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Nitrogen losses from grazed dairy pasture, as affected by nitrogen fertiliser application

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Abstract

Inputs and losses of nitrogen (N) were determined in dairy farmlets receiving nominally 0, 200 or 400 kg N/ha/yr as urea at Dairying Research Corporation No. 2 dairy, Hamilton. In year 1, N_2 fixation by white clover was estimated by ^{15}N dilution at 212, 165 and 74 kg N/ha/yr in the 0, 200 and 400 N treatments respectively. Removal of N in milk was 76, 89 and 92 kg N/ha in the 0, 200 and 400 N farmlets respectively. Loss of N into the air by denitrification was low (6-15 kg N/ha/yr), and increased with N application. Ammonia loss into the air was estimated by micrometeorological mass balance at 15, 45 and 63 kg N/ha/yr in the 0, 200 and 400 N treatments respectively. Most of the increase in ammonia loss was attributed to direct loss after fertiliser application. Leaching of nitrate was estimated using ceramic cup samplers at 1 m soil depth, in conjunction with lysimeters, to be 74, 101 and 204 kg N/ha/yr during the second winter when rainfall and drainage (550–620 mm) were relatively high. Nitrate-N concentrations in leachates increased gradually over time in the 400 N treatment to an average of 37 mg/l during the second winter, whereas the corresponding values for the 0 and 200 N treatments were 12 and 18 mg/l. Preliminary measurements of groundwater suggest that the nitrate-N concentration is increasing under the 400 N farmlet relative to the other two farmlets. Thus, the 400 N treatment had a major effect by greatly reducing N_2 fixation and increasing N losses, whereas the 200 N treatment had relatively little effect on N_2 fixation or on nitrate leaching. However, these results refer to the first 18 months of the trial and further measurements are required over time to determine the longer-term effects of these treatments, particularly on nitrate levels in groundwater.

Keywords: ammonia loss, dairying, denitrification, groundwater, leaching, nitrogen fertiliser, N_2 fixation

Introduction

The main source of nitrogen (N) input to dairy pastures in New Zealand is from N_2 fixation by white clover, which has been estimated at between 100 and 300 kg N/ ha/yr (Ledgard *et al.* 1990). However, grass remains deficient in N for much of the year and readily responds to N fertiliser. Nitrogen-boosted grass growth is generally the cheapest form of "supplementary" feed and the use of N fertiliser by dairy farmers has increased greatly in recent years, e.g., N use has increased 11 -fold in Taranaki during the past 6 years (Kidd & Howse 1994).

There have been no measurements of the effects of intensive dairy farming systems in New Zealand on several key N transformations and losses concomitantly, either in the absence or presence of N fertiliser use. However, indirect evidence suggests that nitrate leaching losses may be significant. Ad hoc surveys (Hoare 1986; Taranaki Catchment Commission 1987) of nitrate-N concentrations in groundwater in the 1970s–1980s (before the period of increasing N fertiliser use) showed that 20–50% of wells in the intensive dairying regions of Taranaki and Waikato exceeding the maximum acceptable level of 10 mg/l set as the NZ drinking water standard (Board of Health 1989). Additionally, the extent to which nitrate leaching is affected by N fertiliser application in NZ dairy pastures is uncertain.

The aim of the reported study was to examine N inputs and losses (particularly by nitrate leaching) from grazed dairy pasture, as affected by N fertiliser application.

Methods

Farmlets and N fertiliser application

A long-term farmlet trial at No. 2 dairy, Dairying Research Corporation, near Hamilton began in June 1993. Site details were given by Harris *et al.* (1994). Research on the fate of N was confined to farmlets (6.47 ha each) stocked at 3.24 cows/ha and receiving nominal rates of N fertiliser (urea) at 0, 200 or 400 kg N/ha/yr. Actual rates of N applied to measurement paddocks in year 1 were 0,225 or 360 kg N/ha/yr, and were applied in 8 applications spread through all seasons except summer.

Measurements

Detailed N measurements were confined to 4 replicate paddocks of each farmlet on a free-draining soil of volcanic material (Umbric Dystrochrept).

