New nitrogen mitigation technologies for evaluation in the Lake Taupo catchment

S.F. LEDGARD[1], B.G. WELTEN[1], J.C. MENNEER[1], K. BETTERIDGE[2], J.R. CRUSH[1] and M.D. BARTON[3]
[1]*AgResearch, Ruakura Research Centre, PB 3123, Hamilton*
[2]*AgResearch, Grasslands Research Centre, PB 11008, Palmerston North*
[3]*Farmer, Chairman of Taupo Lake Care group, R.D. 1, Turangi*
stewart.ledgard@agresearch.co.nz

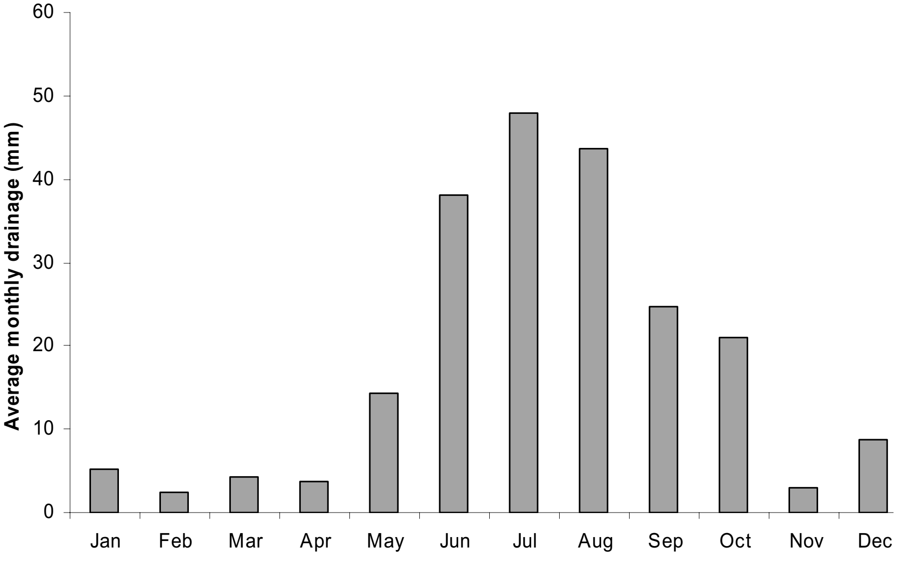
Abstract
Planned implementation of a nitrogen (N) "cap" on land in the Lake Taupo catchment has led to the need for a range of N mitigation options for pastoral farmers to increase profitability while farming within the N cap. A multi-disciplinary research programme has focused on the potential of targeting different parts of the N cycle to increase N efficiency and reduce N leaching losses. A range of research areas have been examined which focussed on soil amendments, improved pasture plants, animal manipulation and farm system options with potential for reduced N leaching. The "best bets" of practical options from this research have been selected, in consultation with local farmers through the Taupo Lake Care group. These are being tested in a new farm grazing system trial with beef cattle in the Lake Taupo catchment. The treatments are; a control (beef heifers), high sugar ryegrass (to potentially increase N absorption by cattle and reduce N excretion in urine), strategic salt supplementation (to increase urine spread), animal DCD supplementation (to achieve delivery of DCD in urine thereby inhibiting nitrification and reducing nitrate leaching) and steers (to compare spread of urine with female cattle). This long-term trial commenced in April 2007 and will evaluate effects of these N mitigation options on pasture production, N cycling and N leaching.

Keywords: DCD, grazing, Lake Taupo, mitigation, nitrogen leaching, salt

Introduction
Environment Waikato is planning to introduce a Variation to its Regional Plan to limit increases in nitrogen (N) inputs into Lake Taupo. A significant source of manageable N inputs occurs via N leaching from pastoral land in the Lake Taupo catchment (Vant & Huser 2000).

