USE OF OVERSEER™ TO COMPARE FARM SYSTEMS AND COUNTRIES FOR NUTRIENT BALANCES, LOSSES AND EFFICIENCY

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Abstract

The model OVERSEER™ provides quantitative estimates of nutrient inputs, outputs and balances on farms. These are useful indicators of farm sustainability and of potential nutrient losses to the environment. They are also useful to compare New Zealand farms with those in overseas countries. This paper presents data from the application of OVERSEER™ to estimate variability in nutrient balances, efficiency and leaching losses within and between farm systems.

Variability in nutrient balances and losses were examined for a range of dairy farms and sheep and beef farms in the Waikato region. There was a wide variation in site nutrient balances (i.e. Σ nutrient inputs - Σ nutrient outputs from the soil/plant/animal system) between farms (e.g. 1-111 kg P/ha/year on dairy farms). On average, the site nutrient balances were positive for N (18-21 kg/ha/year) and P (29-38 kg/ha/year) due to immobilisation/sorption in soil, but were slightly negative for K (-4 to -11 kg/ha/year).

Average data for different pastoral, horticultural and arable farm systems in New Zealand were used to derive preliminary national estimates of N balances and losses. National estimates for site N balance and nitrate-N leaching for farmed land averaged 13 and 8 kg N/ha/year, respectively. These estimates were influenced mainly by results for sheep and beef farms since they constitute most of the total land area under farming in New Zealand. There was a wide range in estimates of nitrate leaching of between 3 and 103 kg N/ha/year for extensive sheep and beef farms through to vegetable farms, respectively. N balance data for average farm systems in New Zealand calculated using OVERSEER™ are compared to those estimated using the OECD soil surface N balance method and the different approaches are discussed.

Efficient conversion of nutrient into produce is important from economic and environmental perspectives. Data are presented comparing the N and P efficiency of dairy farms in New Zealand with several European countries. While conversion of P inputs into milk are generally similar between countries, there is a wide variation in N use efficiency. Conversion of N inputs into milk averaged 14-18% for conventional dairy farms in Europe, compared to 32% for the average New Zealand dairy farm. Estimates of N conversion efficiency ranged from 44% for a productive dairy farmlet reliant on clover N_2 fixation as its sole N input, to 28% for a dairy farmlet receiving 200 kg N/ha/year. A very high producing dairy farm incorporating a feed-pad with cows fed on fruit and vegetable residues high in energy and low in protein had a conversion efficiency of 49%. The latter farm also had the lowest estimated nitrate-N leaching loss per unit of milk production. Thus, some highly productive farms are also capable of high nutrient efficiency.

Introduction

Nutrient balances are useful indicators of farm sustainability and of potential environmental impacts. They can be used to compare the adequacy of fertiliser inputs or of potential environmental effects within different parts of a farming system, or between different farm types. Nutrient balances are also useful to compare farms in New Zealand with those in overseas countries, especially those we trade with.

In New Zealand, the nutrient balance model OVERSEER™ was developed to provide quantitative estimates of nutrient inputs, outputs and balances for a range of different farming systems (Ledgard et al. 1999c). OVERSEER™ was developed by AgResearch, in conjunction with Crop&Food Research and HortResearch, and is available from MAFPolicy.

Fertiliser nutrients represent an important resource input on farms. High efficiency of nutrient use through conversion into agricultural produce is beneficial for profitable production and to reduce the nutrient surplus or potential for loss into the environment. Nutrient output in produce as a proportion of total nutrient inputs is a useful index of nutrient use efficiency and can be calculated using OVERSEER™.

This paper reports on the use of OVERSEER™ to examine variability in nutrient balances and losses within farm systems and to integrate average farm data to produce preliminary national estimates. Nitrogen (N) balances are compared with estimates using the OECD soil surface N balance method (OECD 1997). Data are also presented which compare the N and P efficiency of dairy farms in New Zealand with several overseas countries.