N_2 fixation was determined using a ^{15}N dilution method (Ledgard *et* al. 1990) with 6 replicate plots in each farmlet. Denitrification (i.e., the loss of N_2O and N_2 into the atmosphere caused by soil bacteria) was measured using an acetylene-inhibition technique (Ryden *et al.* 1987) at approximately 2-weekly intervals. Ammonia loss into the atmosphere was measured after each grazing and N fertiliser application using a micrometeorological mass balance method (Sherlock et *al. 1989).*

Leaching losses in the grazed paddocks were determined using ceramic cup samplers (30 per farmlet) located at 1 m soil depth. Samples of solution were collected at approximately 2-weekly intervals and analysed for nitrate. Water drainage was determined from the volume of water passing through lysimeters containing intact soil cores (0.4 m diameter, 1 m depth) which received 0 or 400 kg N/ha/yr (4 replicates) as urea at the same time as in the 400 N farmlet. This drainage was also analysed for nitrate to provide estimates of N leaching in the absence of grazing animals.

Three wells were located in each of the farmlets to a depth of 6 m in March 1994. Samples of groundwater were then collected at regular intervals and analysed for nitrate.

Results

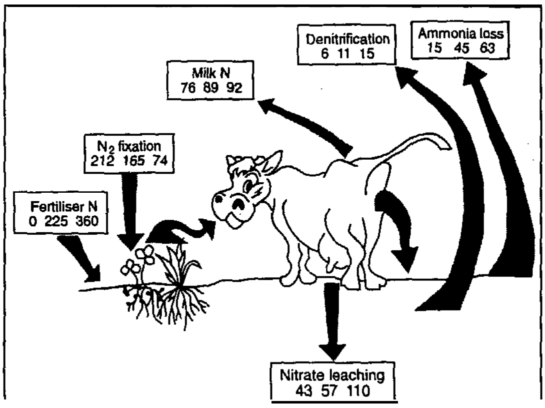
In year I, white clover production was estimated at 2770, 3020 and 1650 kg DM/ha/yr in the 0, 200 and 400 N farmlets respectively. The corresponding estimates of N_2 fixation were 212, 165 and 74 kg N/ha/yr (SED=23) respectively (Figure 1). The mean proportion of total clover herbage N obtained from N_2 fixation was 79, 55, and 46% respectively.

Milk production was 4120, 4860, and 5040 l/cow in the 0, 200 and 400 N farmlets respectively, and this represented the main form of N removal/loss (Figure 1).

Denitrification losses were increased (Figure 1, SED = 1.9) in the N-fertilised farmlets but were small on an annual basis. There was a marked seasonal pattern of denitrification, almost all loss occurring during winter and spring.

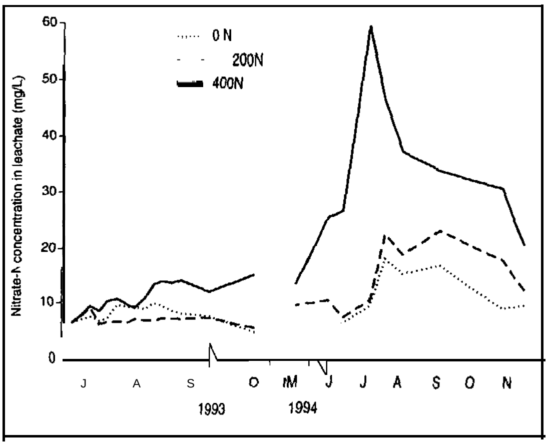
Ammonia loss increased by three- and four-fold in the 200 and 400 N farmlets respectively (Figure 1). There was no obvious seasonal pattern to the amount of ammonia loss after each grazing. Daily ammonia loss measurements indicated that over 80% of the total loss generally occurred within 4 days of grazing.

Figure 1 Nitrogen transformations in farmlets grazed by dairy cows. Data are kg N/ha for year 1 (except for leaching which is the mean of years I and 2) and values from left to right are for 0, 200 and 400 N treatments respectively.



The nitrate concentration in soil solution collected at 1 m depth was initially similar in all treatments but differences developed over time (Figure 2). During 1993 the average concentration of nitrate-N was 6, 6 and 8 mg/l in the 0, 200 and 400 N treatments respectively. The corresponding values for 1994 were 12, 18 and 37 mg/l respectively.

