Application of the nutrient budgeting model OVERSEER™ to assess management options and Regional Council consent requirements on a Hawke's Bay dairy farm

S.F. LEDGARD[1], G.A. EDGECOMBE[2] and A.H.C. ROBERTS[1]
[1]*AgResearch Ruakura Research Centre, Private Bag 3123, Hamilton*
[2]*Hawke's Bay Dairies Ltd., RD9 Matapiro Road, Hastings*

Abstract

OVERSEER™ is a nutrient budgeting model which estimates the inputs, outputs and balances of N, P, K and S for different farming systems. Its main role is as an index of the sustainability of farm systems and to provide information on the potential environmental impacts through estimates of nutrient leaching. OVERSEER was used to assess the N flows and balances associated with different management practices on the farm of Hawke's Bay Dairies Ltd. The 210 ha farm includes a feed-pad for feeding cows with fruit and vegetable processing wastes and pasture which is cut and carried from a 41 ha effluent area (the latter is a requirement of the Regional Council consent). Outputs from OVERSEER for the effluent area revealed that N removal in cut pasture was 1.4 × total N inputs in effluent and clover N_2 fixation and the total N balance was -117 kg N/ha/year. This could lead to significant pasture deterioration and would be unsustainable in its current state. Current N inputs for the whole farm system were estimated at 80, 147 and 87 kg N/ha/year in fertiliser, brought-in feed and clover N_2 fixation. Outputs of N in milk and nitrate leaching were estimated at 154 and 66 kg N/ha/year, respectively. Hawke's Bay Dairies propose changes in management to exclude the cut-and-carry operation. The effects of these changes on N flows and balances are presented and compared with those from the long-term farmlet trial at the Dairying Research Corporation Number 2 Dairy farm. In the Hawke's Bay Dairies farm, high milk production (2200 kg milksolids/ha) is being achieved through utilisation of locally-available fruit and vegetable wastes which are high in energy and low in protein. This results in very efficient conversion of total N inputs into milk (49%) and lower leaching losses than those measured in farmlet systems based on high (400 kg N/ha/year) inputs of N fertiliser.

Keywords: dairy farm, feed-pad, nitrate leaching, nitrogen model, OVERSEER™

Introduction

A nutrient budget is a valuable indicator of the long-term sustainability of a farm system. It indicates where inputs of nutrients are inadequate relative to outputs, thereby leading to a decline in the soil nutrient status. Conversely, it can indicate where excessive inputs result in nutrient surplus and thereby can give an estimate of potential nutrient losses to the environment. A nutrient budget can also provide a method for comparing nutrient flows associated with different management practices on a farm.

OVERSEER™ is a nutrient budgeting model developed for New Zealand farm systems by AgResearch (Ledgard *et al.* 1999b). It provides average estimates of the fate of the nutrients N, P, K and S in kg/ha/year for different nutrient inputs and management practices (e.g., stocking rate, supplementary feed inputs). Leaching of nutrients below the root zone is estimated, which includes potential nitrate leaching to groundwater. This aspect of the model makes it a valuable tool for assessing the effects of different farm practices in relation to requirements by Regional Councils for the Resource Management Act.

A validation of the OVERSEER N model is given in Table 1 using the only detailed long-term study of N flows under dairy cow grazing in New Zealand (Ledgard *et al.* 1999a). It shows close agreement between modelled and measured data (most differences ≤10%), bearing in mind the large variation between years in measured data (e.g., range in N_2 fixation and nitrate leaching in a 400 N farmlet of 15–115 and 65–206 kg N/ha/year, respectively).

Hawke's Bay Dairies Ltd. is a dairy farming system which includes feeding of fruit and vegetable wastes to cows on a feed-pad as part of its total operation. Approval for operation by the local Regional Council in 1996 included specific requirements for land application of effluent from the feed-pad and farm dairy at an annual rate which did not exceed 150 kg N/ha/year *and* use of a cut-and-carry system on the effluent-treated area. Hawke's Bay Dairies Ltd were interested in modifying their farming system and sought the use of OVERSEER to assess the effects of different

Table 1 Comparison of modelled (OVERSEER) and measured data for farmlets at DRC Number 2 Dairy which received nominal N fertiliser inputs of 0, 200 or 400 kg N/ha/year (Penno *et al.* 1996). Measured data are the means for 3 years (Ledgard *et al.* 1999a) except for leaching which are the means for 5 years.

