Nitrogen balances and losses on intensive dairy farms

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Abstract

Nitrogen (N) balances were constructed for "average" dairy farms in New Zealand, south west England and The Netherlands, and for Dairying Research Corporation (DRC) farmlets varying in stocking rate and use of N fertiliser and maize grain. N surpluses were calculated to indicate the potential impact on the environment and these were compared with measured N losses from the DRC farmlets. On the average New Zealand farm, annual N inputs of 186 kg N/ha/year (mainly from N_2 fixation) resulted in N outputs in milk+meat of 55 kg N/ha/year (30% efficiency) and a N surplus of 131 kg N/ha/year. Dutch farms produced 70% more milk/ha but had N inputs of 568 kg/ha, N outputs in produce of 81 kg/ha (14% efficiency) and a N surplus of 487 kg/ha. English farms were intermediate. In the DRC farmlets, applying fertiliser N at 400 kg N/ha/year increased N surpluses and nitrate leaching by 3–4 fold, resulting in nitrate-N concentrations in drainage of 2.5× the recommended maximum for drinking water. The most efficient farm system received no N fertiliser and was highly stocked (3.3 Friesian cows/ha) for very high pasture utilisation. This resulted in similar milk production/ha to Dutch farms (with 1/3 the N inputs) and a 45% efficiency of conversion of N inputs from N_2 fixation into milk and meat products.

Keywords: dairy farm, nitrate leaching, nitrogen balance, nitrogen fertiliser, stocking rate

Introduction

Increased intensity of dairy farming and greater nitrogen (N) fertiliser use have raised questions about the implications to the environment. In the European Union, the main environmental concern of intensive dairy farming is the losses of N, particularly by nitrate leaching into groundwater. This concern has led to several countries introducing mandatory nutrient accounting on farms, with emphasis on N. In The Netherlands, this nutrient accounting is being selected as a procedure to control nutrient use and to tax nutrient surpluses (Breembroek *et al.* 1996).

Dairying in The Netherlands has been characterised by a marked increase in inputs of purchased feed and N fertiliser. By mid 1980s, an "average" Dutch dairy farm on sandy soils used over 7 t/ha of concentrates or maize silage and applied 330 kg N/ha/year (Aarts *et al.* 1992). In New Zealand, there has been a trend for increasing use of supplements and fertiliser N, although at much lower levels to that in The Netherlands (current average of approximately 0.3 t DM/ha/year in purchased feed and 40 kg N/ha/year; B. Atrill & T. Johnston pers. comm.). Current research at DRC Number 2 dairy has been examining the effects of increased inputs of N fertiliser and supplementary feed on farm productivity and profitability (Penno *et al.* 1996).

This paper presents N balances for "average" dairy farms in New Zealand, south west England and The Netherlands, and for farmlets at DRC Number 2 dairy. It also describes the extent of N losses from the DRC farmlets with varying N fertiliser use and stocking rates.

Methods

Calculation of N balances

N balances are a method of summarising N inputs and outputs from a farm system. The N balance for an "average" New Zealand dairy farm was estimated using data from the Livestock Improvement dairy statistics 1995–1996. Production data from farmlets at DRC Number 2 dairy for 1993–1997 were used to construct N balances for farmlets varying in rate of N fertiliser application, supplementary feeding and stocking rate. Published data were used for summarising N balances on dairy farms in south west England (Jarvis 1993) and The Netherlands (Aarts *et al.* 1992).

Farmlet experiment

In June 1993, a farmlet trial was established at DRC Number 2 dairy, Hamilton (Penno *et al.* 1996), which included five farmlets. Three farmlets have been stocked at 3.3 cows/ha and have received nominal rates of N fertiliser of 0, 200 or 400 kg N/ha/year. Two farmlets had 4.4 cows/ha (low and high stocking rates are subsequently described by subscripts L or H), and received 200 or 400 kg N/ha/year. The last two farmlets also used crushed maize grain at approximately 1 t/

cow/year, although this ceased in the third year on the 400 N_H farmlet. Pastures were predominantly perennial ryegrass and white clover.

Milk volume and protein content were measured weekly for each farmlet. N transfer from paddocks to the lanes and milking shed via cow excreta was determined by visual assessment of dung and urine deposition.

