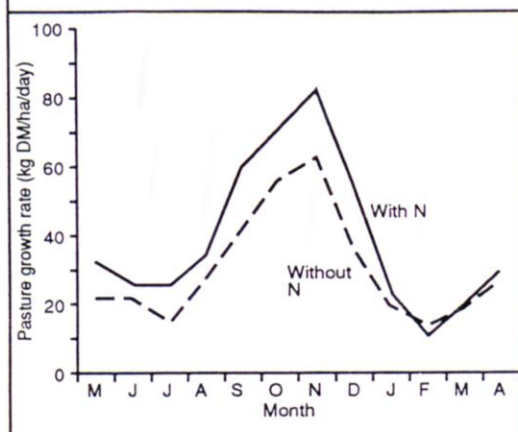
There is increasing concern about the environmental implications of the large increase in use of N fertiliser on dairy farms during the last five years, especially with some farmers using up to 500 kg N/ha/year. This paper briefly describes the effects of N fertiliser use on production and then outlines the consequences of soil acidification and N losses to the environment.

Effects Of N Fertiliser On Production

Pastures are capable of high production without N fertiliser, provided they are adequately supplied with other nutrients (particularly phosphate, sulphur and potassium). In this case, N removals are replaced by fixation of atmospheric N by clovers, and this fixed N gradually becomes

available to grasses. However, increases in grass growth from N fertiliser application can occur at most times of the year (eg Figure 1).

Figure 1: Effect of regular N fertiliser application (400 kg N/ha/year in split dressings) on pasture production (Holmes 1982).



In a series of trials throughout New Zealand, the application of N fertiliser at 420 kg N/ha/year in split dressings increased total pasture growth by 14-57% (average 27%) or 4.0-9.2 kg DM/kg N (average 7.2) applied (Ledgard *et al.* 1994). In contrast, strategic use of single applications of N fertiliser in late winter or spring have typically shown pasture responses of 10-15 kg DM/kg N.

Dairy farmlet trials at Massey University showed increased pasture and milk production from N fertiliser use at 400 kg N/ha/year, but it was generally unprofitable, whereas other farmlet trials showed 100 kg N/ha/year was profitable (Holmes 1982; Roberts *et al.* 1992). A key feature of these trials was a high stocking rate (at least 4 cows/ha) to ensure high utilisation of the extra feed grown.

A current farmlet trial at DRC No 2 Dairy is comparing nil, 200 and 400 kg N/ha/year. Preliminary results during the first year are showing an increase in grass growth and milk production since commencing N fertiliser applications in June 1993. However, they have also shown a marked decrease in clover growth and fixation of atmospheric N by clovers after applying 130 and 240 kg N/ha of N fertiliser in split applications (Harris, this proceedings). In a summary of past field experiments, Ledgard *et al.* (1994) concluded that effects of N fertiliser on N fixation were greater than the effects on clover growth and that for every 1 kg of fertiliser N applied, the clovers fixed approximately 0.5 kg N less.

N Fertiliser Use Increases Soil Acidification

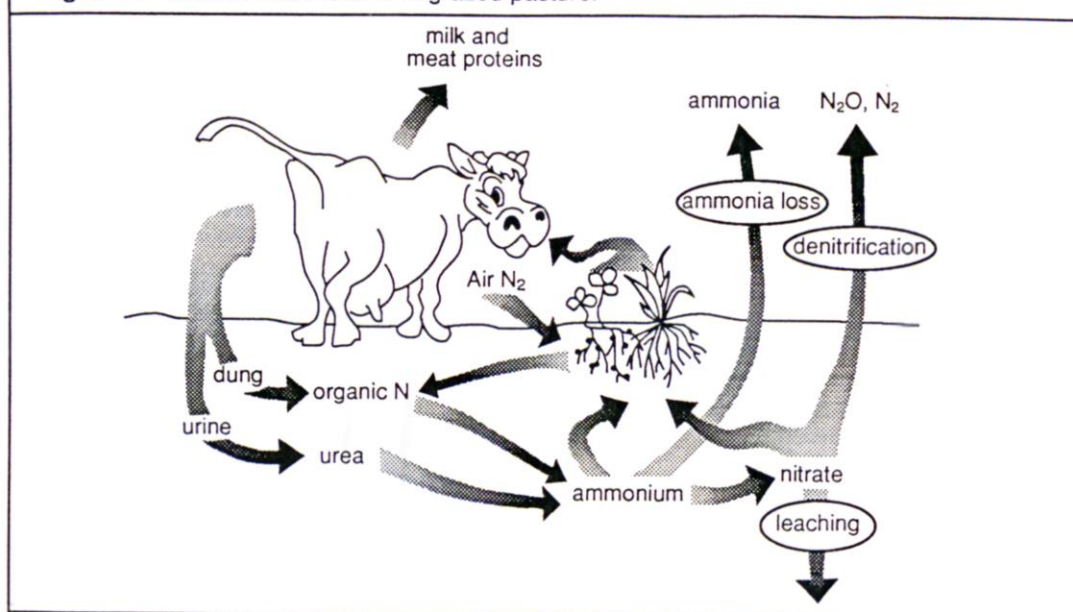
Nitrogen fertilisers which contain ammonium (eg. sulphate of ammonia, DAP) or produce ammonium (eg. urea) have an acidifying effect on soil. The potential acidifying effect varies with form of N fertiliser (Table 1) and is greatest with sulphate of ammonia and least with urea. Thus, 1 t lime/ha would be needed to counter the potential acidifying effects of about 180 kg N/ha as sulphate of ammonia (830 kg/ha), or about 550 kg N/ha as urea (1200 kg/ha).