	0 N		200 N		400 N	
	Model	Measured	Model	Measured	Model	Measured
N inputs						
Fertiliser	0	0	215	215	413	413
N_2 fixation	186	174	132	117	67	40
Purchased feed	3	3	4	4	3	3
N output						
Milk+meat	85	81	98	95	104	98
Surplus silage	0	0	15	15	28	28
Transfer to lanes/sheds	63	57	79	78	90	84
Gaseous loss	12	20	52	58	82	90
Leaching	28	30	63	63	97	122
Site N Balance[1]	1		44		82	

[1]$\sum$ N inputs – $\sum$ N outputs; equivalent to immobilisation in soil organic N

management options (particularly removal of the cut-and-carry system) on N losses from the farm system.

This paper presents information on the effects of different farm management practices at Hawke's Bay Dairies Ltd. on N flows, as estimated using OVERSEER. Outputs from the model relative to measured N flows in farmlet studies at the Dairying Research Corporation (DRC) Number 2 Dairy are also presented.

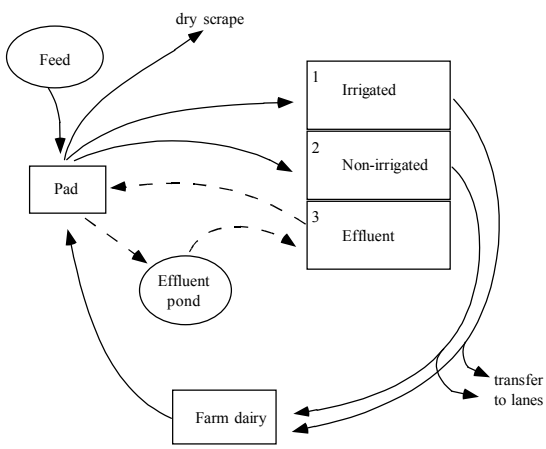
Methods

Farm information

At Hawke's Bay Dairies Ltd., there is a concrete feed-pad and three distinct pasture management units of relevance to the N balance calculations. An irrigated area (Area 1 in Figure 1) constitutes 120 ha, a dryland or non-irrigated area (Area 2 in Figure 1) totals 49 ha, and an effluent area (Area 3 in Figure 1) consists of 41 ha. On average, 740 milking cows are run on the total 210 ha of the farm. The annual milksolids production averages 465 000 kg for the farm, which equates to over 2200 kg/ha. Annual rainfall is 700 mm and a further 750 mm of irrigation water is applied to Area 1. Pastures contain varying proportions of ryegrass, tall fescue, cocksfoot, white clover, red clover and subterranean clover.

Cows are milked throughout the year with approximately half calving in spring and half in autumn. After each milking, the cows spend approximately 3 hours on the feed-pad where they are fed a combination of pasture cut from Area 3 and brought-in feed. The latter is primarily local processing wastes and represents about 11 t DM/ha on a whole-farm area basis. The grazed pastures receive N fertiliser at 100 kg N/ha/year in four split applications.

Figure 1 Conceptual diagram of feed and excreta flows.



Feed-pad management includes dry scraping the excreta into a collection area at regular intervals. The dry scrape is taken off the farm and applied onto a run-off area. Surplus liquid (mainly urine) on the feed-pad is washed into the effluent collection pond. The latter is a small concrete reservoir and its contents are pumped out daily and spray-irrigated onto the effluent area.

N balance calculations

N balance calculations were based on estimates of N inputs and N outputs using the nutrient balance model OVERSEER, with some modifications where specific data were available. Separate balances were calculated for the three pasture areas and were used in estimating a whole-farm balance.