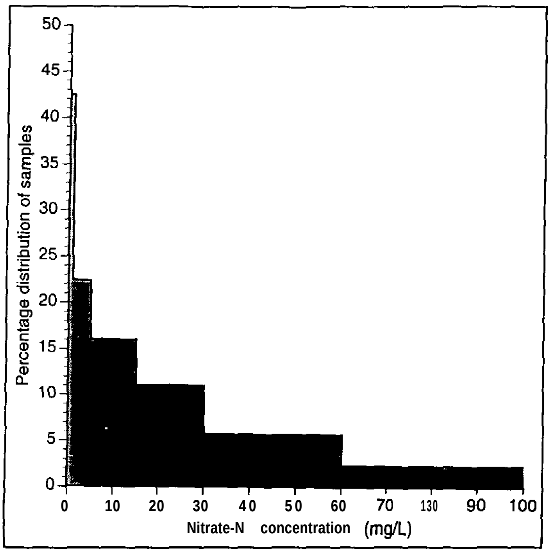
Figure 2 Nitrate-N concentration of leachates sampled at 1 m soil depth from 0,200 and 400 N farmlets. The average SED was 2.8 (range I .9–4.1) in 1993 and 5.0 (range 4.1-6.1) in 1994.



Within any one farmlet there was a wide range in nitrate-N concentrations measured between samplers. For example, during 1993, 43% of the samples collected from the 0 N farmlet contained less than 1 mg/l nitrate-

N, but 28% exceeded 10 mg/l and 2% exceeded 60 mg/l (Figure 3). In contrast, in the ungrazed lysimeters the nitrate-N concentrations of leachates were all between 0 and 0.3 mg/l in the 0 N treatment.

Figure 3 Frequency distribution of nitrate-N concentration in leachates from samplers at 1 m soil depth in the 0 N farmlet during August-October 1993.



The year 1993 was relatively dry and drainage was largely restricted to June-August, whereas in 1994 drainage occurred between May and October. Total drainage measured from the lysimeters during 1993 equated to 205 and 189 mm in the 0 and 400 N treatments respectively. Corresponding drainage for 1994 was 622 and 551 mm respectively.

The amount of nitrate-N leached during 1993, calculated using lysimeter water drainage, was 12, 12 and 15 kg N/ha (SED = 5) in the 0, 200 and 400 N treatments respectively. The corresponding values for 1994 were 74, 101 and 204 kg N/ha (SED=30) respectively.

In winter 1994 the nitrate-N concentrations in groundwater averaged 6, 11 and 10 mg/l (SED=3) in the 0, 200 and 400 N treatments respectively. During spring-summer 1994 the corresponding nitrate-N concentrations were 5, 10 and 20 mg/l (SED=4).

Discussion

During the first year of the trial, application of N fertiliser in the 400 N farmlet reduced N_2 fixation in white clover by 65%. This was due to a decrease in annual clover growth of 40% as competition from associated grasses increased, and to direct substitution of uptake of fertiliser N for N_2 fixation. In contrast, there was much less effect on N_2 fixation in the 200 N farmlet, owing to greater amounts of pasture being carried through the summer period, thereby minimising the effects of over-grazing on clover growth which occurred in the 0 N farmlet. Consequently, clover growth in late-summer–autumn was 140% higher in the 200 N farmlet than in the 0 N farmlet.

Nitrogen application in the 200 N farmlet increased milk solids production in year 1 by 16%, from 1155 to 1335 kg/ha. In contrast, the 400 N farmlet produced only an extra 2% of milk solids relative to the 200 N farmlet despite 10% higher pasture DM production. This reflected adequate feeding and poor utilisation of extra pasture in the 400 N farmlet for the stocking rate of 3.2 cows/ha (Harris et al. 1994).

Removal of N in milk increased in the 200 and 400 N farmlets but was equal to only 6 and 5% respectively of that applied as fertiliser N. Thus most of the increased N intake by cows was returned in excreta.

Loss of N by denitrification was low in year 1 (7-15 kg N/ha) and largely confined to the winter-spring period when soil moisture was at or near field capacity. Similarly, *Luo et* al. (1994) measured low denitrification losses (4-6 kg N/ha/yr) from a poorly drained soil on a dairy farm near Palmerston North.