Detailed measurements of N_2 fixation and N losses were made on the 0, 200 N_L, 400 N_L and 400 N_H farmlets and were confined to four replicate paddocks on a free-draining ash soil (yellow–brown loam; Umbric Dystrochrept). Details of methods were described by Ledgard *et al.* (1996). In brief, N_2 fixation by white clover was determined by ^{15}N isotope dilution, and measurements of N loss were ammonia volatilisation (by a mass balance micrometeorological method), denitrification (using acetylene inhibition) and nitrate leaching (using ceramic cup samplers in conjunction with lysimeters). Data for the first 3 years of the study are presented.

Results

N balances on commercial farms

Milk production/ha on the "average" Dutch farm was 70% higher than that on the "average" New Zealand farm. This was achieved with 3.1-fold higher N inputs and a 3.7-fold higher N surplus (Table 1). Milk production, N inputs and N surplus on farms in south west England were intermediate between those on New Zealand and Dutch farms. Farms differed greatly in the forms of N input, N_2 fixation predominating in New Zealand and N fertiliser being the main N input on Dutch and English farms. Dutch farms also had a large N input in purchased feed.

N balances and losses from DRC farmlets

Increased N fertiliser and maize grain inputs increased milk production/ha by up to 58% (Table 2). This was associated with an increase in N inputs of up to 2.9-fold and an increased N surplus of up to 4-fold. The type of input had a large effect on the efficiency of N use. The two farmlets received N fertiliser at 400 kg N/ha/year had the highest N inputs and N surpluses. The highest-producing farmlet (200 N_H) received N fertiliser at 200 kg N/ha/year and maize grain at 4480 kg DM/ha/year, and was intermediate in its N input and N surplus.

Table 1 Farm characteristics and estimates of N inputs and outputs (kg/ha/year) for average dairy farms in New Zealand, south west England, and in The Netherlands on sandy soils.

	New Zealand (1995–96)	SW England (1991)	The Netherlands (1983–1988)
Farm size (ha)	82	76	25
Cows/ha	2.4	2.2	2.3
Milk (litres/cow)	3182	5554	5737
Total milk (litres/ha)	7360	12219	13195
Nitrogen inputs			
Fertilisers	40	250	331
N_2 fixation	140[1]	10	0
Purchased feed	4	52	181
Atmospheric deposition	2	25	48
Miscellaneous	0	0	8
Total N inputs	**186**	**337**	**568**
Nitrogen output in products			
Milk	47	39	67
Meat	8	28	14
Total N output	**55**	**67**	**81**
Nitrogen surplus	**131**	**270**	**487**
N outputs/N inputs	30%	20%	14%

[1]Based on assumed pasture production of 13 t DM/ha/year, 17% clover and results from past studies on N concentration and proportion of N fixed.

Table 2 Milk production and estimates of N inputs and outputs (kg N/ha/year) for dairy farmlets varying in N fertiliser application (nominally 0, 200 or 400 kg N/ha/year) and stocking rate (L=3.3 cows/ha, H=4.4 cows/ha). Data are the mean of 3 years.

	0 N_L	200 N_L	400 N_L	400 N_H	200 N_H	SED
Cows/ha	3.3	3.3	3.3	4.4	4.4	
Milk (litres/cow)	3953	4735	4858	4410	4592	
Total milk (litres/ha)	12955	15516	15921	19653	20466	
N inputs						
Fertiliser	0	215	413	411	213	
N_2 fixation	174	117	40	37	117	15
Purchased feed	3	4	3	58	101	
Atmospheric deposition	2	2	2	2	2	
Total N inputs	**179**	**338**	**458**	**508**	**433**	
N output in products						
Milk	75	89	92	113	121	
Meat	6	6	6	9	9	
Surplus silage	0	15	28	5	0	
Total N output	**81**	**110**	**126**	**127**	**130**	
Nitrogen surplus	**97**	**228**	**332**	**401**	**303**	
N outputs/N inputs	45%	33%	28%	25%	30%	
Nitrogen losses/removals						
Denitrification	5	17	25	24		4
Volatilisation	15	41	65	68		6
Leaching	40	81	152	136		24
Transfer to lanes/sheds	57	78	84	85		
Total N outputs+losses	198	327	452	440		
Nitrogen balance	-19	+11	+6	+68		

Gaseous N losses were relatively small, although both denitrification and volatilisation increased by approximately 5-fold between the 0 N and 400 N farmlets. Nitrate leaching was a major N loss process and increased to high levels in the 400 N farmlets. Approximately 15% of the excreta N was transferred to lanes and the milking shed, with most to the latter. This was collected and pumped to oxidation ponds, and therefore represented a loss of N from the farmlets. The total N inputs were equivalent to total N outputs, bearing in mind the experimental error in determining the various components.