Inputs of N occur via brought-in feed, effluent or excreta, fertiliser and clover N_2 fixation. Feed brought in to the feed-pad was weighed and samples were regularly taken for nutrient analysis. The amount of effluent-N applied to the effluent area was estimated from the volume and analyses of effluent pumped from the pond. The two grazed areas were assumed to receive additional excreta derived from feed consumed on the pad, and this was estimated from the relative amounts of time spent in each area. Clover N_2 fixation was calculated using estimates of total pasture production, average % clover values, and from equations in the model using total N concentration in clover and the proportion of clover N derived from atmospheric N_2 based on a summary of past field research. N_2 fixation rate was adjusted for the effects of N fertiliser application. The % clover values used were 17, 10 and 10 for Areas 1, 2 and 3 respectively, based on typical average values for long-term pasture and visual observations for the areas.

Outputs of N occur in produce, transfer of excreta to lanes, removal of dry scrape from the feed-pad, gaseous losses and by nitrate leaching. Estimates of N removal in meat and milk were calculated from milk production and average values for N concentrations in milk and meat from an OVERSEER database, which were derived from a summary of past research. Transfer of N in excreta to lanes was based on estimates of excreta production and the proportion of time cows spent on lanes relative to the other areas. Removal of N in dry scrape was estimated from measurement of the weight removed and analyses of the dry scrape. Ammonia loss from excreta deposited on the feed-pad was estimated from a summary of UK research (Pain *et al.* 1998). The remaining losses of N into the atmosphere and by leaching were estimated in the model based on principles outlined by Ledgard *et al.* (1999b). A site-balance for N was calculated from the difference between the total inputs and outputs of N.

Results

Current farm system

Estimates of N flows for the current effluent area (Table 2) show that N removal in cut pasture is almost 1.4 times the total N inputs in effluent and N_2 fixation by clover. Leaching and gaseous losses are calculated to be small and are similar to estimates from a lysimeter study with effluent (Singleton & Barkle, unpublished data). The net result is that the total N balance for the current effluent area is -117 kg N/ha/year.

On a whole farm basis, the main input of N was via the brought-in feed at 147 kg N/ha/year and the total N input was 314 kg N/ha/year (Table 3). The main output of N was in milk at 154 kg N/ha/year. Overall, there was a small net N balance of +22 kg N/ha/year made up of a negative balance on the effluent area (Table 2) and a positive balance on the other areas. The latter was due to immobilisation into the soil organic N and a small amount of inorganic N carried over in the non-irrigated area due to low drainage.

Table 2 N balance for the current effluent area, estimated using the model OVERSEER.

N Inputs (kg N/ha)		N Outputs (kg N/ha)	
Effluent	188	Cut pasture	384
Fixed N (clover)	90	Transfer	0
		Leaching losses	2
		Gaseous losses	9
Sub-total	278	Sub-total	395
Balance (Inputs-Outputs)			**-117**

Table 3 Whole farm N balance, estimated using the model OVERSEER.

N Inputs (kg N/ha)		N Outputs (kg N/ha)	
Fertiliser	80*	Milk	154
Feed	147	Meat	10
Fixed N (clover)	87	Transfer	15
		Leaching losses	66
		Gaseous losses (soil)	30
		Extra gaseous loss (pad, effluent)	13
		Dry scrape	4
Sub-total	314	Sub-total	292
Balance (Inputs-Outputs)			**+22**

* confined to non-effluent treated pastures only i.e., Areas 1 and 2

Proposed management changes

A number of considerations, including application for a change in resource consent conditions, have led to the owners of Hawke's Bay Dairies Ltd investigating management changes for the farm. These include:

1. ceasing the cut and carry operation on the current effluent area,
2. application of dry scrape to the farm,
3. expanding the effluent area to 140 ha, and
4. applying N fertiliser at a rate up to an average of 100 kg N/ha overall.

The first change was based on overcoming the negative N balance in the effluent area. The second change was proposed since it represents only 4 kg N/ha/year on a whole farm basis. Expansion of the effluent area is included to ensure high N use efficiency and so that

the rate of N applied in effluent is reduced below the maximum level of 150 kg N/ha/year required by the Regional Council. Incorporating all these features leads to the calculated N balance in Table 4.

