An evaluation of a strategic de-stocking regime for dairying to improve nitrogen efficiency and reduce nitrate leaching from dairy farms in nitrate-sensitive areas.

CECILE DE KLEIN[1], JIM PATON[1] and STEWART LEDGARD[2]
[1]*AgResearch, Invermay Agricultural Centre, Private Bag 50034, Mosgiel, New Zealand*
[2]*AgResearch, Ruakura Research Centre, Private Bag 3123, Hamilton, New Zealand*
[1]dekleinc@agresearch.cri.nz

Abstract

Strategic de-stocking in winter is a common management practice on dairy farms in Southland, New Zealand, to protect the soil against pugging damage. This paper examines whether this practice can also be used to reduce nitrate leaching losses. Model analyses and field measurements were used to estimate nitrate leaching losses and pasture production under two strategic de-stocking regimes: 3 months off-farm or 5 months on a feed pad with effluent collected and applied back to the land. The model analyses, based on the results of a long-term farmlet study under conventional grazing and on information for an average New Zealand farm, suggested that the 3- or 5-month de-stocking could reduce nitrate leaching losses by about 20% or 35–50%, respectively compared to a conventional grazing system. Field measurements on the Taieri Plain in Otago support these findings, although the results to date are confounded by drought conditions during the 1998 and 1999 seasons. The average nitrate concentration of the drainage water of a 5-month strategic de-stocking treatment was about 60% lower than under conventional grazing. Pasture production of the 5-month strategic de-stocking regime with effluent return was estimated based on data for apparent N efficiency of excreta patches versus uniformly-spread farm dairy effluent N. The results suggested that a strategic de-stocking regime could increase pasture production by about 2 to 8%. A cost/benefit analysis of the 5-month de-stocking system using a feed pad, comparing additional capital and operational costs with additional income from a 5% increase in DM production, show a positive return on capital for an average New Zealand dairy farm. This suggests that a strategic de-stocking system has good potential as a management tool to reduce nitrate leaching losses in nitrate sensitive areas whilst being economically viable, particularly on farms where an effluent application system or a feed pad are already in place.

Keywords: dairying, feed pads, nitrate leaching, nitrogen efficiency, productivity, strategic de-stocking

Introduction

The expansion and intensification of dairy farming in New Zealand has increased concern for impacts on the environment, in particular nitrate contamination of ground and surface waters. A recent study in Edendale, Southland, has shown that nitrate leaching from cattle-grazed pasture under low to moderate stocking rates with 0–150 kg fertiliser-N/ha were within acceptable limits for drinking water quality (Monaghan *et al.* 2000). However, nitrate leaching losses were higher under more intensive systems and with higher N inputs. This could be of particular concern in areas with a history of high nitrate concentrations in groundwater, such as found in the Oreti Plains, Southland. Nitrate leaching losses mainly occur in autumn and winter, when excess rainfall coincides with high concentrations of nitrate in the soil (especially in urine patches) and when pasture growth and N uptake are limited owing to low temperatures. Studies in the UK have shown that, of urine N deposited in autumn (April and May equivalent), 30 to 65% still remained in the soil at the start of the drainage season, while only 5 to 15% of urine-N deposited in spring and summer (November to March) remained in the profile (Cuttle & Bourne 1993; Sherwood 1986; Titchen *et al.* 1989).

A strategic de-stocking system (from about mid May to mid August) is a common management practice on dairy farms in Southland, New Zealand, to protect the soil against pugging damage. By avoiding the deposition of urine patches in the autumn/winter period, such a system is likely to have an additional benefit of reducing nitrate leaching. On most farms the animals are grazed off-farm during that period, while on a small number of farms the cows are kept on a feed pad. When using a feed pad, the animal excreta can be collected and utilised on-farm to increase pasture and milk production. In addition, with a feed pad the de-stocking period could more easily be extended from April to August, which could reduce nitrate leaching losses even further. However, a potential disadvantage of using feed pads in winter is the increase in capital and/or operating costs, and the success of this type of strategic de-stocking will also depend on whether these increased costs can be compensated for by an increase in pasture and milk production.

In this paper, the potential of strategic de-stocking systems for dairy farming as a management tool to reduce nitrate leaching is examined based on model analyses and preliminary field measurements. The economic implications of a 5-month strategic de-stocking regime using feed pads are also investigated, by estimating the effect of increased N use efficiency on pasture and milk production, and by calculating a cost/benefit analysis.