Variability in nutrient balances between pastoral farms

Examples of the range in inputs and nutrient balances within dairy and sheep and beef farms are demonstrated in Table 1, using data from the MAFPolicy Monitor Farm Programme for the Waikato region. In general, the average, minimum and maximum nutrient inputs, balances and leaching losses were higher for dairy farms than for sheep and beef farms. However, there was a very wide range in nutrient inputs, balances and leaching losses within each farm type.

Table 1. Summary of farm inputs of N, P and K in fertiliser, and nutrient balances and leaching (all in kg/ha/year) estimated using OVERSEER™, for 43 dairy farms and 20 sheep and beef farms in the MAFPolicy Monitor Farm Programme in the Waikato region.

	Fertiliser inputs			Site nutrient balance			Nutrient leaching		
	N	P	K	N	P	K	N	P	K
Dairy farms									
Average	36	53	60	18	38	-11	28	<1	22
Minimum	0	16	0	2	1	-86	15		8
Maximum	166	123	133	74	111	46	56		45
Sheep/beef farms									
Average	6	31	13	21	29	-4	11	<1	11
Minimum	0	14	0	-9	9	-22	0		5
Maximum	38	68	91	71	65	70	27		21

Site N and P balances (Σ inputs in fertiliser, supplements, rainfall, N_2 fixation - Σ outputs in produce, animal excreta transferred off site, leaching and atmospheric losses) were positive in most cases and reflect model estimates of immobilisation of N in soil organic matter and of P immobilisation and/or sorption (to very slowly-available forms) in soil. High P balances may reflect farmers using capital P fertiliser application to raise soil Olsen P tests to desired levels. In the Netherlands, the government has implemented a system to limit excessive inputs of nutrients whereby farmers must provide data for calculation of N and P surpluses (e.g. Breembroek et al. 1996). Dutch farmers are taxed when N and P surpluses exceed set levels, which are currently 275 and 15 kg/ha/year for N and P, respectively. For P, they can work towards a P surplus near zero (i.e. Σ P inputs $\approx$ P outputs in produce) because their pastoral soils have soil organic P levels at equilibrium and very high levels of adsorbed P in soil (Aarts, pers. comm.). However, this would be inappropriate for New Zealand because in many cases immobilisation and sorption will be a significant removal from the plant-available P pool.

Site K balances were slightly negative, on average, for both farm types. However, this does not mean that K was limiting production since calculation of site K balances does not account for K supply from non-exchangeable sources in the soil. Nevertheless, it does suggest that a slow decline in total soil K levels is occurring over time.

The estimates of K leaching were of a similar magnitude to those for N leaching. Estimates of nitrate-N leaching were higher for dairy farms than for sheep and beef farms, with average values similar to those for the national averages for dairy and intensive sheep and beef farms (compare Tables 1 and 2). Net drainage from most dairy farms is typically above 350 mm/year and therefore the average leaching loss of 28 kg N/ha would result in the average nitrate-N concentration in water draining to groundwater of < 8 g m^{-3}. This is below the recommended maximum for drinking water of 11.3 g m^{-3} (Ministry of Health 1995). However, farms near the maximum of 56 kg N/ha leached could exceed the drinking water standard.

Preliminary N balances for New Zealand

Preliminary N balances for the main pastoral, arable and horticultural practices in New Zealand are summarised in Table 2. Estimates were obtained using OVERSEER™ and were based on typical average data collected from the MAF Farm Monitoring Programme, from MAFPolicy for the cropping systems, or from Livestock Improvement (1998) statistics for dairy farming. Values for site N balance were calculated from the difference between estimated nutrient inputs (in fertiliser, supplements, clover N_2 fixation and rainfall) and nutrient outputs (via produce, prunings/residues or animal excreta transferred off-site, atmospheric losses and leaching). This represents an estimate of the complete net N flows into and out of the plant/soil/animal system. The site N balance increased with increased intensity of sheep and beef farming and reflected increased incorporation of N into the soil organic N pool. Similarly, the highest site N balance for orchards (based on averages for apples and kiwifruit) reflects relatively large immobilisation of N into soil organic matter. In contrast, the negative N balance for arable crops (based on a broad “average” cereal crop) occurred because of losses of N from net mineralisation of soil organic N due to cultivation (e.g. Francis et al. 1992). The N balance for vegetables (based on an average for potatoes) was close to zero and coincided with much lower net N mineralisation than for arable crops because of the longer average period that land has been continuously growing vegetables.