Table 4 Whole farm N balance incorporating the proposed management changes.

N Inputs (kg N/ha)		N Outputs (kg N/ha)	
Fertiliser	93*	Milk	156
Feed	147	Meat	11
Fixed N (clover)	103	Transfer	17
		Leaching losses	74
		Gaseous losses (soil)	35
		Extra gaseous loss (pad, effluent)	9
Sub-total	343	Sub-total	302
Balance (Inputs-Outputs)			**+41**

* based on fertiliser N at 80 kg N/ha + 60 kg N/ha (as effluent) on 140 ha effluent area and 120 kg N/ha for 21 ha irrigated and 49 ha dryland areas

The main changes in the N balance compared to that for the current system are:

1. Higher average N inputs in fertiliser and from clover N_2 fixation (by 13 and 16 kg N/ha/year, respectively). The latter is due to an assumption that the average clover content in the former effluent area will increase from the current 10% to 17%, which is a typical average value and is similar to that for the current irrigated area.
2. Slightly higher output of N in milk and transfer based on an assumed increase in pasture production and efficiency of utilisation from the former effluent area.
3. Reduced gaseous loss from the pad and effluent due to less being fed on the pad without the cut-and-carry operation.
4. Higher leaching and gaseous losses (by 10–15%) from the paddocks due to more N cycling.
5. Larger positive N balance due to removal of the depletive cut-and-carry operation and greater immobilisation of N associated with the higher N inputs.

Discussion

Application of OVERSEER to the farm system of Hawke's Bay Dairies Ltd. estimated that the current cut-and-carry operation on the effluent area results in an N balance of -117 kg N/ha/year. This level of depletion of N and other nutrients is unsustainable in the long-term and would result in marked deterioration of pastures. A limit for effluent application of 150 kg N/ha/year is clearly too low for a cut-and-carry system. The large N removal in cut pasture and the minimal estimate of nitrate-N leached in the effluent area means that water draining from this area should be near 'pristine' and would easily meet any Regional Council requirements for N and water quality. However, it is ignoring the effects of the whole farm system.

Potentially, N can be more efficiently cycled in a farm using a cut-and-carry system where the effluent is applied evenly across pastures. In grazed pastures the excreta are deposited in localised areas at high N concentrations and are subject to significant losses (Haynes & Williams 1993). However, in the current farm operation the cows only spend about 6 hours per day on the feed-pad. Approximately 15–16 hours a day are spent in the paddocks, with the remainder in the farm dairy or in transit to it. Thus, three-quarters of the excreta generated from feed consumed on the feed-pad is deposited on the grazed pastures, assuming that excreta are deposited in proportion to time spent on the different areas. This indicates that there would be limited benefit in overall farm N efficiency associated with the cut-and-carry operation. In the proposed changes the effluent is spread over a larger area at a relatively low rate of N (c. 60 kg N/ha/year) to aid efficient use by pasture.

Total N inputs to the current and proposed Hawke's Bay Dairies Ltd farm operations of 314 or 343 kg N/ha/year are similar to the total N inputs in the 200 N farmlet of the DRC Number 2 Dairy trial (Table 1). However, in the Hawke's Bay Dairies Ltd farm the following N outputs differ from those in the DRC 200 N farmlet:

1. Lower N transfer.
2. Higher estimate of nitrate leaching.
3. Much higher N output in milk.

The estimate of N transfer was low in the Hawke's Bay Dairies Ltd farm because it refers only to transfer to lanes since excreta deposited in the farm dairy was recycled back onto the pastures.

In the DRC farmlets, N transfer included excreta deposited in the farm dairy because it went to processing ponds and therefore represented a loss from the farmlet system. However, all Regional Councils promote land application of farm dairy effluent as a more efficient utilisation of resources and to minimise direct emissions to waterways. If the 200 N farmlet had incorporated recycling of farm dairy effluent to land and reduced fertiliser N inputs to account for the effluent-N, OVERSEER indicates that nitrate leaching would have increased from 63 to 70 kg N/ha/year (data not presented).