Research to date in the catchment has examined management options to reduce N leaching from pastoral farm systems, based on knowledge of N cycling and loss developed over the past few decades. This research recognises the animal urine patch as the major source of N leaching (e.g. reviewed by Ledgard 2001). It also acknowledges that most N leaching occurs over the

Figure 1 Average monthly drainage from a Taupo pumice soil, based on water budget calculations (Woodward *et al*. 2001), using 1972-1993 data from the Taupo airport meteorological station.



winter period when most drainage occurs (Fig. 1). This led to research examining practices to reduce N excretion by animals in late-autumn/winter such as grazing out of the catchment or on feed-pad based systems, which showed that N leaching could be reduced by up to 50% (e.g. Ledgard & Menneer 2005; Betteridge *et al*. 2005). However, a social research study with farmers in the catchment identified that feed-pad based systems were only of interest to some farmers and that a range of other N management options were required (Dooley *et al.* 2005). There was a large variation between farmers in their decision criteria associated with possible adoption of new management practices to reduce N leaching or to meet the proposed 'cap' on N leaching from farms, while increasing profitability (Dooley *et al.* 2005). This highlighted the need for a range of potential N mitigation options for farmers.

Proof of Concept Testing of N Mitigation Options

An AgResearch FRST-funded research programme entitled "Nitrogen and Lake Taupo" has a strong focus on developing second-generation or new N mitigation practices for use in the Lake Taupo catchment. This research programme has involved scientists from a range of disciplines covering soil, plant and animal sciences who have targeted different parts of the N cycle with the aim of identifying options to increase N efficiency and reduce N losses. This paper describes some of the research on increasing N efficiency and reducing N leaching associated with four parts of the N cycle (see Fig. 2) and focusing on the following questions:

1. Can we strategically increase immobilisation of animal urinary-N deposited on soil, thereby reducing the N surplus in soil prone to leaching?
2. Can we select grass characteristics such as increased root depth or chemical composition to increase recovery of N from soil and/or increase efficiency of N cycling?
3. Can we increase the spread of animal urine thereby reducing the high N rate in urine patches and reduce N leaching?
4. Can we use the animal to deliver nitrification inhibitors in the urine stream thereby reducing nitrification (conversion of ammonium to nitrate) from urinary-N and reducing N loss?

Potentially, the use of practices or technologies which reduce N leaching will have a feed-back effect on reducing clover N_2 fixation and operate a tighter and more efficient N cycle.

1. Strategic N immobilisation in soil

Adding a carbon source (e.g. sawdust or sugar) to the soil surface (or mixed in the top soil) has the potential to reduce N leaching under urine patches. This is due to the high C:N ratio in the carbon source that leads to soil bacteria immobilising urinary-N as the carbon is degraded. We carried out a field lysimeter study using intact soil monoliths encased in PVC (30 cm diameter by 50 cm deep) to investigate the effect of adding a carbon source (sucrose) to the soil surface immediately after the application of cow urine applied at a rate equivalent to 550 kg N/ha. The sucrose (42% carbon), in the form of refined household sugar, was applied to the lysimeters at three rates (0, 3 and 12 t sucrose/ha) immediately after urine application, and N leaching and herbage yield were recorded.

Figure 2 General diagram of the N cycle in sheep and cattle grazed pastures, and four parts of the cycle where research is targeting increasing the efficiency of N cycling and reducing N losses.