Nitrate leaching calculated using OVERSEER™ gives a more direct estimate of the potential environmental effect on groundwater quality. Table 2 shows that estimates of nitrate leaching were very low for extensive and moderate sheep and beef farming, and that they increased with increasing inputs and intensity of farming through to 103 kg N/ha/year for vegetables. Data on the approximate relative area occupied by the different farming practices were used to aggregate the N balances and nitrate leaching losses into a national figure. Sheep and beef farming occupies the main area of farmed land in New Zealand and therefore it had a dominant effect on the weighted estimates.

This approach of assessing nutrient balances and losses within and between different farm systems using OVERSEER™ is valuable for assessing the impacts of different farm systems and key farm management practices. It warrants extending beyond the preliminary approach used in Table 2 to use of more accurate data, inclusion of other nutrients and application of OVERSEER™ using overseas data.

Table 2. Preliminary estimates of site N balance and nitrate leaching using OVERSEER™ for different farm systems in New Zealand.

Farm system	New Zealand area	Site N balance (kg N/ha/year)	Nitrate leaching (kg N/ha/year)
Sheep / beef			
- extensive	29 %	3	3
- moderate	41 %	17	1
- intensive	12 %	30	13
Deer	2 %	36	19
Dairy	13 %	13	27
Orchard	0.5 %	50	27
Arable	1.5 %	-43	36
Vegetable	1 %	-3	103
NZ average		13	8

OECD soil surface N balances compared with NZ N surpluses

The OECD has a number of agri-environmental indicators, which include a simple soil surface N balance (OECD 1997). This is similar to the "N surplus" or farm gate N balance concepts, which do not account for N output in transfer, atmospheric loss or leaching. Data for the different New Zealand farm systems was used to calculate a soil surface N balance using the OECD methodology, and this is compared to the N surplus (Σ N inputs – N in produce) calculated using results from OVERSEER™ (Table 3). These estimates were the same for the different cropping or horticultural systems, but the OECD soil surface N balance estimates for the pastoral systems were all negative. This was due to the OECD methodology for pastoral systems which considers livestock manure as an input and pasture N uptake as an output. It uses a constant coefficient per animal for manure, which is relatively high for New

Zealand animals grazed outdoors on pasture. Clearly, this indirect approach is not well suited for grazed pasture systems.

Table 3. Preliminary estimates of N surpluses for different farm systems in New Zealand using OVERSEER™ compared to estimates calculated using the OECD soil surface N balance equation.

Farm system	New Zealand area	OVERSEER N surplus[1] (kg N/ha/year)	OECD soil surface N balance[2] (kg N/ha/year)
Sheep / beef			
- extensive	29 %	9	-1
- moderate	41 %	34	-35
- intensive	12 %	72	-34
Deer	2 %	94	-56
Dairy	13 %	100	-63
Orchard	0.5 %	100	100
Arable	1.5 %	8	8
Vegetable	1 %	172	172
NZ average		42	-26

[1] Σ N inputs – N outputs in produce

[2] Σ N inputs (including animal excreta) – N outputs in plants. For pastoral systems, the latter refers to total N uptake by pastures.

Soil surface N balances for a range of OECD countries

Estimates of soil surface N balances for agricultural land in a range of countries in the OECD are given in Table 4. The estimate for New Zealand is different from that in Table 3 because it was not calculated separately for the different farm systems but was based on national animal and crop data and average estimates for the whole country e.g. pasture production of 9 t DM/ha/year.

