Improved nitrogen management with *eco-n* nitrification inhibitor — an example of *"Growing for Good"*

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Abstract

The recent report by the New Zealand Parliamentary Commissioner for the Environment, called "Growing for Good", highlighted the adverse impacts that nitrate leaching can have on water quality. It called for a 'redesigning for sustainability' of New Zealand farming in order to reduce the impacts of intensive farming and achieve more sustainable farming systems.

Reducing the leaks in the nitrogen cycle provides an opportunity to reduce the impact of dairying on the environment. The development of a new soil treatment method, called *eco-n* technology, can be used to improve the efficiency of the nitrogen cycle, reduce the environmental impacts of dairy farming and at the same time increase farm productivity. The development of '*eco-n*' technology by Lincoln University and Ravensdown Fertiliser Co-operative Ltd is therefore a significant step towards 'redesigning for sustainability'.

Our research results show that *eco-n* can:

- reduce nitrate leaching by 60%
- reduce cation leaching by 50%
- reduce nitrous oxide emissions (a potent greenhouse gas) by 75%
- increase spring pasture production by 20%, and
- increase annual pasture production by 15% per year.

This paper will cover the science behind the development of *eco-n* technology and the practical application of using *eco-n* technology.

Introduction

The recent report by the New Zealand Parliamentary Commissioner for the Environment, called "Growing for Good", examined the impacts that the intensification of farming is having on the New Zealand environment (PCE 2004). The report particularly highlighted the adverse impacts that nitrate leaching from dairy farming can have on water quality. The report then called for a 'redesigning for sustainability' of New Zealand farming to reduce such impacts and achieve more sustainable farming systems.

The nitrogen cycle in grazed pasture systems is known to be 'leaky' with excessive amounts of nitrogen being deposited in animal urine patches causing leaching losses of nitrate, and also emissions of nitrous oxide gas (a powerful greenhouse gas) (Fig. 1). Both of these reactions are considered undesirable because they not only represent a loss in soil fertility (and therefore a lost opportunity in pasture production as well as higher costs in applying more fertiliser) but are also increasingly being targeted as major sources of environmental pollution.

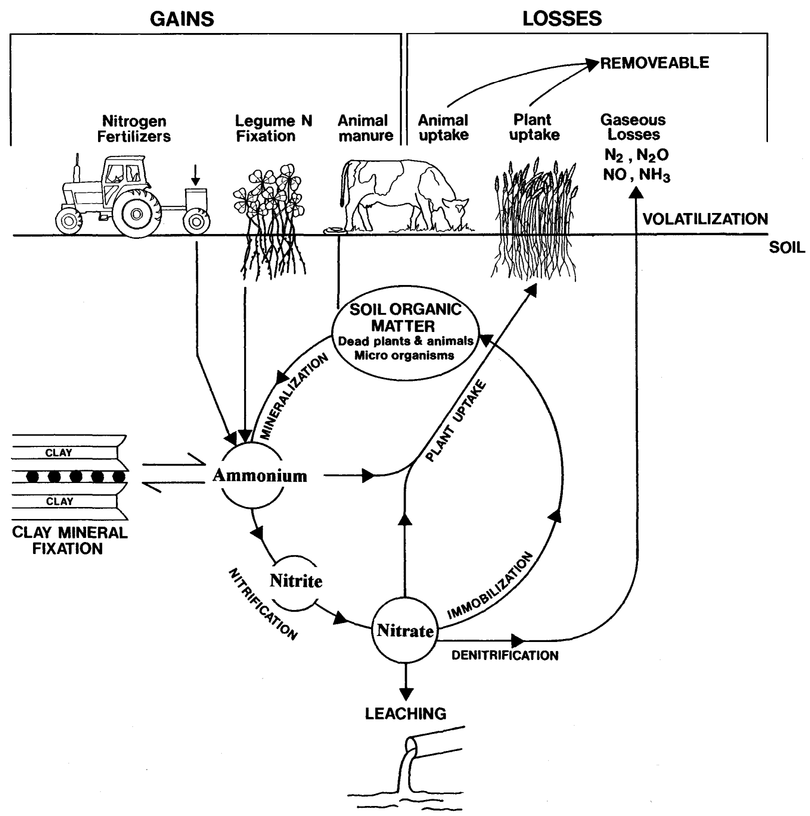

Figure 1. The nitrogen cycle in grazed pasture systems (from McLaren and Cameron, 1996).

The development of 'eco-n' technology by Lincoln University and Ravensdown Fertiliser Co-operative Ltd represents a new way of managing the nitrogen cycle in order to provide more soil nitrogen to meet plant demand. This innovation enables us to progress from simply applying more nitrogen fertiliser to meet this demand, to developing new ways of improving the efficiency of the soil nitrogen cycle by reducing the 'leaks' from the soil.