Discussion

Milk production and N inputs

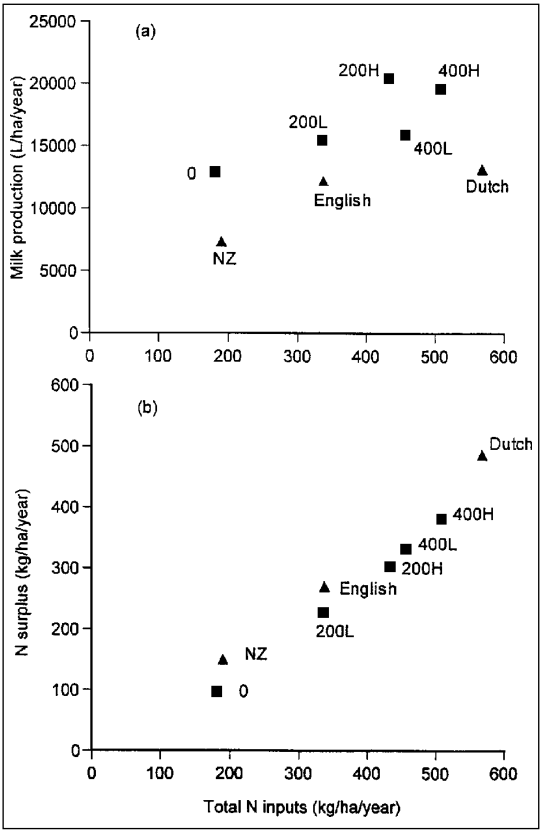
Commercial farms in New Zealand and overseas had a lower level of milk production/ha over a range of N inputs than the farmlets at DRC Number 2 dairy (Figure 1a), which could be attributed to the greater pasture production and utilisation in the farmlets. This is evident from the much higher stocking rates in the DRC farmlets, although per cow production was lower than in the Dutch and English systems (Tables 1, 2). Milk production/ha from the 0 N farmlet was similar to that for the Dutch and English dairy farms, even though the latter had 2- to 3-fold higher N inputs.

On the DRC farmlets stocked at 3.3 cows/ha, increasing N fertiliser application from 0 to 400 kg N/ha/year increased milk production by 23% and most of this increase (20%) had occurred with 200 kg N/ha/year. Increasing the stocking rate to 4.4 cows/ha at the 400 N rate increased milk production/ha by a further 5% (Penno unpublished). Including maize grain in the cows' diet at the high stocking rate, in conjunction with 200 kg N/ha/year, led to the largest increase in milk production (+58% over 0 N). Economic analyses (based on 1995 milk prices and 47c/kg maize grain) indicated that the 200 N_L farmlet was the most profitable, although its Economic Farm Surplus was only $66/ha (+2.7%) ahead of the 0 N farmlet (Penno *et al.* 1996). Use of lower rates of N fertiliser (e.g., 100 kg N/ha/year) applied strategically for defined feed shortages is likely to be more profitable per unit N than the 200 or 400 N rates (e.g., Ledgard *et al.* 1994).

N inputs in the 0 N farmlet were almost entirely from N_2 fixation by white clover, and varied between 100 and 230 kg N/ha/year. Applying N fertiliser at 400 kg N/ha/year decreased N_2 fixation to low levels (15–60 kg N/ha/year), owing to a large reduction in clover growth and to clover substituting fertiliser N uptake for N_2 fixation.

N outputs and losses

Figure 1 Relationship between total N inputs and (a) milk production or (b) N surplus (i.e., N inputs – N outputs in milk+meat) for a range of farm systems. Triangles refer to "average" farms and squares to DRC farmlets, with numbers representing N fertiliser application (kg N/ha/year) and letters being stocking rate (L=3.3 cows/ha, H=4.4 cows/ha).



N outputs in produce generally increased with increasing N inputs. However, the N outputs in produce were the same for the 0 N farmlet and the average Dutch farm despite much higher N inputs in the latter.