Materials and methods

Nitrate leaching – model analyses

Nitrate leaching was estimated for strategic de-stocking systems in which the animals were either grazed-off farm for 3 months (late May to late August), or kept on feed pads for 5 months (April to August). In the latter system, it was assumed that pasture grown between April and August is harvested and fed to the animals, while the collected animal excreta are evenly returned to the pasture via surface spreading. The effect of excreta return on pasture production was also estimated. A detailed description of the model analyses is given by de Klein (2000) and de Klein & Ledgard (2000). Briefly, nitrogen losses of both systems and pasture production of the feed pad system were estimated based on information from systems under conventional grazing and on N losses and/or apparent N recoveries from animal excreta or farm dairy effluent during collection, storage and land application. Information for conventional systems was taken from detailed measurements of N cycling and pasture production of a long-term farmlet study under conventional grazing (Penno *et al.* 1996; Ledgard *et al.* 1999a; Ledgard *et al.* 2000). These farmlets were stocked at 3.3 cows/ha and received nominally 0 or 200 kg N/ha/year as fertiliser. Model analyses were also carried out for an average New Zealand farm stocked at 2.5 cows/ha (LIC 1996) and receiving 50 kg N/ha/year as fertiliser. The N losses for the average farm under normal grazing were calculated using AgResearch's nutrient budgeting program OVERSEER™ (Ledgard *et al.* 1999b).

The model analyses were based on the assumption that nitrate leaching occurred from excreta deposited (or applied) to the pasture, or in the lanes. Nitrate leaching from excreta deposited in pasture from September to May, or from September to March was calculated as 75% and 25% of the total annual leaching from excreta under conventional grazing, respectively (Cuttle & Bourne 1993; Sherwood 1986; Titchen *et al.* 1989). For the 5-month de-stocking system on a feed pad, where farm dairy effluent (FDE) was collected and re-applied to pasture, nitrate leaching from this land-applied FDE was estimated by assuming that 85% of the effluent N collected from the feed pad was returned to pasture and that 4% of this was lost through leaching. These assumptions were based on a review of published research on ammonia volatilisation losses from housed animals and on nitrate leaching losses from surface-applied effluent (de Klein & Ledgard 2000). The fate of excreta deposited in the lanes is unknown, but preliminary measurements in the Waikato indicated high concentrations of nitrate in the soil water under lanes. It was therefore assumed that leaching losses were as high as 50% of N deposited on the lanes.

Nitrate leaching – field measurements

Nitrate leaching measurements were carried out in a cocksfoot/white clover pasture on a Koau sandy loam soil (Taieri Plain; 3 km NNW of Dunedin airport). Plots were established within the paddock (12 x 4 m) and treatments were randomly assigned in a block design (three replicates per treatment), and included:

1. grazed all year on a rotational basis by dairy cows.
2. As for 1, but no grazing from mid April to mid September. In spring, these plots received a surface application of farm dairy effluent at a rate of about 50 kg N/ha.

Drainage water was collected using 65-mm-diam. plastic pipes (eight per plot) inserted into the ground at 45° angle with slots 50–80 cm below the soil surface allowing water to flow into the pipe as drainage occurred.

Following the establishment of the trial in September 1997, the El Niño and La Niña weather patterns caused two drought periods and as a result, no drainage water could be collected in 1998 and 1999. It was therefore decided to simulate an average rainfall year by irrigating the plots in the winter of 1999. Between 25 June and 24 August 1999, 100 mm water was applied in 12 applications of 5–10 mm per application. This allowed the soil to reach field capacity and any rainfall during this period to be collected as drainage. Drainage was collected on five occasions during this period, with a total of 22 samples collected per treatment. Nitrate concentrations in the drainage water were determined using a Technicon continuous-flow AutoAnalyser system.

Effect of increased N use efficiency on pasture production – model analyses

The effect of increased N efficiency on pasture production under a 5-month de-stocking regime on a feed pad was estimated based on the assumptions that (i) during April to August the DM production under conventional grazing is increased by excreta N returned to the pasture as urine and dung, and (ii) during April to August the DM production under a strategic de-stocking regime is increased by excreta N returned to the pasture as FDE. The DM production can then be calculated as follows:

$$DM_{SD} = DM_{C} - DM_{UD} + DM_{FDE} \quad (1)$$
$$DM_{UD} = ANE_{U} * U + ANE_{D} * D \quad (2)$$
$$DM_{FDE} = ANE_{FDE} * FDE \quad (3)$$