Nitrate leaching from dairy farming is a major environmental concern because a high nitrate concentration in drinking water is potentially harmful to humans and livestock, and elevated nitrate concentrations in surface waters may cause pollution which in turn affects recreational use of rivers and lakes (Cameron et al. 2002; Di & Cameron 2002a). It is now well proven that in a grazed pasture system direct leaching losses of nitrate from applied fertiliser nitrogen (N), or farm dairy effluent (FDE), are relatively small compared to the large leaching losses that occur from animal urine patches (Scholefield et al. 1993; Di et al. 1998, 2002a; Silva et al. 1999; Ledgard et al. 1999; Di & Cameron 2002b; Monaghan et al. 2002). Because of the random distribution and irregular timing of cow urine returns it is very difficult to reduce nitrate leaching from animal urine patch areas compared with that from the fertiliser per se.

Science behind eco-n technology

Di and Cameron (2002c, 2003, 2004a,b) recently reported a series of trials showing the effectiveness of treating grazed pasture soils, including animal urine patches, with a nitrification inhibitor (*eco-n*) to reduce nitrate leaching from a free-draining shallow stony Lismore soil and a deep sandy Templeton soil. This work involved making direct measurements of nitrate leaching from large soil lysimeters at Lincoln University and is underpinned by our soil science capability.

The use of lysimeters allows examination of treatment effects at the scale of the animal urine patch and allows accurate calculations to be made of paddock average values by taking into account the relative proportional coverage of urine patch and non-urine patch areas. The average NO_3^--N leaching losses from a paddock can be calculated according to Equation 1 below (Di and Cameron 2000):

$$N_L = N_{L1} \text{ x } P_1 + N_{L2} \text{ x } P_2 \qquad (1)$$

where N_L is the annual average NO_3^--N leaching losses from a grazed paddock, N_{L1} and N_{L2} are the leaching losses from the urine and none urine patch areas, respectively, as determined on the lysimeters, and P_1 and P_2 are the proportion of areas covered by urine and non-urine patch areas, respectively. The values of P_1 and P_2 will vary depending on the stocking rate. On a dairy farm with 3 cows/ha, the area covered by the urine patches is around 20 -25% of the grazed paddock area (Haynes and Williams 1993; Silva *et al*. 1999).

The nitrification inhibitor slows the first stage of nitrification and reduces the rate that ammonium is converted into nitrate in the soil (Figure 2). Ammonium (NH_4^+) is adsorbed onto the negatively charged cation exchange sites on soil clays and organic matter, thus protecting it from leaching and allowing it to be taken up by plants or be immobilised into soil organic matter. However, nitrate (NO_3^-) is easily leached from the soil because it has a negative charge and is repelled by the negatively charged sites on the clay and organic matter. Therefore reducing the rate of conversion from ammonium to nitrate can help to retain more nitrogen in the soil for plant use.

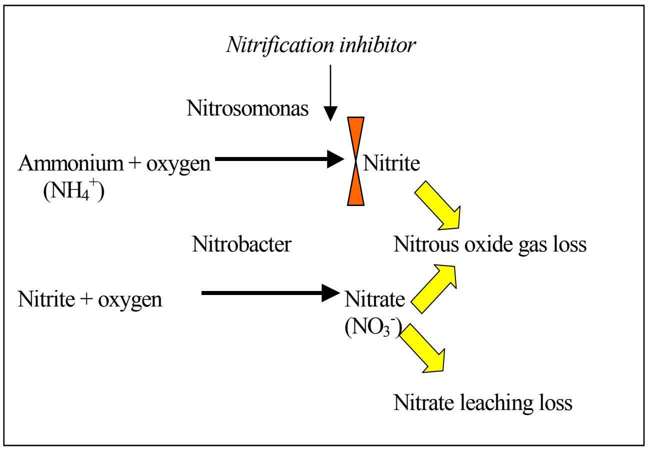

Figure 2. The nitrification inhibitor slows the rate of conversion of ammonium into nitrate in the soil and thus reduces the loss of nitrogen.

Nitrification inhibitors have been used in the past to increase the efficiency of N in fertilisers but until recently their potential to reduce nitrate leaching losses from grazed pasture systems had not been rigorously tested through direct measurements of leaching losses from lysimeters.

How many applications of eco-n are required?

Our recent results show that reductions in nitrate leaching of 60% can be achieved from an autumn urine patch with a single application of *eco-n* in the autumn (May), or two applications in the autumn plus spring (May plus August), (Figure 3).

