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Dairy farming, nitrogen losses and nitrate-sensitive areas

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ABSTRACT

Dairy farms exhibit large nitrogen (N) fluxes throughout the soil/plant/animal system. These fluxes increase with increasing N inputs and farming intensity, and can lead to significant N losses into the environment. Under New Zealand grazed pastoral systems, the N losses occur predominantly from animal urine. Nitrogen can impact on water quality for human consumption or for aesthetics, recreational use and fisheries via enhanced aquatic plant or algae growth. In this paper, N flows in dairy farms in New Zealand are compared with those in the European Union (EU), where dairy farming is generally more intensive. In the EU, legislation is being used to reduce N losses from intensive dairy farming in nitrate sensitive areas through defined maximum rates of manure application. Progressive reduction in these rates will potentially reduce stocking rates on intensive EU farms such as in the Netherlands, where taxation of farm N surpluses is also used as a deterrent. New Zealand has a lower average farming intensity and lower N losses to the environment than in intensive EU farms. However, farmlet systems research has shown that high N inputs of c. 400 kg N/ha/yr can increase nitrate-N concentration in groundwater by up to twice the recommended maximum for drinking water. In nitrate sensitive areas, such as around Lake Taupo, it is desirable to minimise nitrate leaching and the associated lateral movement to surface water bodies. A range of on-farm options are discussed including limiting external N inputs, increasing N use efficiency via lower protein feed sources, reducing farm dairy effluent N losses, and avoiding direct deposition of excreta to land in autumn/winter using grazing-off or feed-pad systems. Off-farm, there is potential to intercept leached nitrate before it enters surface waters via riparian strips or trenches, or in-stream removal by aquatic plants. In nitrate sensitive areas, there is a need to use a whole catchment approach by examining all contributions to nitrate leaching and not simply targeting one agricultural practice such as dairy farming.

Keywords: dairy farming; mitigation; nitrate leaching; nitrate sensitive areas; nitrogen

INTRODUCTION

Nitrogen (N) is a key nutrient in determining pasture productivity. The quantity of N cycling in pastoral systems is greater than that for other nutrients and it is more mobile than most other nutrients. This leads to the potential for significant losses of N into the environment from nitrate leaching to groundwater and gaseous N emissions (e.g. Jarvis *et al*., 1995).

High nitrate levels in groundwater may restrict the use of the water for drinking, particularly for young children because of the risk of methaemoglobinaemia (Burden, 1982). Thus, the New Zealand Ministry of Health (1995) and World Health Organisation have a recommended maximum concentration of nitrate-N in drinking water of 11.3 mg/L. Nitrogen can have other impacts on water quality. Groundwater nitrate moves laterally into surface waters where it can affect algae and plant growth in streams, fish and other animal habitat requirements, and may also influence water supply and water usage (Boothroyd *et al.*, 1997).

Dairy farming is generally the most intensive system of pastoral land management and the stocking rate on New Zealand farms has increased steadily over the past two decades (Livestock Improvement, 1998) together with the use of N fertiliser. Are the environmental impacts from N increasing? A “clean green” image is used in the marketing of our dairy produce overseas and it is important that sales are not jeopardised. Other developed countries (e.g. in the EU) are placing some restrictions on farming practices to reduce losses of N into the environment.

This paper will briefly describe the EU and NZ scenes concerning dairy farming, N losses and legislation. Data will be presented on N flows in NZ dairy farm systems and the options for reducing N losses for dairy farming in sensitive areas, such as around Lake Taupo.

THE EU SCENE

In 1991, member countries of the EU agreed to a Nitrate Directive with an aim to identify regions or “vulnerable zones” with nitrate-N concentrations in groundwater in excess of the 11.3 mg/L limit. Austria, Denmark, Germany, Luxembourg and the Netherlands designated their whole country as vulnerable zones. Action programmes were then required with mandatory restrictions on farmer activities to reduce nitrate levels. The most significant implication to pastoral farming was a maximum application rate of animal manure to land of 210 kg N/ha/year from December 1998 and reducing to 170 kg N/ha/year from December 2002. This restriction has major implications for EU farms where the animals are housed, and manure is collected in the dairy and barns during a significant part of the year. For example, in the Netherlands, it could correspond to a reduction in stocking rate from 2.5 to 1.2 milking cows/ha and result in a major reduction in the level of milk production (Stelwagen and Davis, 2000).