where DM_{SD} is the annual DM production of a strategic de-stocking regime (t/ha); DM_{C} is the annual DM production of a conventional grazing regime (t/ha); DM_{UD} is the urine- and dung- induced DM production in a conventional grazing regime between April and August (t/ha); DM_{FDE} is the farm dairy effluent-induced DM production in a strategic de-stocking regime between April and August (t/ha); ANE_{U}, ANE_{D}, and ANE_{FDE} are the apparent N efficiency (the increase in DM per unit of N applied) of urine, dung and farm dairy effluent, respectively (tDM/kg N); and U, D and FDE are the amounts of N returned between April and August as urine, dung and farm dairy effluent, respectively (kgN/ha).

The rate of N returned as urine and dung was estimated using information on total excreta production and a Poisson distribution (Petersen *et al.* 1956), to calculate the total area of pasture covered by urine or dung. The rate of N returned as FDE was calculated from the total excreta production (based on DM and milk solids production) minus any losses from the farm dairy, the feed pad or effluent pond.

The ANE values were estimated using a negative exponential function of the rate of N return, which was derived from published results on DM production from urine- and dung-affected pasture or following application of effluent (de Klein 2000). These results showed that the N efficiency was largely dependent on N application rate, rather than N source (urine or dung vs. FDE). Since FDE is applied more evenly, the rate of N return per hectare was lower, which resulted in higher ANE values than for urine or dung. The published results also indicated that the apparent N efficiency of the excreta N is affected by the timing of application. It is likely that in the cooler autumn/winter months, when pasture growth rates are reduced, the response to N is lower than in the spring–summer period. The model analyses were therefore run with different ANE values, by assuming that between April and August the ANE values were one, half or one-third the average annual value as calculated based on the rate of N return (ANE, ½ANE and $^{1}/_{3}$ANE, respectively).

Results and discussion

Nitrate leaching

The model analyses suggested that nitrate leaching losses under the 3-month strategic de-stocking regime were about 20 to 30% lower than under conventional grazing (Table 1). For the 5-month de-stocking regime with effluent returned to pasture the estimated losses were 35 to 50% lower than under conventional grazing. These estimates are based on three different leaching factors used in the model analyses: the proportion of annual leaching under conventional grazing by not grazing the pasture during the 3 or 5 months during autumn/winter (60 and 25% of the annual losses respectively), 4% of surface applied effluent N in the feed pad system, and 50% of excreta N deposited in lanes. A sensitivity analysis of these factors showed that the model analyses were most sensitive to the first two factors (de Klein & Ledgard 2000). However, these factors could increase

Table 1 Results of model analyses of nitrate leaching losses, and annual dry matter and milk solids production of strategic de-stocking systems for dairy farming, compared to a conventional grazing system. Values in brackets indicate percentage reduction compared to the conventional system. The model analyses are carried out based on an average New Zealand farm receiving 50 kg N/ha/year as fertiliser, and on a long-term study of farmlets receiving nominally 0 and 200 kg N/ha/year as fertiliser (Penno *et al.* 1996; Ledgard *et al.* 1999a; Ledgard *et al.* 2000).

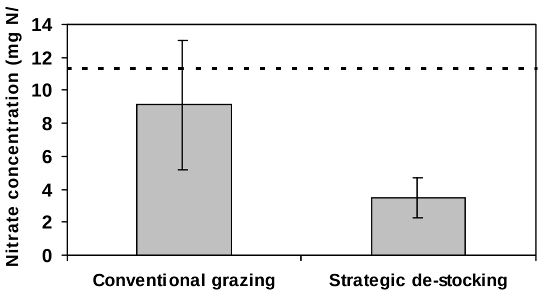
	Average New Zealand farm	Farmlet 0N	Farmlet 200N
Nitrate leaching (kg N/ha/year)			
Conventional	36*	39 [1]	77 [1]
Strategic de-stocking			
3 months off-farm	29 (19)	30 (23)	55 (29)
5 months on feed pad	22 (39)	25 (36)	39 (49)
Dry matter production (t/ha/year) [2]			
Conventional	13.0	16.4 [3]	18.5 [3]
Strategic de-stocking			
5 months on feed pad	13.3–14.0	16.8–17.7	18.9–20.0
% increase	2–8	2–8	2–8
Milk solids production (kg/ha/year) [2]			
Conventional	750 [4]	1100 [3]	1250 [3]
Strategic de-stocking [5,6]			
5 months on feed pad	795-835	1120–1185	1275–1350
% increase	7–11	2–7	2–7