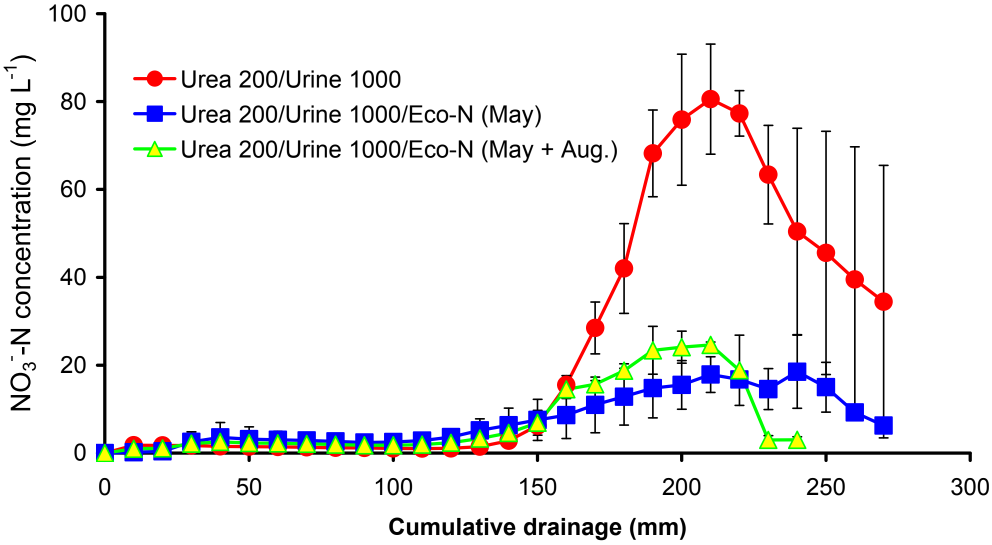

Figure 3. The effect of *eco-n* applied in May and May plus August on the nitrate concentration in drainage water from below cow urine patches applied in May (Templeton soil) (Di and Cameron, 2004b).

Under normal farming conditions we recommend two applications of *eco-n* to reduce nitrate leaching from both the winter and spring urine depositions. The effect of two applications of *eco-n*, one in May followed by one in August, on the amount of nitrate leached from a Templeton soil are shown in Figure 4. Both have significantly reduced the amount of nitrate leaching by over 60%.

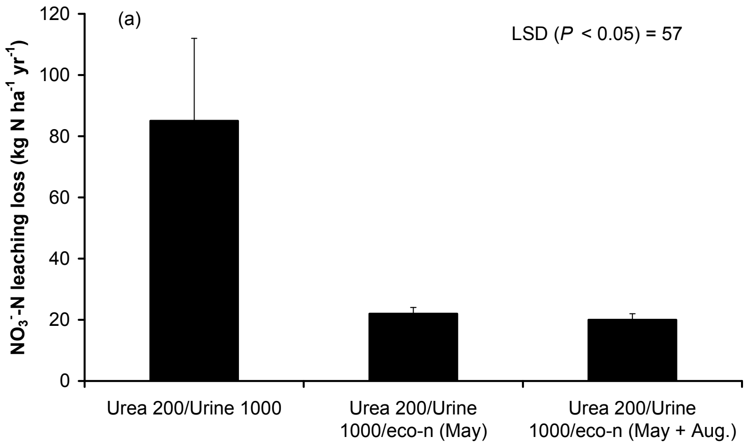

Figure 4. Total amount of nitrate leaching losses from large Templeton soil lysimeters following one application (May) and two applications (May and August) of *eco-n* (Di and Cameron, 2004b).

On-farm field scale measurements of Nitrate leaching

A pipe drainage measurement and monitoring system (Plate 1) has been established to measure the effect of 'eco-n' in reducing nitrate leaching in Temuka clay soils (Gley soils) on the new Lincoln University dairy farm. This drainage monitoring system represents a significant scaling-up of measurements from lysimeters to a typical on-farm field scale. The drainage plots are grazed by the cows as part of the normal grazing rotation on the farm (Plate 2). These plots also receive irrigation and fertiliser as part of normal farm operations.

In brief, we have six plots measuring 20 m x 5 m hydraulically sealed off from the outside paddock and each other. The water sampling and data recording facilities are highly automated to create a complete profile of rainfall and drainage events at the site. Tipping buckets simultaneous measure and record drainage from all 6 plots. Automatic samplers are configured to collect drainage water samples at each outfall in proportion to the flow rates of the drains. Tipping-bucket sensors are used to determine the drainage flow rate (Plate 3). Rainfall and irrigation are recorded at the site using a tipping bucket rain gauge, attached to a data logger. Data from the drainage samplers, rain gauge and other sensors are sent by telemetry to the Centre's laboratories, which alerts staff about the need to collect samples. Environmental research projects of this nature require state-of-the-art technology to deliver robust results.