Table 4 highlights that some countries have intensive agriculture over much of the country and have high national N balances. New Zealand is at the middle-lower end of the range, although there has been concern expressed by MAFPolicy about the accuracy of the estimate for New Zealand (e.g. see comment above about pastoral system methodology) and this is being revised. Some countries are known to have areas of intensive agriculture with significant N losses to the environment (e.g. France and USA) but have very low N balances on a national basis. Thus, in their report on data in Table 4 the OECD (1997) noted that it is desirable to improve N balance calculations and to examine the spatial variation and results for different farming systems. OVERSEER™ has been presented to the OECD as an alternative for calculating N balances.

Table 4. Soil surface N balances estimated using OECD methodology for a range of OECD countries for 1993-1995 (OECD 1997).

Country	N input to agricultural land ('000 tonnes)	N input to agricultural land (% as fertiliser)	Soil surface N balance (kg N/ha/year for agric. land)
Australia	8174	7	2
Austria	411	30	57
Belgium	434	39	177
Canada	3151	44	9
Denmark	647	52	138
France	4155	55	4
Germany	3411	50	66
Greece	713	47	45
Ireland	854	47	55
Japan	1253	52	136
Korea	773	61	215
Netherlands	1005	?	272
New Zealand	1285	8	27
Poland	1822	44	51
Switzerland	286	?	86
Turkey	3312	40	17
UK	3041	45	76
USA	29380	37	21
OECD	75159	37	17

Nutrient use efficiency in dairy farm systems

In all farming systems, efficient conversion of nutrient inputs into product is important from economic and environmental perspectives. Dairy farming is relatively intensive and consequently is sometimes considered to be 'leaky' and inefficient with respect to nutrient use. Table 5 shows a comparison of the efficiency of conversion of the total inputs of N (from fertiliser, N_2 fixation and rainfall) and P (from fertiliser and slow-release soil P) into milk for the average New Zealand dairy farm, two farmlets at DRC Number 2 dairy near Hamilton and a commercial farm called Hawkes Bay Dairies Ltd. The latter farm achieves a very high milk production due to use of a feed-pad system whereby fruit and vegetable residues are fed to cows for about 3 hours per day and constitute almost half the dietary dry matter intake (for details, see Ledgard et al. 1999a).

The lowest conversion of total N inputs into milk-N occurred in the average New Zealand farm and the DRC farmlet receiving fertiliser N at 200 kg N/ha/year (Table 5). This N conversion efficiency was about 1.5 x higher in the DRC 0 N farmlet and Hawkes Bay Dairies farm. The high N efficiency in the 0 N farmlet occurred because of low N inputs (almost all from clover N_2 fixation) and relatively high milk production due to high pasture utilisation. High N efficiency on the Hawkes Bay Dairies farm was due to very high milk production at modest total N inputs. The main reason for this was that the fruit and vegetable residues were high in energy but very low in protein and gave a good balance to pasture which has more protein than cows need. Therefore, more dietary N was converted into milk and much less was excreted. These feed residues had about one-third the protein level of N-fertilised pasture. In highly N-fertilised pasture, <15% of the N consumed by cows is converted into milk. The rest is excreted, mostly in urine which is the main source of leached nitrate (e.g. Ledgard et al. 1996). Another measure of farm N efficiency is the amount of N leached per unit of milk production. Table 4 shows that this was least for the nil N farmlet and Hawkes Bay Dairies. Thus, highly productive farms are capable of high nutrient efficiency and low nutrient leaching per unit of milk production.

The highest conversion of total P inputs into milk-P occurred on the Hawkes Bay Dairies farm. Again, this can be attributed to greater conversion of dietary P into milk. One-half of the total P input at Hawkes Bay Dairies was in the fruit and vegetable residues. It is uncertain if the relatively low P fertiliser input in conjunction with the residue-P input is sufficient to maintain optimum soil P levels. One of the reasons for the greater P efficiency on Hawkes Bay Dairies is that it is on a sedimentary soil, which has a slightly lower net P loss than the volcanic ash soils of the DRC farmlets, and therefore has a lower maintenance P fertiliser requirement (Metherell et al. 1995).

Table 5. Comparison of milk production and N and P efficiency on different dairy farms in New Zealand.