In the Netherlands, most drinking water is pumped from groundwater and drinking water companies face costs for treatment to remove nitrate of US$35-70 million/year (Joosten *et al*., 1998). Prevention is seen as being cheaper than treatment and some water companies are subsidising

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farmers to reduce farming intensity (e.g. to move to organic farming) to reduce nitrate contamination.

The Dutch government has established an alternative system to restrict excessive N losses to the environment, which targets farm systems as a whole rather than one aspect such as manure applications. This mineral accounting system (MINAS) requires all farmers to provide records on all inputs of N and P to the farm and any farm-gate outputs so that a N or P surplus can be calculated (Oenema *et al*., 1998). Farmers are then taxed if these surpluses exceed defined levels (see Table 1). This approach encourages farmers to minimise the inputs to the farm and to maximise the utilisation of nutrients recycling within the farm (e.g. animal excreta) to maintain production. It is, therefore, more sensible than crude restrictions on manure or stocking rate and our research has shown that nitrate leaching to groundwater is correlated with on-farm N surpluses (e.g. Table 2; Ledgard *et al.,* 1999a).

TABLE 1: Levy-free N or P surpluses permitted on pastoral farms in The Netherlands. Surpluses are calculated from the difference between inputs of N or P to the farm (in fertiliser, feed or manure brought onto the farm) and outputs via produce, feed, and manure sold off farm (Oenema *et al*., 1998).

	1998	2000	2002	2005	2008
N surplus (kg/ha/yr)	300	275	250	200	180
P surplus (kg/ha/yr)	17	15	13	11	9

THE NZ SCENE

In New Zealand, Parliament passed the Resource Management Act (RMA) in 1991 which promotes sustainable management of natural resources. The tenor of the Act is effect-based rather than being prescriptive to activities. The RMA is enacted through Regional Plans of the various Regional Councils. Most Regional Councils have set regulations for maximum N loadings in farm dairy effluent application to pasture land of 150 or 200 kg N/ha/yr, and two of the 16 Regional Councils have similar maxima for application of fertiliser N.

The farm dairy effluent typically contains about 5-10% of the total animal excreta deposited, with most returned in the paddocks during grazing. This contrasts with the EU scene where collected manure represents a much larger proportion of the total amount of excreta deposition and N flux.

Total N inputs on an average New Zealand dairy farm are lower than those for EU farms (Table 2), and most N is from clover N_2 fixation whereas fertiliser and imported feed are the main N inputs on EU farms. Farm N surpluses (S N inputs – N outputs in produce) and nitrate leaching on New Zealand farms are half those of farms in Brittany and a quarter of those in the Netherlands (Table 2).

EFFECT OF INCREASING N INPUTS

New Zealand farms cover a wide range in intensity and N inputs. For example, in the Waikato, about 15% of dairy farms apply no N fertiliser whereas 3% apply 150-200 kg N/ha/yr and just over 2% apply >200 kg N/ha/yr (T. Johnston pers. comm.). The impact of increasing N fertiliser inputs on nitrate leaching was determined in a farmlet study at the DRC Number 2 dairy and showed a marked increase in nitrate leaching with increasing N rate (Figure 1). The average concentrations of nitrate-N in leachate draining to groundwater under the farmlets were 5, 12 and 25 mg/L for the 0, 200 and 400 N farmlets, respectively. Groundwater analyses showed similar values and indicate that application of fertiliser N at 400 kg N/ha/yr increased the nitrate concentration to about twice the recommended maximum for drinking water.

TABLE 2: Comparison of N inputs, outputs, surpluses and nitrate leaching for "average" dairy farms in New Zealand, France and the Netherlands.