Ammonia was the main form of gaseous N loss, which increased markedly in the N-fertilised farmlets (from 15 to 45-63 kg N/ha). Associated measurements indicated that this increase was due mainly to direct loss after fertiliser application and was equivalent to about 14% of the urea-N applied.

Leaching of nitrate from the unfertilised farmlet varied markedly between years (12 vs. 74 kg N/ha/yr in years 1 and 2 respectively). This was due mainly to a three-fold difference in the amount of drainage during winter-spring, which reflected differences in annual rainfall (893 mm vs. 1178 mm/yr). The large amount of N leached in 1994 was probably due in part to "carry-over" of a high proportion of potentially-leachable N from the relatively dry year of 1993 (Scholefield et al. 1993).

Nitrate leaching increased in the N-fertilised farmlets in year 2, with the largest increase at the high N rate. Similar effects have been measured in other studies with sheep and beef cattle (Field et al. 1985; Scholefield *et* al. 1993). The two possible causes of increased nitrate leaching are increased cycling and loss of excreta N, and direct leaching of N from fertiliser. Cow intake of pasture N was estimated (using regular visual estimates of pasture cover and plant N analyses) to increase by about 120 kg N/ha/yr in the 200 N farmlet, and at least 80% of this will have been returned in excreta, predominantly urine. However, there was relatively little apparent change in intake between the 200 and 400 N farmlets, indicating that increased loss of urine N was only part of the cause of high nitrate leaching in the 400 N farmlet. Measurements of ^{15}N recovery in plots in the farmlets revealed lower efficiency of use of fertiliser N at the higher rate of application (Sprosen & Ledgard unpublished) and suggest that direct leaching of fertiliser N was significant in the 400 N farmlet.

The average nitrate-N concentration in leachate from grazed paddocks was much greater than that from ungrazed lysimeters and was characterised by a skewed distribution (Figure 3) with a small proportion of samples at very high concentrations (e.g., 2% > 60 mg/l). This was probably caused by the effect of recycling of N in cow urine at very high rates (e.g., 1000 kg N/ha) in localised patches.

Differences between farmlets in the average nitrate-N concentration of leachates were 1 1–20% greater than differences in the amount of N leached. This occurred because N fertiliser enhanced pasture growth and evapotranspiration, and resulted in 8-l 7% less drainage in the 400 N treatment.

There is a time lag associated with changes in activity on the land surface (e.g., N fertiliser application) and increased nitrate in leachate at 1 m depth and in the groundwater (at 3-4 m depth in this study) (Cameron & Haynes 1986). This, along with variations in annual rainfall and drainage and changes in immobilisation in soil organic N necessitate the need for long-term measurements in order to determine the "equilibrium" effect on nitrate leaching and nitrate-N concentrations of leachate. Nevertheless, the extent of drainage in years 1 and 2 (740–830 mm) is equivalent to approximately 1.5 times the volume of soil water in the O-3 m soil depth and indicates that if leaching approximates simple "piston-flow" then the effects on groundwater nitrate-N concentration should be starting to occur (Cameron & Haynes 1986). Indeed, groundwater monitoring suggests that there was some increase in nitrate-N concentration in groundwater in the 400 N farmlet towards the end of year 2, although further monitoring and measurements of groundwater flows are necessary to quantify any effects.

Conclusions

Results from the first year indicated that the 400 N rate appeared excessive for the stocking rate of 3.24 cows/ha in that it gave little extra milk production relative to 200 N, and the increase was unprofitable. The 400 N treatment also severely reduced clover growth and N_2 fixation, and enhanced N losses. Leaching of nitrate increased steadily over time and during the second winter the average nitrate-N concentration of leachate at lm depth was 37 mg/l (over 3 times the NZ recommended limit for drinking water of 10 mg/l) compared with 12 mg/l in the 0 N farmlet. Monitoring of groundwater (at 3-4 m depth) suggested that some increase in nitrate-N concentration was also beginning to occur.

In contrast, the 200 N treatment had only a minor impact on N_2 fixation and N losses, while producing an 18% increase in milk production. There was relatively little effect of the 200 N treatment on the nitrate-N concentration of leachate during the first 18 months of the experiment. However, further measurements over time are needed to determine the long-term effect of N applications on the extent of N_2 fixation and N losses, particularly nitrate leaching into groundwater.

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