In practice, the natural buffering ability of soils means that at low-moderate rates of N fertiliser, farmers are unlikely to notice any effects on soil pH in the short-term. Where high rates of N fertiliser are being used, farmers should regularly monitor soil pH and apply extra lime as required to maintain an optimum pH of 5.8-6.0.

Table 1: Approximate lime requirement to neutralise the potential acidifying effect of N fertiliser.

Form of N fertiliser	Amount of lime (kg/ha) needed to neutralise 25 kg N/ha	Number of applications of 25 kg N/ha before 1 t/ha of lime is required
Sulphate of ammonia	135	7
Diammonium phosphate	90	11
Urea	45	22

Figure 2: Transformations of N in grazed pasture.



N Losses To The Environment

N undergoes a wide range of dynamic changes and movements in the soil/plant/animal system and a simplified diagram of this is given in Figure 2. Bacteria in root nodules of clover fix N from the atmosphere and this N enters the soil after clover root material decomposes or after clover has been eaten by cows and the N is returned in excreta. In soil, the N in excreta is broken down to ammonium by microorganisms.

This ammonium is then absorbed by plants, lost into the air as ammonia, or converted to nitrate by other microorganisms. Nitrate is then subject to plant uptake, or to loss into the air by a process called denitrification, or to leaching through soil into groundwater.

Losses of N by the three processes of ammonia loss, denitrification and leaching are outlined in subsequent sections. Until now there have been no measurements of N losses under dairying in New Zealand.

In the current experiment at No 2 Dairy, we are measuring N inputs and losses in dairy farmlets receiving up to 400 kg N/ha/year of N fertiliser. Some preliminary results from this experiment are discussed in subsequent sections.

Effects on environment and human health.

The gaseous losses of ammonia, nitrous oxide (N_2O) or dinitrogen (N_2) (see Figure 2) are mainly of concern because they represent an inefficiency in the system. However, N_2O is implicated in ozone destruction and as a greenhouse gas, and therefore it is desirable to minimise N_2O losses.

The main concern for human health and the environment is from nitrate leaching into groundwaters and movement into surface waters. When groundwater is used for drinking, the ingested nitrate is reduced to nitrite and absorbed into the bloodstream, where it reduces the oxygen carrying capacity of blood. This is particularly important in infants under three months where it can cause death. However, there have been no reported cases of human deaths from ingestion of water high in nitrate in New Zealand. To safeguard against this, there is a recommended limit on nitrate-N concentration in drinking water of 10 g/m³ set by the World Health Organization (WHO) and adopted by the NZ Department of Health.

Nitrate can also enter surface waters, either directly from runoff or via lateral movement of groundwater, where it can enhance algal and plant growth. This can result in a loss of fisheries, reduced aesthetic appeal, and increased cost of

obtaining good quality water (Cameron and Haynes 1986).

Ammonia loss

Significant loss of ammonia into the atmosphere can occur from cow urine patches, particularly during dry summer/autumn conditions. Ammonia can also be lost from N fertiliser, with most loss occurring within 1-2 days of application.

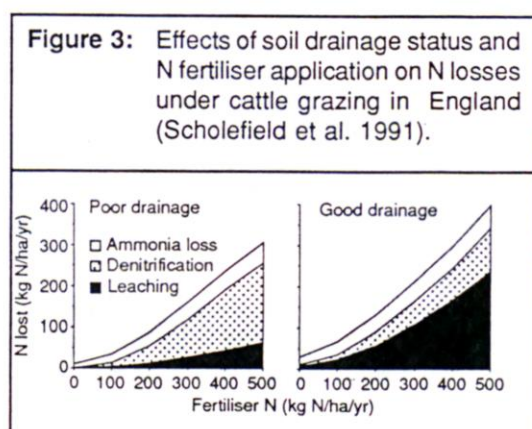
The extent of ammonia loss varies with the form of N fertiliser. In experiments in Canterbury, the average loss of ammonia-N was 12, 5 and 1% from urea, diammonium phosphate and sulphate of ammonia respectively (Black *et al* 1985). Measurements at No 2 dairy after regular inputs of urea between 22 and 90 kg N/ha have produced ammonia losses of 2-9% of the N applied between July and December.