The difference between N inputs and N outputs in products is the N surplus, and this was linearly related to the N input levels (Figure 1b). Detailed measurements in the DRC farmlet study indicated that the N surplus was transferred or lost from the paddocks. Transfer of excreta-N to lanes and the milking shed showed a small increase with increasing N inputs, whereas gaseous and leaching losses all increased by approximately 4-fold between the 0 and 400 N farmlets. The main environmental concern is from nitrate leaching to groundwater and analyses of the water draining through these soils showed average nitrate-N concentrations of 6, 13 and

27 mg/litre in the 0, 200 and 400 N_L farmlets, respectively. Similar concentrations were measured in the groundwater. Thus, drainage water from the 400 N farmlet had nitrate-N concentrations well above the recommended maximum for drinking water of 11.3 mg/litre (Ministry of Health 1995). Associated studies indicated that the main source of leached N was from cow urine (Ledgard *et al.* 1996), leaching occurring during the period of net drainage (predominantly June–September).

A reduction in N losses to the environment could be achieved by decreasing N inputs, reducing levels of potentially-leached N in soil in late-autumn–winter, or increasing feed-N utilisation by cows. Options for reducing potentially leached N include avoiding N fertiliser application in late-autumn–winter (when growth responses are slow and direct leaching losses can occur), and using “grazing-off” strategies during this period (e.g., using feed pads with effluent collection for redistribution in spring–summer). Improving feed N utilisation by cows through conversion into milk reduces the N susceptible to loss.

N utilisation efficiency

The efficiency of conversion of pasture (and maize) N consumed by dairy cows into milk and meat averaged 14.9, 14.0, 13.5, 16.6 and 15.9% in the 0 N, 200 N_L, 400 N_L, 200 N_H and 400 N_H farmlets, respectively. Thus, N fertiliser application reduced the efficiency of N utilisation whereas maize supplementation increased it. Maize represents a high energy feed with a low N concentration (e.g., 1.5% N compared to c. 4% for N-boosted pasture). This has the additional benefit of increasing N excretion in dung relative to urine and reducing possible N losses. Potentially, N use efficiency could also be increased through plant breeding and management practices to lower the plant N concentration or manipulate other plant characteristics to increase amino acid absorption (Van Vuuren & Meijs 1987). The maximum theoretical utilisation of dietary N is 40–45% (Van Vuuren & Meijs 1987).

Despite the relatively low efficiency of N utilisation from pasture consumed by cows, the overall farm conversion of total N inputs to N output in products was high in the 0 N farmlet at 45%. This apparent contrast was owing to the efficient recycling of N within the grazed pasture system, as evidenced by total annual N uptake in pasture herbage at 543 kg N/ha relative to the annual N input of 181 kg N/ha/year. The high pasture utilisation by cows (about 90%) in the 0 N farmlet also favoured high milk production, so that the N output in milk was 60% greater than on an average New Zealand farm even though both systems had a similar total N input.

The N output/input ratio decreased greatly to 25–32% in the N-fertilised farmlets and was only 14% in the intensive Dutch farms. Current research in The Netherlands is examining practices to increase N recovery in milk to about 30% by reducing stocking rate, reducing N fertiliser use, growing more maize, better matching feed demands with concentrate supply, and improved storage and application of slurry (Aarts *et al.* 1992). This would coincide with a reduction in N surplus from 480 kg N/ha/year to about 200 kg N/ha/year and thereby markedly reduce the potential for N loss. Some of these practices could also be used on more intensive moderate-high N input farms in New Zealand to reduce N losses. However, achieving N losses below that in the 0 N farmlet would be difficult without significant changes to management and costs, e.g., substituting some pasture for maize silage, or use of a feed pad system to reduce excreta return in late-autumn–winter.

Conclusions

Increasing N inputs on dairy farms increased N surpluses and led to relatively large increases in gaseous losses and nitrate leaching. Applying N fertiliser at 400 kg N/ha/year was less efficient than 200 kg N/ha/year + maize supplementation at increasing milk production and N off-take, and high rates of N application had an adverse effect on groundwater nitrate levels. The most efficient farm system used no N fertiliser, had an N surplus of only 100 kg N/ha/year, and a high stocking rate which resulted in similar production per ha to the Dutch farms and a very high (45%) conversion of N inputs from N_2 fixation into milk.

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