	New Zealand (1997/98)[1]	Brittany, France (1997)[2]	The Netherlands (1994-1997)[3]
Cows per ha[a]	2.6	1.4	1.64
Milk (litres cow^{-1})	3420	5810	7250
Total milk (litres ha^{-1})	8890	8000	11890
Nitrogen inputs			
Fertilizers	50	200	291
N_2 fixation	110	0	0
Purchased feed	5	64	145
Atmospheric deposition	2	3	49
Total N inputs	**167**	**267**	**486**
Nitrogen output in products			
Milk	52	47	64
Meat	9	14	14
Total N output	61	61	78
Nitrogen surplus	**106**	**206**	**407**
Nitrate leaching	30[4]	c.60	124

[1]Livestock Improvement (1998) national summary; [2]Simon *et al*. (1997) for 133 farms;
[3]Van Bruchem *et al*. (1999) national summary and Aarts *et al.* (1999);
[4]estimated using OVERSEER (Ledgard *et al*., 1999b).

OPTIONS FOR REDUCING NITRATE LEACHING IN SENSITIVE AREAS

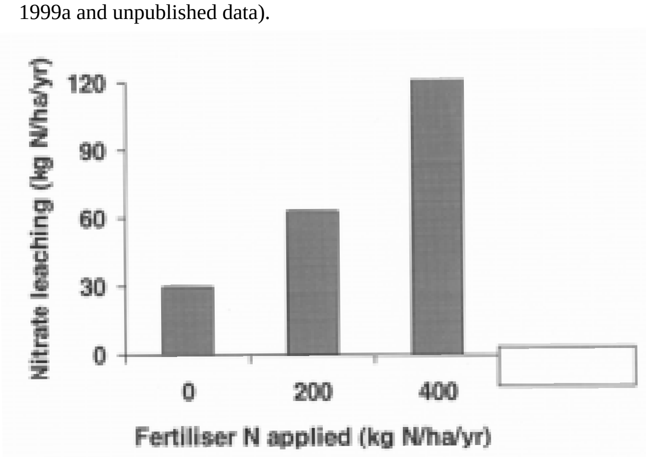
The potential options for reducing nitrate leaching from pasture centre around reducing N inputs, reducing loss from farm dairy effluent, decreasing animal stocking rate, and increasing N efficiency. There is also potential to reduce nitrate entering sensitive surface water bodies by removal as groundwater nitrate moves laterally to streams. This removal may occur via denitrification in artificial denitrification walls (Schipper and Vojvodic-Vukovic, 1998) or natural riparian zones, or via uptake by stream plants (e.g. Cooper, 1990). The following sections will consider on-farm options only.

Reduced N inputs

Reduction in the annual input of N in fertiliser or imported feed sources will reduce the amount of N cycling and decrease the potential for N loss (e.g. Figure 1). There is little potential to reduce nitrate leaching by altering the timing of N fertiliser application. Detailed measurements using ^{15}N in the DRC farmlet study revealed that there was minimal direct leaching of fertiliser N in the 200 N farmlet (where N was applied after most grazings at 22 kg N/ha) and approximately 10% direct leaching of fertiliser N in the 400 N farmlet. In all farmlets, the source of leached nitrate was predominantly from N deposited in cow urine. Direct leaching losses of fertiliser N generally only occur when applied in late-autumn and winter, and avoiding N fertiliser application during this period of the year can minimise direct leaching of fertiliser N (Ledgard *et al*., 1988).

The "average" New Zealand dairy farmer only applies about 50 kg N/ha/yr as N fertiliser and imports c. 5 kg N/ha/yr in feed (Table 2). Removal of both of these additional N sources could reduce nitrate leaching from 30 kg N/ha/yr to about 20 kg N/ha/yr (estimated using OVERSEER). The later loss is a product of N inputs via clover N_2 fixation and leaching of urinary N.

FIGURE 1: Effect of rate of N fertiliser application on nitrate leaching from farmlets at DRC Number 2 dairy stocked at 3.3 cows/ha on a free-draining volcanic ash soil. Data are the mean for 5 years (Ledgard *et al*. 1999a and unpublished data).