Ammonia loss varies with season and has been measured at up to 40% from urea applied in a dry autumn (Theobald and Ball 1984). The loss of ammonia declines considerably if rain falls within 12-24 hours of application.

Denitrification

N can also be lost into the atmosphere as N₂O or N₂ by denitrification. This loss requires anaerobic (lacking oxygen) areas in the soil (eg. due to water-logging), and the mechanism is used in effluent ponds to "remove" N.

Losses by denitrification are greatest in poorly-drained soils and can be reduced by artificial drainage. However, drainage appears to have little effect on total N losses, but simply changes the form of loss from denitrification to nitrate leaching (Figure 3).



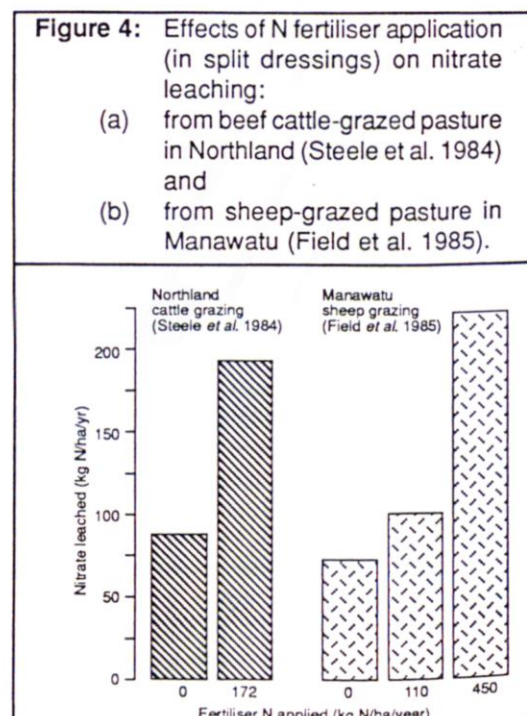
Initial measurements in the No 2 Dairy trial on moderately-well drained soils indicate that annual N losses by denitrification from surface soil are low (probably less than 10 kg N/ha/year).

Nitrate leaching and effects of N fertiliser use

Nitrate in soil can be leached out of the root zone and down to the groundwater in drainage. This occurs mainly during winter when rainfall exceeds evapotranspiration and when plant uptake of N is slow.

In grazed pastures, most nitrate leaching is associated with animal urine patches where N is returned at rates equivalent up to 1000 kg N/ha. This localised input is well in excess of that which pastures can readily absorb.

There have been no published experiments where nitrate leaching has been measured under dairy cow grazing in New Zealand. A range of experiments have examined nitrate leaching in sheep grazed pastures without N fertiliser and most estimates were between five and 35 kg N/ha/year with one at 68-78 kg N/ha (see Figure 4). The latter may have been high due to previous soil cultivation. There is only one published estimate for pastures grazed by beef cattle at 88 kg N/ha (Figure 4), which occurred in Northland in a year of excessive rainfall and drainage.



Preliminary data from the trial at DRC No 2 Dairy have indicated average nitrate-N concentrations in drainage water between June and October 1993 of around 5-10 g/m³, which under normal drainage would equate to leaching of roughly 20-40 kg N/ha/year. This trial has not been going for long enough to determine the effects of N fertiliser use on nitrate leaching. In the Hamilton Basin, leaching into shallow aquifers was recently estimated at 60 kg N/ha/year under intensive farming (Selvarajah *et al.* 1994).

Only two grazing experiments in New Zealand have examined the effects of N fertiliser application on nitrate leaching (Figure 4). Although the unfertilised values in these experiments were relatively high (as discussed earlier), they indicate that increasing N fertiliser use increased nitrate leaching. Associated measurements in these experiments indicated that most of the increased leaching of nitrate was not due to direct leaching of fertiliser N. In most cases a high proportion of fertiliser N is absorbed by pasture which is then consumed by cows. Most (about 60-70%) of the consumed N is returned in urine where it is prone to loss.

Thus, the extent of nitrate leaching is influenced by farming practices and these then determine the concentration of nitrate in groundwater.