Based on estimates using OVERSEER™ and estimates of losses from lanes. [1] Based on 5-year average of field measurements of nitrate leaching under pasture and estimates of losses from lanes. [2] The DM and MS production are estimated using $^{1}/_{3}$ANE, ½ANE and ANE (see text). [3] Based on 5-year average of field measurements. [4] LIC (1996). [5] Feed conversion efficiency for an average New Zealand farm increased by 3% from 58 to 60 kg MS/t DM (McGrath *et al.* 1998). Feed conversion factor for farmlets remained at 68 kg MS/t DM. [6] 10% DM losses during feeding out of silage were taken into account.

about three to five times before nitrate leaching losses under the strategic de-stocking system were equal to those under conventional grazing.

The results of the model analyses are supported by the preliminary findings in the field study (Figure 1). Although the interpretation of these results is hampered by the limited number of samples that could be collected owing to the drought conditions, the average nitrate concentration of the drainage water of the strategic de-stocking treatment was about 60% lower than under conventional grazing.

Figure 1 Average nitrate concentration in drainage water collected under dairy pasture that was grazed all year round (Conventional grazing) or where stock were excluded from April to August (Strategic de-stocking). Data for 1999 are compared to the recommended maximum for drinking water of 11.3 mg N/L (dashed line). Bars indicate one SE.



As mentioned above, strategic de-stocking for 3 months during winter is a common management practice in Southland. The results presented here suggest this practice could reduce nitrate leaching from the farm. Although this could be viewed as transferring some of the potential leaching to another farm, such practice could have beneficial effects if the transfer occurred from a farm in a nitrate sensitive area, to an area where nitrate concentrations in groundwater are historically low. The results further suggest that if the off-grazing period was extended to 5 months, with the excreta collected and returned to pasture, nitrate leaching losses could be reduced even further.

Pasture production

Strategic de-stocking regimes, in which the animals are kept on a feed pad and the excreta collected and returned to pasture, can affect pasture production in two ways: by increasing the N use efficiency of the excreta and by eliminating treading and pugging damage. Some of the positive effects of eliminating treading may, however, be outweighed by the negative effects of increased machinery for harvesting and/or effluent application. Therefore, the estimates of pasture production presented here are solely based on the increased N efficiency of the excreta.

The model analyses suggested that an increase in N efficiency of a de-stocking system with effluent return may increase the annual DM production, compared to a conventional grazing system, by 2 to 8%, depending on the apparent N efficiency (ANE) value used (Table 1). The lowest increase was obtained when it was assumed that the N efficiency of the animal excreta during the cooler autumn/winter period is a third the average annual value as calculated based on the rate of N return ($^1/_3$ANE), while the highest increase was obtained when assuming that ANE was not reduced. Given the range of responses, more information is required on the effect of timing of N application and pasture growth rates on N use efficiency.

Cost/benefit analysis

To evaluate the economic implications of the feed pad de-stocking system, a cost/benefit analysis was calculated. The capital cost requirements (Table 2) included a feed pad of $125 per cow and an effluent application system at $15 500 (Heatley 1998). The main additional operating costs of a feed pad system are assumed to be extra labour for feeding the animals, cleaning the feed pad and applying the effluent to the land (Table 2). Although these extra labour requirements will vary for individual farms, they are estimated at about one full labour unit for the 5-month non-grazing period, i.e., about 0.4 units per year. In addition, since some of the extra pasture production of a strategic de-stocking regime is likely to occur in late spring/early summer when feed supply is generally not limited, it was assumed that 50% of the extra DM production of these systems was ensiled, and that 10% of the silage was lost during feeding out. The cost of silage making was estimated at $10/t fresh weight which amounts to about $0.03/kg DM, assuming a DM content of 35% (D. Aitkin, pers. comm.). Finally, the operating costs included depreciation and repair and maintenance costs of the capital equipment. These latter costs were adjusted to allow for the fact that the strategic de-stocking system is operational for 5 months per year.

The additional income from a strategic de-stocking system was estimated from the average increase in MS production, which was estimated from the average increase in DM production of 5% (Table 1). It was assumed that the increase in MS production was owing to an increase in per cow production, rather than an increase in cow numbers. The effect of silage making (10% feeding losses) was also accounted for. In addition, for the average New Zealand dairy farm where the feed conversion efficiency was about 58 kg MS/t

Table 2 Capital cost requirements and additional operating costs for a strategic de-stocking system, based on an average New Zealand farm and the DRC farmlets.