Reducing effluent N loss to ground or surface water

Farm dairy effluent is either processed through two pond systems with discharge to surface waterways or applied to land. Land application of farm dairy effluent increases utilisation of nutrients by pasture, and is promoted by Regional Councils. Average two-pond processing systems remove about 75% of incoming N by conversion into gaseous forms (Selvarajah, 1996) and the remainder is typically discharged into streams. With the N component of farm dairy effluent corresponding to approximately 20-50 kg N/ha/yr on a whole farm basis, this discharge equates to approximately 5-12 kg N/ha/yr.

Where effluent is applied to land, a significant component of the effluent N is absorbed by plants, which is subsequently consumed by cows, excreted and subject to leaching losses. Thus, it is akin to fertiliser N application although the slower N availability from organic forms in the effluent and the recalcitrant nature of some constituents mean that more N remains in organic forms in soil than with fertiliser N, at least in the short-medium term.

It can be estimated that land application of the farm dairy effluent would increase total nitrate leaching by approximately 5-10 kg N/ha/yr and total losses to waterways (leaching+runoff) by c. 10-16 kg N/ha/yr. However, if land application of effluent was used to reduce N fertiliser use by the equivalent N input, there would be little or no effect of effluent on farm nitrate leaching loss.

Reduced stocking rate

Reduction in stocking rate can decrease N losses if it corresponds to a reduction in N excretion. In this case, less N is excreted in urine patches where it is inefficiently used by pasture and more flows through the pasture senescence/mineralisation of litter pathway from which losses are low. However, if a lower stocking rate coincides with a higher per-cow pasture intake there may be little change in per-hectare intake, and N excretion and nitrate leaching will be similar.

Increased N efficiency

Two major inefficiencies in the cycling of N in grazed pastures and the conversion into milk-N are i. The high protein content of pastures compared to the dietary requirement of cows, and ii. The high concentration of excreted N in urine patches equivalent to c. 1000 kg N/ha (Haynes and Williams, 1993).

In the EU, considerable research effort is targeting optimising the integration of maize cropping with pastures to provide a diet with optimal protein content for milk production. Van Vuuren and Meijs (1987) examined the N efficiency of cows fed the same dry matter levels of pasture or a 50:50 pasture:maize silage diet and measured 40% greater conversion of dietary-N into milk and 45% less N excreted in urine from the pasture:maize silage diet. Farm N efficiency will be significantly higher if increased feed requirements are met through the use of low N supplements such as maize silage as an alternative to using N fertiliser-boosted pasture. The total N concentration of the former is typically less than half that of N boosted pasture. Dairy research on this topic in England (S. Peel, *pers. comm.*) and the Netherlands (Aarts *et al.*, 1999) is assessing replacement of a proportion of the pastoral land with maize cropping for best N use efficiency. While this research has shown reduced nitrate leaching, it has identified the importance of managing cultivated land during and after conversion into maize. Mineralisation of soil organic N is large following cultivation and overseas research highlighted the need for cover crops following maize to utilise inorganic N which remained in soil after the maize crop. This may be less important in New Zealand where maize silage is harvested sufficiently early in autumn to establish grass capable of significant N uptake before winter. Integrating maize into New Zealand pastoral systems has shown beneficial effects on milk production but there has been no research on the effects on N use efficiency or nitrate leaching losses. In the longer-term, genetic engineering of forage grasses for high energy:protein content may contribute to improving conversion of pasture N into milk.

The second main area where N efficiency can be increased is to reduce losses from urine-N. The main leaching loss of N from urine is likely to be from urine deposited in autumn and winter. Leaching is largely confined to the winter period when soil moisture is at field capacity and net drainage occurs (between May and September, and mostly in June-August, in the Waikato). At this time, the lower temperatures also mean that uptake of urinary N by grass is relatively slow.