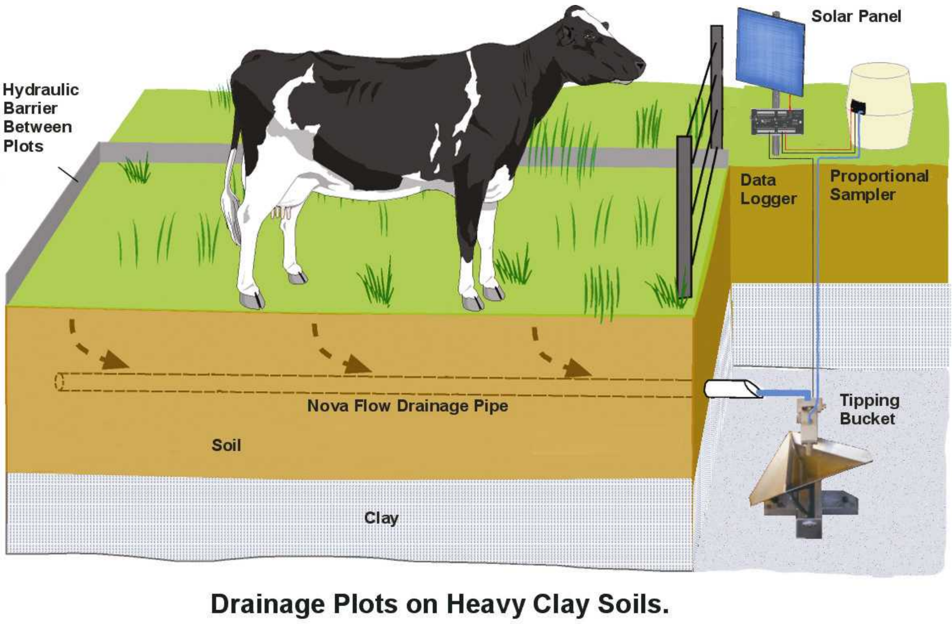

Plate 1. Environmental Monitoring System for measuring the effect of dairying on water quality

Plate 2. The six drainage plots outside the fence are grazed as part of the dairy farm.

Plate 3. Simultaneous measurement of the drainage rate from six plots by the tipping bucket method

In May 2004 urine patches (8) were laid down on all plots, and *eco-n* nitrification inhibitor was applied to three of the six plots at a rate of 10 kg ha^{-1} (active Ingredient) in a fine particle suspension form. A second application of *eco-n* was applied in August. The effect of *eco-n* on the concentration of nitrate in the drainage water from the Lincoln University dairy farm Temuka soil, field plots is shown in Figure 5. The nitrate concentration in the drainage water from the *eco-n* treated plots is consistently below that from the controls.

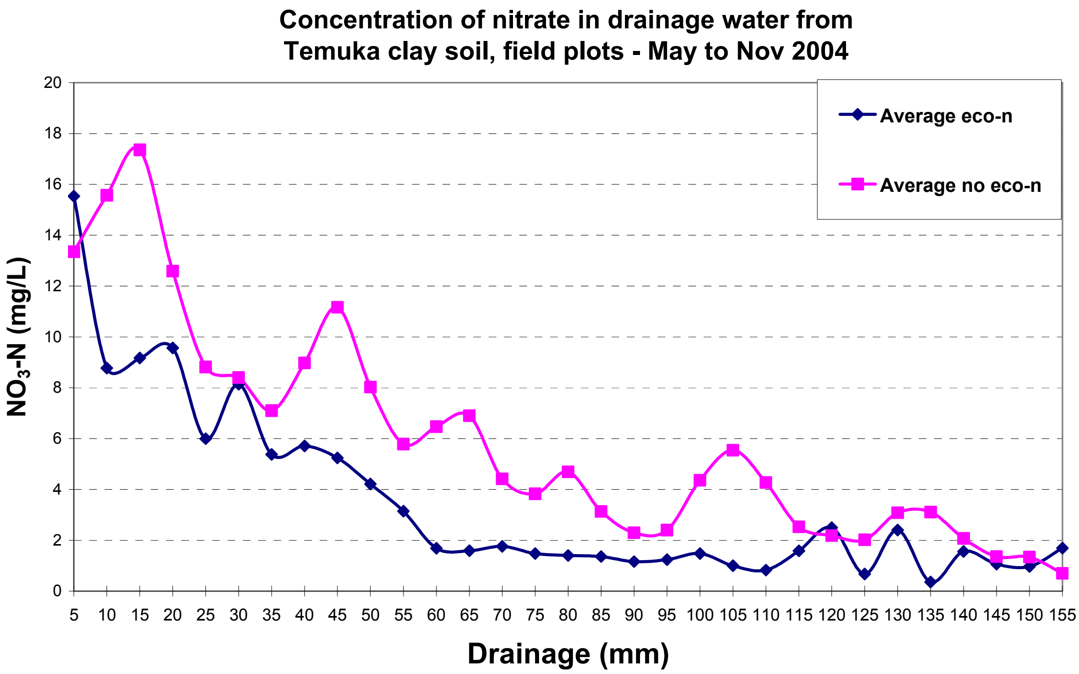

Figure 5. Nitrate concentration in drainage water between May and November 2004.

How long does eco-n last in the soil?

We have recently completed a detailed incubation experiment conducted under controlled temperature conditions to make direct measurements of how long *eco-n* will last in the soil (Di and Cameron, 2004c; Table 1).