Nitrate leaching over the whole of the Hawke's Bay Dairies Ltd farm was estimated at 66 and 74 kg N/ha/year for the current and proposed systems, respectively. Nitrate leaching may have been overestimated in the current model application due to the conservative approach used. The soil group selected was free-draining volcanic soil which is the same as on the DRC farmlets. In practice, the Hawke's Bay Dairies Ltd farm is a free-draining sedimentary soil over gravel. If the sedimentary soil option in the model had been selected, the estimates of nitrate leaching would have been 57 and 64 kg N/ha/year for the current and proposed systems, respectively. In addition, losses of excreta-N were assumed to be the same as that for a pasture-only system. In practice, a farm system that reduces dietary protein content using low protein supplements results in more N partitioned into dung relative to the more readily-leached urine-N and can improve N use efficiency (Van Vuuren & Meijs 1987).

High N output in milk in the Hawke's Bay Dairies Ltd farm was due to very high milk production at 2200 kg milksolids/ha, compared to 1300 kg/ha in the 200 N farmlet. Thus, there was a very high efficiency of conversion of the total N input into milk at 49%, compared to 26% in the 200 N farmlet. This can be attributed to integration of an additional feed component which is high in energy and low in protein (c. 1.4%N) to complement pasture with a protein content (c. 3.2%N) in excess of that required by cows. In the DRC farmlet trial, fertiliser N was also applied at 400 kg N/ha/year and only gave a small increase in milk production above that in the 200 N farmlet (Penno *et al.* 1996), but resulted in a large increase in nitrate leaching to groundwater (Table 1). This indicates that low-moderate N fertiliser use in combination with high energy/low protein supplements are most effective in achieving high milk production while limiting environmental effects. Nevertheless, the relative economics of N-boosted pasture versus supplements must also be considered.

Conclusions

Application of OVERSEER to the Hawke's Bay Dairies Ltd farm indicated that the current cut-and-carry operation for the effluent block is unsustainable due to severe N depletion and likely pasture deterioration over time. The effects of a proposed change in management, involving effluent application over a larger area of grazed land at a relatively low rate (c. 60 kg N/ha/year) and a small increase in clover and fertiliser N, was assessed using OVERSEER. It indicated that the changes would lead to a small increase (10–15%) in total N inputs and nitrate leaching over the whole farm.

REFERENCES

Haynes, R.J.; Williams, P.H. 1993. Nutrient cycling and soil fertility in the grazed pasture ecosystem. *Advances in agronomy 49*: 119–199.

Ledgard, S.F.; Penno, J.W.; Sprosen, M.S. 1999a. Nitrogen inputs and losses from clover/grass pastures grazed by dairy cows, as affected by nitrogen fertilizer application. *Journal of agricultural science, Cambridge 132*: 215–225.

Ledgard, S.F.; Williams, P.H.; Broom, F.D.; Thorrold, B.S.; Wheeler, D.M.; Willis, V.J. 1999b. OVERSEER™ – a nutrient budgeting model for pastoral farming, wheat, potatoes, apples and kiwifruit. *In*: Best soil management practices for production. Ed. Currie, L.D. Occasional Report No. 12. Fertilizer and Lime Research Centre, Massey University, Palmerston North (in press).

Pain, B.F.; Van Der Weerden, T.J.; Chambers, B.J.; Phillips, V.R.; Jarvis, S.C. 1998. A new inventory for ammonia emissions from U.K. agriculture. *Atmospheric Environment 32*: 309–313.

Penno, J.W.; Macdonald, K.A.; Bryant, A.M. 1996. The economics of No 2 dairy systems. *Proceedings of the Ruakura Farmers' Conference 48*: 11–19.

Van Vuuren, A.M.; Meijs, J.A.C. 1987. Effects of herbage composition and supplement feeding on the excretion of nitrogen in dung and urine by grazing dairy cows. pp. 17–25. *In*: Animal manure and fodder crops. Eds. Van der Meer, H.G. *et al.* Dordrecht, Martinus Nijhoff Publishers.

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