Nitrate concentrations in groundwater

The extent of groundwater contamination of nitrate in New Zealand is poorly documented, and data have been collected on an ad hoc basis. Nitrate-N concentrations measured in well water from selected regions throughout New Zealand during the past 25 years have shown a wide range between 0 and 67 g/m³. The highest proportion of wells with nitrate concentrations exceeding the WHO limits were in the intensive dairying regions of Taranaki and Waikato. Many of the surveys were restricted in area and it was difficult to determine the causes of variation with certainty. Environment Waikato are currently planning a detailed survey of nitrate in groundwater in relation to farming and industry practices in the Waikato region.

The nitrate concentration in groundwater is also influenced by soil properties. Some soils (eg. recently-developed peats) are very slow at converting ammonium to nitrate (see Figure 2),

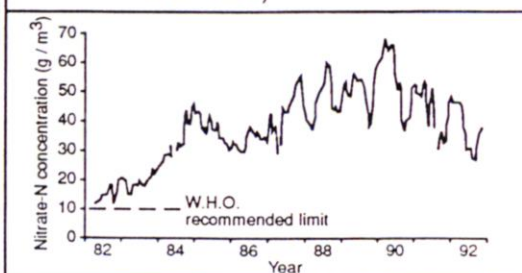
which reduces the amount of nitrate susceptible to leaching. In some poorly drained soils, significant amounts of nitrate can be denitrified into the atmosphere thereby minimising leaching into groundwater (eg. Figure 3). Presence of reduced iron in groundwater may also lead to denitrification and reduction of nitrate. These soil characteristics can lead to areas differing in nitrate concentration in groundwater. For example, Selvarajah *et al.* (1994) showed that only 2% of wells in the Piako area of the Waikato region had nitrate-N exceeding 10 g/m³ whereas 54% of those from the Hamilton Basin exceeded 10 g/m³.

High N inputs increase groundwater nitrate

Increasing inputs of N into a farming system can indirectly lead to more nitrate leaching (eg. Figures 3 and 4), which can result in increased nitrate concentrations in groundwater. For example, Figure 5 shows the effect on groundwater nitrate of applying dairy factory effluent onto dairy pastures at 1200 kg N/ha/year. Effluent application from 1982 onwards caused a steady increase in nitrate concentration until 1985 and thereafter it fluctuated between about 30 and 70 g/m³, well in excess of the WHO recommended limit.

Groundwater provides the base flow for rivers and streams and, therefore, elevated nitrate concentrations in groundwater can lead to increased nitrate concentrations in adjacent surface water ways. Measurements of nitrate-N in a stream adjacent to pastures on a 110 ha farm irrigated with dairy factory effluent (Figure 5) showed an increase from about 7 g/m³ upstream to about 20 g/m³ (range 10-35)

Figure 5: Effect of application of dairy factory effluent sprayed onto dairy pastures at 1200 kg N/ha/year on nitrate-N concentration in groundwater (effluent applications commenced in 1982) (Selvarajah *et al.* 1994).



Conclusions and Implications

Research has shown that N fertiliser use increases grass growth and milk production, and that it can be profitable when used strategically with stocking rates sufficiently high to utilise the extra feed growth. However, N fertiliser use also has negative impacts through reduced clover growth and N fixation, increased soil acidification and increased N losses to the environment. Of these effects, N losses to the environment are the most insidious and difficult to manage. Also, these effects extend beyond the farm, and can lead to eutrophication of rivers, lakes and estuaries.

Regional Councils are concerned about the impacts of N on the environment, as evidenced by the intended restrictions on rate of N application as effluent, which are likely to be set at 150-200 kg N/ha/year. This is similar to the EEC limit of 170 kg N/ha/year for effluent-N. The EEC are imposing other restrictions on N fertiliser use by their farmers, particularly within the designated Vulnerable Zones. The need for similar regulations in New Zealand is being considered by some Regional Councils. It is preferable that any regulations follow consultation with farming groups and that they are based on results of local research.

In New Zealand there is currently limited research information on N losses under dairying and the impacts of N fertiliser use, although AgResearch have a research programme underway on this subject. In the meantime, we have released AgFacts relating to good N fertiliser practice based on our current knowledge. This suggests that for environmental reasons, annual N fertiliser inputs are best limited to a maximum of 150-200 kg N/ha/year.

We believe that a farmer's first priority should be to promote N fixation by clovers (eg. through optimum use of non-N fertilisers) and then to use N fertilisers strategically to meet the main feed shortages. Regular use of high rates of N fertiliser may provide some additional increase in production but it indirectly impacts more severely on the environment, detracts from our clean green image, and leaves us vulnerable to imposition of non-tariff trade barriers.

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