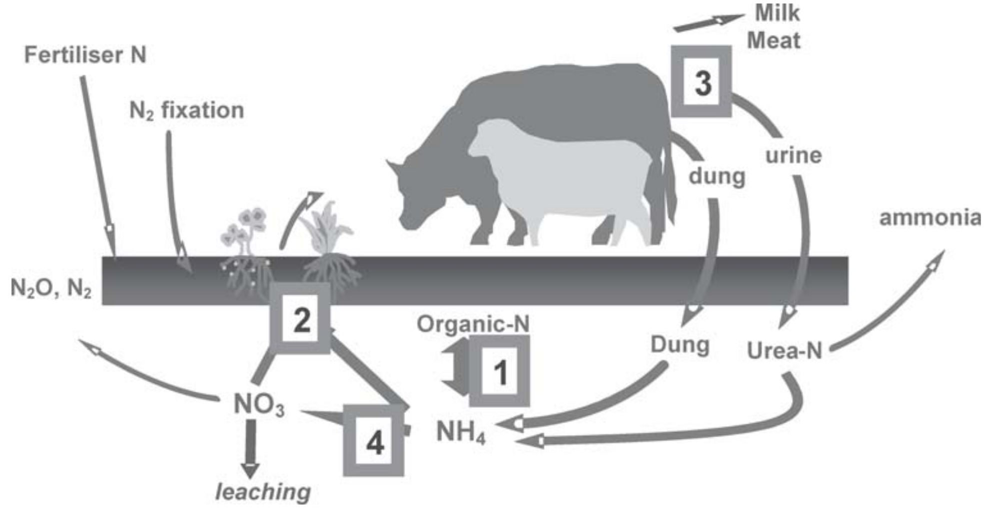
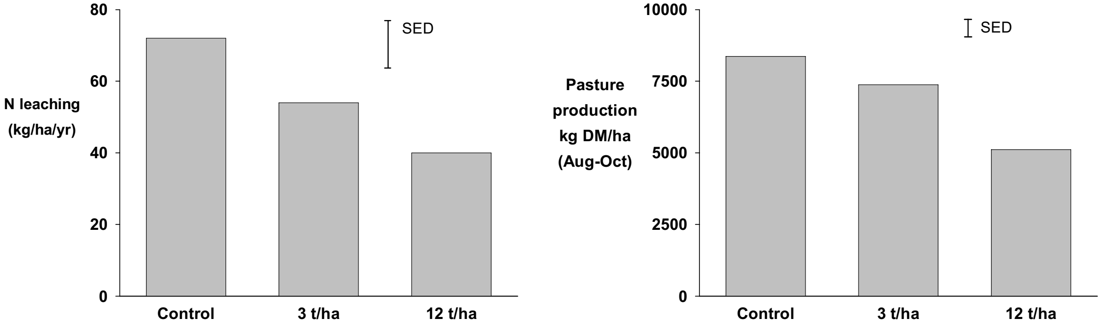


Figure 3 Effect of carbon supplementation (t sucrose/ha) on nitrate-N leaching and pasture production (August-October) from lysimeters containing established grass/clover pasture on Taupo pumice soil and all receiving cow urine.



This study showed that carbon addition (as sugar) reduced nitrate leaching losses by between 24% and 45% for the range of carbon application rates used (Fig. 3). However, the apparent increased immobilisation of N and associated reduced urinary-N availability led to a loss in pasture yield of between 12% and 39% across the different rates of applied sugar. This represents a significant loss of pasture production which could outweigh the benefit of reduced nitrate leaching by use of carbon enriched materials. Furthermore, the large amounts of carbon that may need to be applied, could render the technology impractical. Further research is investigating the effects of rate and form of carbon application to determine if effectiveness can be improved. However, it must be recognised that this may only be a short-medium term strategy for reducing N leaching because a new equilibrium level of organic matter in soil will be attained in the long-term after which increased mineralisation would counter immobilisation.

2. Grasses for improved N recovery and N cycling efficiency

Breeding perennial ryegrass (*Lolium perenne* L.) for specific root characteristics that might assist in reducing nitrate leaching compared to conventional pasture species has only recently received attention in New Zealand (e.g. Crush *et al*. 2005). Current research has identified some strains of ryegrass with increased rooting depth (Crush *et al*. 2007) and increased ability to intercept and remove nitrate from a greater depth of soil, thereby potentially reducing N leaching. Plant composition can also affect the fate of plant-N consumed by animals and influence N losses. For example, UK research with high sugar ryegrass has shown increased animal recovery of grass-N and less excretion of N in urine relative to dung, indicating the potential for increased N efficiency (Miller *et al*. 2001). Although, aspects of plant growth and composition have the potential to reduce N leaching, there is still considerable research needed to determine the magnitude of reduction in N leaching in grazing systems.

3. Increased spread of excreted urine using salt as a diuretic

Dairy and beef cow urine patches contain very high rates of N (e.g. 400-1000 kg/ha; Whitehead 1995) and represent the main source of N leaching from grazed pastures. One potential option to reduce N leaching is to increase the spread of urine, thereby diluting the rate of urinary-N and increasing plant uptake of N. Supplementing a diuretic in the form of salt (NaCl) to a cow's diet is a potential mitigation option to reduce N leaching.