Management options to reduce leaching of urinary N include grazing cows off the farm over winter (although this simply transfers the potential leaching from the sensitive catchment to someone else's catchment!), putting cows on a feed-pad over autumn/winter, or a complete animal housing/cut-and-carry system. The latter two systems require collection of excreta and re-application of the collected effluent onto pasture during spring and summer. The potential effect of the latter two management options on nitrate leaching losses for the average New Zealand dairy farm and the 0 or 200 N farmlets at DRC Number 2 dairy is summarised in Table 3. These model calculations indicate that a nil grazing system can reduce nitrate leaching losses by about 60-70%, with greater reductions for the higher N input system. Restricted grazing equivalent to use of a feed-pad for 5 months resulted in a 45-55% reduction in nitrate leaching (Table 3). In practice the decrease in estimated nitrate leaching corresponded to an increase in gaseous N losses associated with the collection, storage and application of effluent from the housing system. This includes increased loss of nitrous oxide (a greenhouse gas) and ammonia, which both have environmental impacts (e.g. Jarvis *et al*., 1995).

Associated calculations (de Klein, unpublished) indicate that even return of effluent associated with partial or full cut-and-carry systems can result in greater pasture production and that potentially the increased milk production from this could at least offset the extra costs associated with a partial cut-and-carry system. However, field research is required to verify assumptions used in the model calculations.

TABLE 3: Model calculations of the effect of restricted grazing (Sept.-March grazing; remainder on feed-pad) or nil grazing with full cut-and-carry of pastures (based on de Klein and Ledgard, 2000) on N losses. Calculations are based on effluent collected from the feed-pad system being stored and surface-applied to pasture. The three farm systems refer to the 'average' NZ dairy farm and farmlets at DRC Number 2 dairy which received fertiliser N at 0 or 200 kg N/ha/year (Ledgard *et al*., 1999a and unpublished data).

	Conventional grazing			Restricted grazing			Nil grazing		
	Av.	0N	200N	Av.	0N	200N	Av.	0N	200N
Gaseous N losses	37	50	97	57	74	124	86	115	175
'Run-off' of N	8[a]	10[a]	13[a]	7	8	10	6	6	7
Nitrate leaching	35[b]	37[b]	72[b]	16	21	33	11	16	20

[a]includes N emission to waterways from farm effluent ponds
[b]includes estimated nitrate leaching from farm lanes

Implications for nitrate sensitive areas

A change in farming systems from sheep and beef to intensive dairy farming in nitrate sensitive areas such as around Lake Taupo could result in a significant increase in nitrate-N inputs via leaching. Estimates of nitrate leaching from sheep and beef farms (8-12 stock units/ha) using the OVERSEER model are about 5-15 kg N/ha/yr and these could increase to about 30 kg N/ha/yr based on the "average" New Zealand dairy farm (Table 2). The summary of management options discussed in this paper suggest that the latter could be reduced to around 15-20 kg N/ha/yr by avoiding grazing between mid-autumn and early-spring (e.g. using feed-pads) or by decreasing farming intensity through no N fertiliser use and nil bought-in feed. Significant reduction in leaching below 15-20 kg N/ha/yr would require more extreme measures such as the use of grass-only pastures with minimal N inputs that would not be sustainable in the longer-term and /or interception of leached nitrate before it enters surface waters via riparian strips or walls, or in-stream removal using specific aquatic plants.

In practice, the issue of nitrate losses into sensitive areas such as Lake Taupo should NOT simply target one agricultural system such as dairy farming but must consider all potential nitrate sources. Studies in the Oteramika (Thorrold *et al*., 1997) and Pukekohe (Crush *et al*., 1997) areas showed that there are many diffuse N sources in large catchments. These include dairy farms, arable farms, effluent disposal areas and winter forage crop areas. The effect from a specific N source will depend on its N loss per ha and the relative area it occupies. In the Lake Taupo catchment, there are currently few dairy farms and therefore they will make a relatively small contribution to total N inputs into the lake. Thus, a whole catchment perspective is required. Specific areas of higher nitrate emissions could be countered by other areas of very low emissions (e.g. native bush or forests) to ensure that the impact of the whole catchment meets the desired standards.

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