Table 1. Half-life of *eco-n* in the soil at two soil temperatures

Treatments	Half-life (days)	% remaining after 25 days
Temperature of 8 °C	111	84 %
Temperature of 20 °C	25	50 %

The results in Table 1 show that at a soil temperature of 8°C the 'half-life' of *eco-n* was 111 days (the 'half-life' of a substance is the time taken for the concentration of that substance to be reduced by half). Thus a half-life of 111 days means that there will still be half the original concentration of *eco-n* remaining in the soil after this 3.5-month period. The rate that *eco-n* is decomposed in the soil is influenced by soil temperature and at a soil temperature of 20°C the half-life of *eco-n* was found to be 25 days. At 8°C the percentage of the applied *eco-n* remaining in the soil after 25 days is 84% and at 20°C the percentage remaining is 50%.

In New Zealand nitrate leaching mostly occurs during the main drainage period of the year (approximately June to September) when the soil temperatures are generally below 10°C (see Figure 6). During these winter months the *eco-n* is therefore likely to remain effective during this critical time of the year. The effectiveness of *eco-n* following a May application will be approximately 3 to 4 months (i.e. covering the critical drainage period from May to August). A subsequent application of *eco-n* in August will normally be effective for about another 2 months and will reduce leaching losses during the spring.

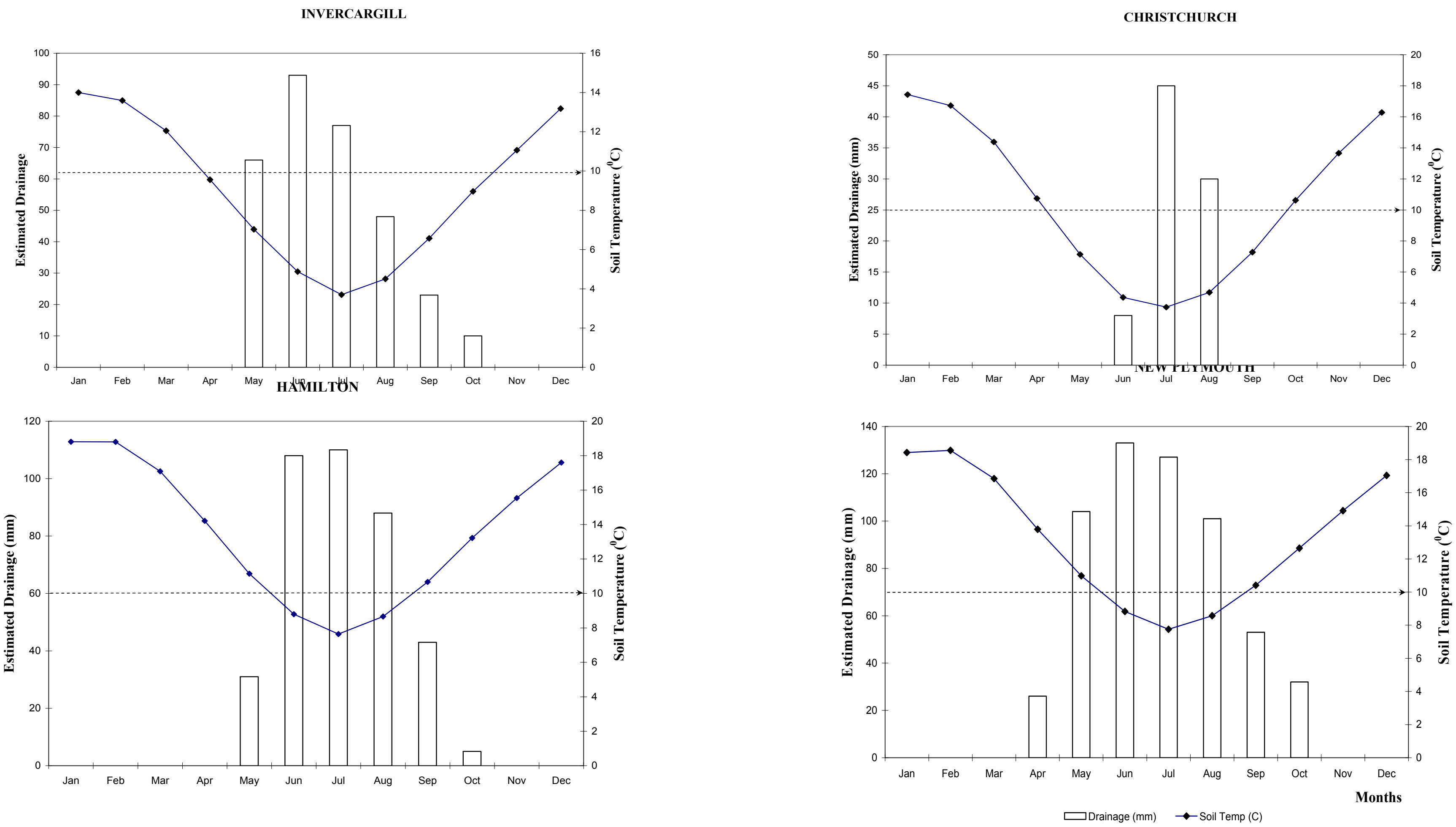

Figure 6. Long-term average monthly soil temperatures and estimated drainage in key dairying regions of New Zealand (NB. Actual drainage amounts will vary depending on soil type and actual rainfall.