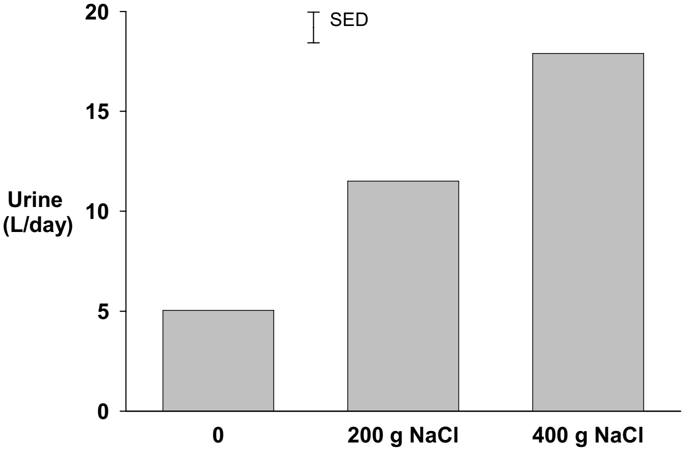
A dairy cow metabolism stall study was carried out in collaboration with Dexcel at Lye Farm, Hamilton during winter 2006. Three treatments involved 15 non-lactating dairy cows drenched with water (control) or salt (200 or 400 g/cow/day) solution over a 6 day trial period. Cows were fed pasture silage from the Lake Taupo catchment at the equivalent of approximately 10 kg DM/cow/day. Daily water intake, urine volume and feed intake were monitored throughout the trial.

There were no adverse effects of salt on cow liveweight or feed intake. Daily water intake averaged 19, 24 and 34 L/day for 0, 200 or 400 g/day salt treatments respectively ($P<0.001$). Similarly, supplementing with salt significantly ($P<0.001$) increased cow urine volumes by approximately 2- and 3-fold respectively, compared to the non-salt control treatment (Fig. 4). This coincided with reduced urinary-N concentration (9.6, 4.0 and 3.0 g N/L for the 0, 200 or 400 g/day salt treatments respectively; $P<0.001$) and increased urination frequency such that the volume of urine voided with each urination was similar in all treatments. Thus, the differences in Figure 4 reflect the likely increase in spread of urinary N and the potential for reduced N leaching.

4. Animal delivery of DCD in urine

Research has shown that dicyandiamide (DCD) surface-applied onto urine patches can be effective in inhibiting nitrification (conversion of ammonium to nitrate) and reducing nitrate leaching (e.g. Di & Cameron 2005). Potentially, this could be achieved by administration of DCD to animals so that they deliver the DCD in their urine stream. The first research study to examine this involved fistulated sheep in metabolism crates with DCD infused into their abomasum or rumen. This study showed that 86-99% of the DCD infused was voided in the urine in an unaltered form and was effective in inhibiting nitrification of urinary N in soil. About 1-2% of the infused DCD was excreted in the animal dung. The study also showed that when DCD infusion ceased the concentration of DCD in urine declined to background levels within several days, indicating that a continuous source of DCD delivery is required for a long enough period to reduce leaching from urine excreted by grazing animals. Current research is examining the use of a slow-release bolus to achieve sustained delivery of DCD.

Figure 4 Comparison of average daily urination volume in non-lactating cows supplemented with different levels of salt in a metabolism stall study.



A Grazing Trial to Evaluate N Mitigation Options

A key part of the Nitrogen and Lake Taupo research programme is the selection of potential N mitigation options for evaluation in a grazing study in the Lake Taupo catchment. Regular communications and meetings with farmers in the catchment on this topic have been used to identify a farm in the catchment for evaluation of the N mitigation options under grazing conditions representative of those for beef cattle. Additionally, these farmer interactions have been used to discuss results from research to date (including those outlined in previous sections) and identify up to four N mitigation options for evaluation.

The outcomes of the research on strategic immobilisation of animal urinary-N were not seen as being sufficiently practical and this option was not considered for field evaluation. The use of salt and animal delivery of DCD were seen as new and potentially practical options warranting testing under field conditions. Similarly, improved grasses were seen as a useful option which could be introduced when pastures were being renovated or following winter crops. However, because selections for increased root depth and N recovery were not yet ready for field scale testing it was decided to only test high sugar ryegrass. Farmers were also particularly keen on evaluating male cattle as an alternative to breeding cows to test anecdotal evidence of greater spread of urinary-N by male cattle than female cattle.