	Costs ($000) Average NZ farm	DRC farmlets
Capital costs		
Feed pad ($125/cow) *	25.0	32.5
Effluent application *	15.5	15.5
Total	**40.5**	**48.0**
Extra operating costs		
Labour ($26,000 per unit)	10.4	10.4
Silage making (50% of extra production ensiled at 3 c/ kg DM)	0.7	0.9
Electricity ($5 per cow) [1]	0.4	0.5
Repair &Maintenance (5% on effluent system, 2% on feed pad) [1]	0.5	0.6
Depreciation (3% on feed pad and effluent system) [1]	0.5	0.6
Total	**12.6**	**13.1**

Heatley, 1998. [1] Costs are estimated for a 5-month de-stocking system, i.e., 5/12 times the annual costs.

Table 3 Additional cash surplus for a strategic de-stocking system compared to a conventional grazing system for an average New Zealand dairy farm. Calculations are also made for a 80 ha farm based on the results of the DRC farmlet study.

	Costs ($000)		
	Average NZ farm	0N farmlet	200N farmlet
Extra costs			
Extra operating costs	12.6	13.1	13.1
Opportunity cost (10% of capital)	4.1	4.8	4.8
Total	**16.7**	**17.9**	**17.9**
Extra income *	**18.8**	**14.6**	**16.6**
Extra cash surplus	**2.1**	**- 3.3**	**- 1.3**
Return on capital investments (%)	**5**	**- 7**	**- 3**

***** Calculated for average increase in MS production (see Table 1); assumes pay-out of $3.50 per kg MS.

DM, it was assumed that this efficiency increased by 3% to 60 kg MS/t DM (McGrath *et al.* 1998). For the DRC farmlets, where the feed conversion factor was already high at about 68 kg MS/t DM, no increase in efficiency was assumed.

Assuming a pay-out of $3.50 per kg MS, the extra income, the additional annual cash surplus and the return on capital of a strategic de-stocking system, were calculated (Table 3). For an average New Zealand farm, this resulted in a 5% return on capital. This indicated that a 5% increase in DM production and the assumed increase in feed conversion efficiency of 3% (McGrath *et al.* 1998) compensated for the additional costs of such a system. Using the production values of the DRC farmlet study, a strategic de-stocking system showed a negative annual cash surplus. Based on these results, a pay-out of $4.28 and $3.77 per kg MS would be required to break even for the 0N and 200N farmlet, respectively. The difference in % return on capital between the average farm and the DRC farmlet was a result of the assumption that the feed conversion efficiency of the extra herbage grown on the average farm was higher than for the conventional system. For the DRC farmlet, where the conversion efficiency was already high, no such increase was assumed.

Based on the cost/benefit analysis presented above, the economic viability of a strategic de-stocking regime depends solely on the additional income generated from an increase in pasture and MS production. The results presented here suggested that with a pasture production increase of about 5% on an average New Zealand farm, the estimated additional income would counter-balance the additional costs of a feed pad, effluent application system and extra labour. However, on an increasing number of farms, feed pads are being built to protect the soil against pugging and compaction damage. If the collected effluent is returned to the pasture, this type of strategic de-stocking system also has a beneficial effect on both nitrate leaching and pasture production, which provides an extra incentive for building a feed pad. In addition, many New Zealand dairy farms have converted to a land-based effluent system in recent years. On these farms, the capital costs of the effluent application system can be excluded from the cost/benefit analysis. For the average New Zealand farm and the 0N and 200N farmlets, this would increase the return on capital to 9%, -4 and 1%, respectively.

The estimated increase in pasture production from evenly applied effluent compared to the patchy return of urine and dung is solely based on the nitrogen response. However, P and K responses could also play a role. In grazed pasture, the return of excretal nutrients is spatially separated, with P being returned in dung and K mainly in urine (Haynes & Williams 1993). Therefore, pasture response to evenly spread effluent could increase owing to P and K fertilisation, particularly in pasture where the P and K fertility is low.

Conclusion

Strategic de-stocking for 3 or 5 months during the autumn/winter period can reduce nitrate leaching by about 20% or 35–50%, respectively. This could be of particular benefit in areas with a history of high nitrate concentrations in groundwater. When used in combination with a feed pad and a land-based effluent system, strategic de-stocking can also increase pasture production. With an estimated increase in production of 5%, such a system is also economically sustainable, particularly on farms where an effluent application system or a feed pad are already in place.

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