Eco-n reduces leaching losses of potassium, calcium and magnesium
Because nitrate leaching is usually accompanied by calcium, potassium or magnesium ions (i.e. ions with an opposite electrical charge), the leaching of these nutrients has also been found to be reduced by applying *eco-n* (Di & Cameron 2004b: Figure 7).

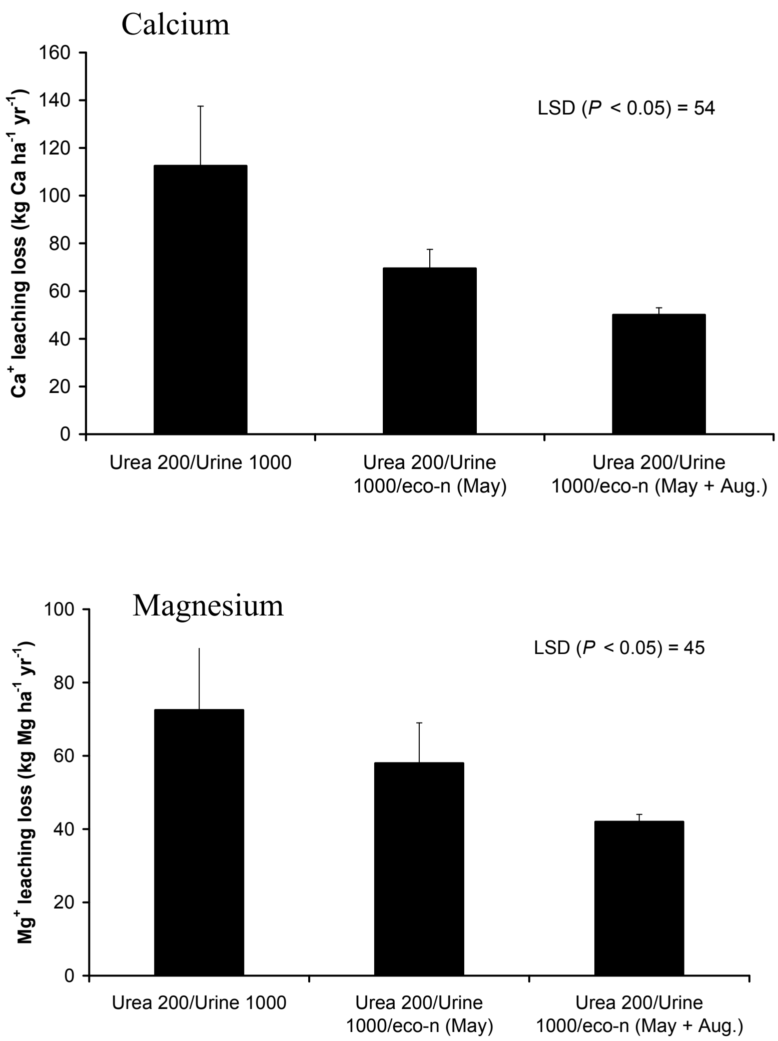

Figure 7. Effectiveness of *eco-n* application in reducing the leaching loss of calcium and magnesium from Templeton soil lysimeters (Di and Cameron, 2004b).

Eco-n also reduces greenhouse gas emissions

The use of *eco-n* has also been shown to reduce nitrous oxide (N_2O) emissions by 75% (Figure 8). This is important because nitrous oxide is a powerful greenhouse gas and its emission from grazed pasture soil represents about 33% of all greenhouse gases emitted from NZ agriculture and 17% of New Zealand's total greenhouse gases. The availability of *eco-n* technology to reduce this greenhouse gas emission provides NZ farmers with a new tool to reduce greenhouse gas emissions, as required by the Kyoto protocol. This farmer-funded research breakthrough was of considerable significance during the recent debate about the scrapping of the so-called 'flatulence tax' and will continue to be of increasing importance in future years.