A grazing system trial (planned to run for at least 3 years) commenced on a commercial farm in the Lake Taupo catchment in autumn 2007 with the following treatments:

1. A control with beef breeding heifers under standard management,
2. High sugar ryegrass sown after spraying out existing grasses and managed as for the control,
3. Strategic supplementation of salt to beef breeding heifers under standard management,
4. Strategic supplementation of DCD to beef breeding heifers under standard management,
5. Steers, of similar age to heifers, managed to achieve similar pasture intake to that of the control treatment.

Measurements in the grazing systems (six paddocks/treatment) include pasture intake, pasture chemical composition, cattle water intake, cattle urination frequency and composition, and N leaching. The latter uses ceramic cup samplers (150 per treatment; 60 cm depth) for regular sampling of soil solution at depth combined with measurements of drainage (using lysimeters and water balance calculations).

A series of small plot and lysimeter trials have also been set up on-site to provide related data on N leaching from urine patches and a better understanding of mechanisms and appropriate rates and timing of application of these and other potential mitigation options.

ACKNOWLEDGEMENTS

We gratefully acknowledge Taupo landholders who actively participated in the meetings and discussions on mitigation options. We thank Alan Napper, Mark Bryant and Dave Phipps (Dexcel) and David Pacheco and Jason Peters (AgResearch) for expertise in conduct of the metabolism stall studies, and Moira Dexter, Martin Kear and Stuart Lindsey for analytical expertise. We also thank Dairy Insight for funding support for the salt supplementation study and FRST for overall research funding.

REFERENCES

Betteridge, K.; Ledgard, S.F.; Lambert, M.G.; Thorrold, B.S.; Costall, D.A.; Theobald, P.W.; Hoogendoorn, C.J.; Park, Z.A. 2005. Reduced nitrate leaching from livestock in the Lake Taupo catchment: results from 2 years research. pp 49-56. *In*: 2nd European Conference on Precision Livestock Farming. Ed. Stafford, J.V. Wageningen Academic Publishers, The Netherlands.

Crush, J.R.; Waller, J.E.; Care, D.A. 2005. Root distribution and nitrate interception in eleven temperate forage species. *Grass and Forage Science 60*: 385-392.

Crush, J.R.; Easton, H.S.; Waller, J.E.; Hume, D.E.; Faville, M.J. 2007. Genotypic variation in root distribution patterns, nitrate interception, and moisture stress response of a perennial ryegrass (*Lolium perenne* L.) mapping population. *Grass and Forage Science 62*: in press.

Di, H.J.; Cameron, K.C. 2005. Reducing environmental impacts of agriculture by using a fine particle suspension nitrification inhibitor to decrease nitrate leaching from grazed pastures. *Agriculture, Ecosystems and Environment 109*: 202-212.

Dooley, A.E.; Smeaton, D.; Ledgard, S.F. 2005. Identification of important criteria in farm systems decisions around Lake Taupo. pp 27-35. *In*: New Zealand Agricultural and Resource Economics Society, AERU No. 152.

Ledgard, S.F. 2001. Nitrogen cycling in low input legume-based agriculture, with emphasis on legume/grass pastures. *Plant and Soil 228*: 43-59.

Ledgard, S.F.; Menneer, J.C. 2005. Nitrate leaching in grazing systems and management strategies to reduce losses. pp. 79-92. *In*: Developments in fertiliser application technologies and nutrient management. Eds. Currie L.D.; Hanly, J.A.. Occasional report No. 18. FLRC, Massey University, Palmerston North.

Miller, L.A.; Moorby, J.M.; Davies, D.R.; Humphreys, M.O.; Scollan, N.D.; Macrae, J.C.; Theodorou, M.K. 2001. Increased concentration of water-soluble carbohydrate in perennial ryegrass (*Lolium perenne* L.). Milk production from late-lactation dairy cows. *Grass and Forage Science 56*: 383-394.

Vant, B.; Huser, B. 2000. Effects of intensifying catchment land use on the water quality of Lake Taupo. *Proceedings of the New Zealand Society of Animal Production 60*: 262-264.

Whitehead, D.C. 1995. Grassland nitrogen. 397pp. CAB International, Wallingford, UK.

Woodward, S.J.R.; Barker, D J.; Zyskowski, R.F. 2001. A practical model for predicting soil water deficit in New Zealand pastures. *New Zealand Journal of Agricultural Research 44*: 91-109.