	NZ average[1]	DRC Number 2 dairy		Hawkes Bay Dairies[3]
		0 N[2]	+200 N[2]	
kg milksolids/ha/year	750	1040	1210	2200
Total N input (kg/ha/year)	161	165	315	314
Total P input (kg/ha/year)	c.40	54	54	47
N efficiency:				
milk N/total input N	32%	44%	28%	49%
kg leached N per '000 kg milksolids	36	29	52	30
P efficiency:				
milk P/total input P	c.22%	22%	26%	54%

[1]N and P data estimated using OVERSEER from Livestock Improvement (1998) statistics; [2]Ledgard et al. (1999b and unpublished data); [3]Ledgard et al. (1999a)

A lower conversion efficiency of N inputs into milk and higher nitrate leaching loss are evident in dairy farms in Europe compared to New Zealand (Table 6). In The Netherlands the low N efficiency is due to the very high total N inputs in fertiliser and concentrates. Nitrogen inputs are lower on French and Danish farms but the efficiency of conversion of N inputs into milk is not much higher than in The Netherlands. However, the N efficiency is higher on organic dairy farms than on conventional farms due mainly to much lower N inputs (Table 6). In Denmark and to a lesser extent in France, the whole farm N efficiency is higher than indicated from conversion into milk since a significant amount of N is exported from the farms in crop and manure. The latter increases N efficiency to up to 38% on Danish organic dairy farms.

Table 6. Comparison of N and P inputs, surpluses and efficiency on 'average' dairy farms in Europe and New Zealand. Data includes comparison of conventional and organic farms.

	Netherlands[1]	Brittany, France[2]		Denmark[3]		NZ[4]
	Conv.	Conv.	Organic	Conv.	Organic	Conv.
Total N input (kg/ha/year)	479	267	115[5]	274	150	161
N surplus	405	206	77	173	112	100
Total P input (kg/ha/year)	51	*nd*[6]	*nd*	37	14	c.40
P surplus	37	*nd*	*nd*	19	7	c.31
N efficiency:						
milk N/total input N	13%	18% (20%)[7]	21% (23%)	14% (30%)	19% (38%)	32%
kg leached N per '000 kg milksolids	c.100	c.80	c.50	-	-	36
P efficiency:						
milk P/total input P	26%	*nd*	*nd*	19%	36%	22%

[1]Van Bruchem et al. (1999) national summary; [2]Simon et al. (1997) for 133 farms; [3]Halberg (1999) for 20 farms; [4]Livestock Improvement (1998) national summary; [5]N_2 fixation was probably underestimated by up to 40% and therefore this will be an underestimate; [6]not determined; [7]includes output from farm in crop and 'sold' manure.

These comparisons indicate that the New Zealand farm system dependent on clover N_2 fixation for most of the N input is generally more efficient at conversion of N input into milk than their European counterparts. However, there is much less variation in the efficiency of conversion of P inputs into milk between average farms in New Zealand and the conventional EU farms. The P efficiency was higher on the Danish organic farms than the conventional farms. This was due to negligible inputs of P on several of the organic farms, which is unlikely to be sustainable in the long term.

Future additions to OVERSEER™

Further additions to OVERSEER™ proposed for 2000/2001 include incorporation of forestry, options for dairy farm effluent management, and greater environmental N information. The current version of OVERSEER™ can be used to examine the detail of many agricultural systems but when it comes to producing a national nutrient budget it is currently not possible to extend this to cover the large area of New Zealand under forestry.

The current model provides estimates of the per-hectare loss of N into the atmosphere and by nitrate leaching. An additional environmental N output page will be generated which separates atmospheric N losses into ammonia, total denitrification and N_2O emissions. Nitrate leaching information will be extended to include an estimate of the potential nitrate-N concentration in groundwater. Thus, it will give more direct estimates of N impacts on the environment.

In future, OVERSEER™ could also be extended to include nutrient balances for a wider range of crops, nutrients (e.g. C, Ca, Mg) and possibly to cover eco-efficiency in allied industries (e.g. product processing plants). Before the end of the year 2000, the nutrient balance model will be linked with the pastoral nutrient and lime requirement models in a single framework, which will be called OVERSEER™.

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