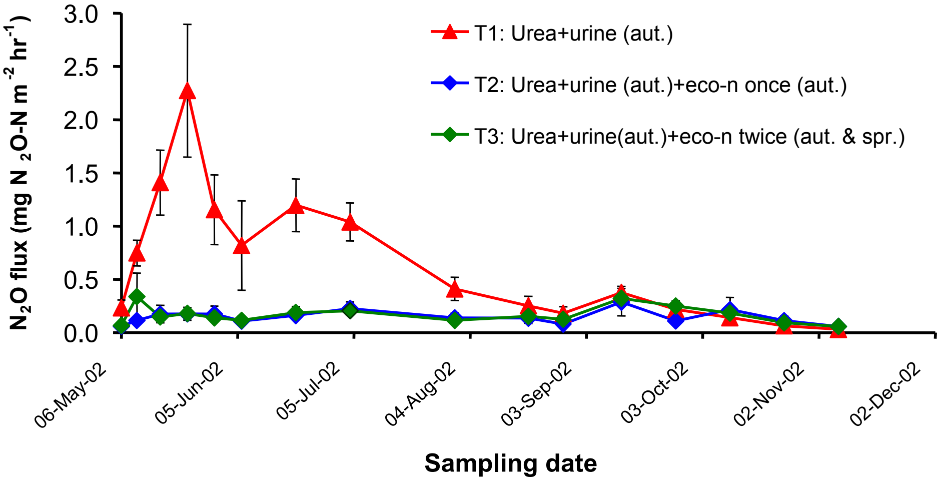

Figure 8. The effect of *eco-n* on nitrous oxide emissions from urine patches (Di and Cameron 2003).

How many applications are needed to get a significant pasture response?

Pasture yield increases occur because of the reduction in N losses and significantly more plant-available nitrogen remains in the soil for the plant to use. There is understandably some variability in the pasture yield data, similar to the variable responses to nitrogen fertilisers, but whole paddock measurements under dairy grazing e.g., on a poorly drained Temuka soil (Figure 9) suggest annual production lifts of 10% to 15% are likely to occur.

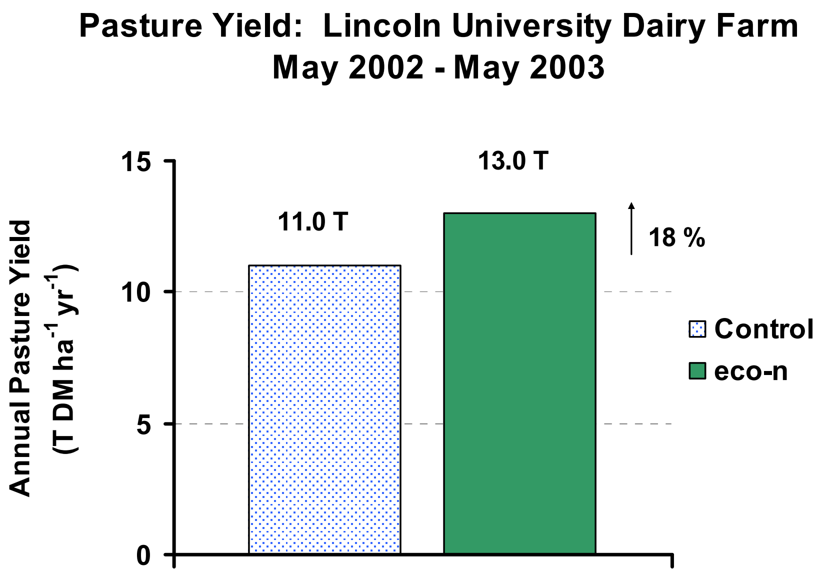

Figure 9. Increase in pasture production due to *eco-n* application under dairy grazing on a Temuka soil.

Plant responses in the spring have been very significant, with increases of over 20% being recorded on the Lincoln University dairy farm pasture plots (Fig 10). Increased pasture production is being achieved between urine patches as well as from within the urine patches (Fig. 10). This extra growth in the spring is particularly valuable.

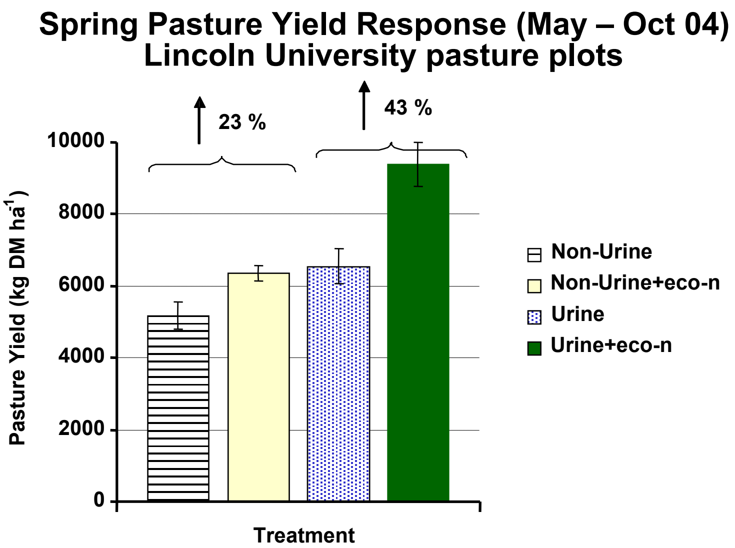

Figure 10. Spring pasture response to 'eco-n' applied in May and August.

Cost effectiveness of eco-n
Each application of *eco-n* costs $62.05/ha, with two applications required per drainage season (or per calendar year). The annual applied cost is therefore $124.10 /ha/year (GST exclusive). Valuing environmental gains at the farm level is difficult but dairy farmers can more easily relate to the value of additional feed grown, as discussed by Christie (2004) and Christie and Roberts (2004).

The research work indicates that when *eco-n* is used to retain more nitrogen in the soil over late autumn/winter/spring that increases of over 15% in annual paddock pasture production can be achieved. The additional feed produced with *eco-n* can be compared to the cost of purchasing feed, the cost of growing additional feed (typically with urea) or the value gained by converting additional feed into milk production.

Bought in feeds are typically purchased at 15-20 cents per kilogram drymatter (kgDM) while the cost of growing additional feed with urea can range from 10 – 15 cents per kg DM, depending on the nitrogen response. A 10% annual increase in feed with *eco-n* by comparison would cost 9.5 cents per kg DM while a 15% increase would only cost 6.4 cents per kg DM (assuming current production of 13,000 kg DM per hectare per year). Table 2 summarises the comparative cost of additional feed.

Table 2. Comparative cost of additional feed sources

Source of additional feed	**Cost per kg DM**
Eco-n (used as recommended in autumn and winter)	6-10 cents/ kg DM
Urea	10-15 cents / kg DM
Bought in feed	15-20 cents / kg DM

Converting additional feed directly into milk production is the most efficient means of harvesting and valuing the additional feed produced with *eco-n*. At a payout of $4.00 / kg milksolids, and a typical conversion ratio of 15 kilograms drymatter per kilogram milksolids, a 10% increase in pasture production provides an additional $347 / hectare income. Subtracting the cost of *eco-n* results in a net increase of $223/ha. A 15% increase as the result of applying *eco-n* will provide a net increase of $396/ha. (based on 13,000kg DM /ha/year as above). Table 3 outlines the return per hectare from converting additional pasture grown with *eco-n* into milk production.

Table 3. Return on investment with *eco-n* at 10% and 15% increased pasture production[1]

	Return with 10% increase in Pasture Production	**Return with 15% increase in Pasture Production**
Increased pasture production	1300 kg DM /ha/yr	1950 kg DM/ha/yr
Additional Milksolids	87 kg MS/ha/yr	130 kg MS/ha/yr
Total gross return	$347 /ha/yr	$520 /ha/yr
Net return	**$223 /ha/yr**	**$396 /ha/yr**
Return on investment	179%	319%

Note: [1] (Based on current production of 13,000kgDM/ha/year and $4.00 / kg MS)

The sensitivity to increased grass production achieved by *eco-n* (due to the better retention of nitrate-N) can be seen in the different financial outcome for 10% and 15% pasture production increases. At 13,000 kg DM base production, achieving a 10% lift in production with *eco-n* produces additional feed at a lower cost than using urea, or buying in feed at standard market prices. When the farm maximises the conversion of additional feed to milksolids, both the return per hectare and the return on investment are excellent, even with 10% extra grass growth.

Dairy farmers who produce around 13,000–15,000 kg DM hectare a year and apply *eco-n* can expect increased pasture production. Higher N users (at around 200 kg/ha) and who produce very high pasture yields such as 18,000 kg DM hectare a year should be able to apply *eco-n*, reduce their N inputs, and still have similar levels of pasture production.

When should eco-n be applied?

Eco-n should be applied to recently grazed (short) pasture where it can more quickly get into the soil, and receive 10 mm of rainfall or irrigation soon after application to wash it into the soil. Treat in a similar manner to fertiliser by not applying while stock is in the paddock and allowing it to be washed in before regrazing. It is unlikely to have any effect on animals if grazed after application, but its effectiveness will be reduced if it does not reach the soil.

Application in fine particle suspension form is necessary because it is vital to ensure even coverage of the whole grazed pasture soil area. A suspension is used as the most practical way to apply *eco-n*. Timing is very important. The April/May application covers the high-risk leaching period over winter, while the August/September dressing ensures coverage through spring. The product is not persistent over long periods and three to four months of protection per application is achieved.

Ravensdown closely manages the application of *eco-n* through the use of approved spray applicators that can provide proof of placement. This means that the product is sold on a per hectare applied cost basis. Taking this approach allows Ravensdown to ensure that the new product is applied appropriately (at the right rate and time) and on farm types where it will be economically effective. The accurate recording of where all product is applied also allows further studies on a regional and national basis in relation to the environmental benefits, particularly for greenhouse gas inventory calculations.

Conclusions

The development of a new soil treatment method, called *eco-n* technology, can be used to improve the efficiency of the soil nitrogen cycle, reduce the environmental impacts of dairy farming and at the same time increase farm productivity. Our research results show that the use of *eco-n* on grazed pasture soils can:

- reduce nitrate leaching by 60%
- reduce cation leaching by 50%
- reduce nitrous oxide emissions (a potent greenhouse gas) by 75%
- increase spring pasture production by 20%, and
- increase pasture production by 15% per year.

The development of '*eco-n*' technology therefore represents a significant step towards 'redesigning NZ farming systems for sustainability', as requested by the NZ Parliamentary Commissioner for the Environment.

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