NITROGEN LOSSES IN DIFFERING DAIRY WINTERING SYSTEMS IN CANTERBURY

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Abstract

Three dairy farm systems, all on light free-draining Lismore soils, were compared for nitrogen use over two seasons, 2011-12 and 2012-13. These included System A (DairyNZ System 2), representing relatively low inputs with all cows grazed off-farm on 108 ha and 103 ha of forage crops fed during June and July in 2011-12 and 2012-13, respectively; System B (DairyNZ System 4), where greater than 90% of annual supplement was fed on a large feed pad, and animals were wintered off-farm on 87 ha and 58 ha in the respective seasons; and System C (DairyNZ System 5), a full indoor-housed system where animals were inside year round, with the feed sourced from an accompanying 80-ha support block and imported supplements.

OVERSEER® nutrient budgets were used to define N cycling at the paddock level and for overall system-level performance. Annual predicted nitrate-N leaching losses at the system level were highest in System B at 48 kg N/ha, approximately 9 kg N/ha higher than in System A. Losses were lowest in System C, at approximately 26 kg N/ha. Stocking densities during wintering of System B were greater than in System A, leading to higher losses from the wintering system alone of 65 kg N/ha compared with System A losses of 50 kg N/ha. Nitrogen conversion efficiency (N inputs relative to N losses) at the whole farm system level was highest for System C at 39%, while the efficiencies of Systems A and B varied between 25 and 33%.

Introduction

Winter feeding practices in the South Island are the focus of increasing scrutiny, as significant environmental pressures have emerged around the management of nitrogen (N) and the sustainability of current systems. Dairy wintering systems in New Zealand involve high stocking rates up to 30 cows/ha on high yielding forage crops, and this can contribute a disproportionately large fraction of whole-farm generation of water contaminants such as nitrates (Monaghan et al. 2007; Chrystal et al. 2012).

The risks of excessive nitrate leaching associated with grazing during winter in wet conditions are high (Chrystal et al. 2012; Shepherd et al. 2012; Cameron et al. 2013; Monaghan et al. 2013); however, there are insufficient data to demonstrate the scale of impacts at a system level. Some preliminary modelling work by Chrystal et al. (2012), using the OVERSEER® Nutrient Budgets model to simulate six different dairy farm systems with contrasting approaches to wintering, indicated that winter brassica forage crops had a relatively high potential for generating N leaching losses, and accounted for between 11 and 24% of total annual system N leaching losses, despite representing only 4 to 9% of the area. Similarly, work by Smith et al. (2012) reported high leaching losses beneath winter-grazed forage crops in northern Southland, with annual losses as high as 125 kg N/ha over three seasons.

The contribution of winter support blocks to the whole system environmental footprint varies with the type of system and the intensity of feeding on land or on feed pads. In the South Island, non-lactating dairy cows are commonly grazed off the milking platform on high yielding forage crops during winter, with potential for high N returns. Alternatively, systems involving effluent capture and dispersal may be required in future to reduce the potential N loss. In this study, we compared three systems in Canterbury with increasing intensification and varying reliance on wintering off the milking platform and amounts of feed imported onto the farms.

The aim was to provide metrics for comparing the N use efficiency of each farming operation and to characterise the respective system N footprint using OVEERSEER and from information collected in farm monitoring.

Materials and Methods

System comparisons

The wintering systems considered in this study represented a range of existing practices:

- System A (DairyNZ level 2) represented a relatively low stocked farm typical of Canterbury, with wintering on support land. Wintering herds were partitioned on the basis of calving date or herd composition (young stock). All feed was supplied by paddock grazing, with some in-shed feeding of grain during lactation.

- System B (DairyNZ level 4) was primarily an off-farm winter grazing operation, with the option of feeding or standoff on a concrete pad during winter with higher stocking rate and a greater proportion of imported feed. The majority of supplements were fed on a large concrete feed pad and cows were also wintered off the milking platform during June and July on forage crops. The feed pad enabled high feed use efficiency and the capture and redistribution of nutrients from the combined dairy shed and feed pad areas. In-shed grain feeding was also practiced during lactation.

- System C (DairyNZ level 5) consisted of a high input system, and cows were housed in a large barn year round. All effluent was captured and distributed back onto the support block. A small proportion of the cows were dried off from the beginning of May 2013 and remained housed throughout the facility, but were removed for calving.

As the systems were conceptually different, care was taken to make valid comparisons between systems for metrics of cow performance and feed requirements. Systems A and B had a defined wintering period when animals were moved off the milking platform and onto winter support areas. In System B, the main herd was split so that around 50% of the animals were milked until mid June and the other 50% comprised an early calving herd. System C was in a continuous ‘wintering mode’, as feed use was not markedly different from season to season. A full annual cycle beginning in May 2012 was considered to represent the best impact of this system on productivity, net feed requirements and environmental loading.

A block structure was set up in OVERSEER for all wintering paddock x feed type combinations within the systems. The impact of the wintering practices was evaluated within the context of milking platform and wintering components, and then interpreted at the paddock (block) level, and the whole-farm system (including the milking platform) with all hectares counted (excluding purchased supplements).

Farm comparisons

Any comparison of system efficiency will be influenced by factors such as stocking rate, feed composition, fertiliser applied and production targets. These are summarised for the study farms in Table 1. The systems compared were examples of common farm types in Canterbury. The selected farms were on the same soil type (Lismore series), all located within 28 km of each other. Various input parameters for the modelling exercises were standardised between the farms and seasons. For example, all climate and soil input data were the same for each farm, as these can strongly influence processes in OVERSEER. In addition, months and amounts of irrigation were consistent on the milking platforms, given that OVERSEER calculates the amount of irrigation applied based on soil moisture deficit, which is derived from long-term rainfall distribution data.

Table 1. Production details for Canterbury study farms with different dairy wintering systems.

Herd	**System A**	**System B**	**System C**
Milking Platform			
Hectares	222	168	80
Herd size	1050	1000	199
Stocking rate (cows/ha)	3.4	4.0	2.5
Feeds	Pasture, grain	Pasture, grain	Lucerne silage, wheat silage, vegetable waste, range of high value supplements
Nitrogen fertiliser applied (kg N/ha/y)	260	227	6
Production targets (kg MS/ha)	1500	2000	2000
Actual milking platform production (kg MS/ha)	1498 (2011-12) 1476 (2012-13)	1972 (2011-12) 1807 (2012-13)	1876 (2012-13)
Wintering block			
Stocking rate (cows/ha)	10.0	11.6	2.5
Feeds	Kale, fodder beet, straw, barley silage, rolled grain (+ small area of pasture standoff)	Kale, barley silage, straw, rolled grain (+ small area of pasture standoff)	Lucerne silage, wheat silage, vegetable waste, range of high value supplements
Target overall farm nitrate losses (kg N/ha)[a]	40	45	20

[a] Corrected for all hectares used

Crop biomass and feeding

All standing feeds were monitored for biomass before and midway through the wintering period. Each paddock was sampled at 10–20 random locations. Sample size was 3 m^2 for fodder beet, 1 m^2 for kale and 0.5 m^2 for all other crops and pasture. Biomass yield was corrected to dry matter (DM) basis by drying a representative subsample of whole plants at 90°C for 2 days. All supplementary feeds were processed using the same drying methods to determine intake. Five subsamples of all feeds making up composite diets were taken at monthly intervals for DM analysis.

Independent estimates were made of both the amount of feed grown and the amounts fed as standing crop, or as supplement fed in the shed, on the feed pad or on paddocks. These data sources were used to estimate the actual feed consumed to support wintering of stock. Adjustments were made to account for losses from incomplete utilisation of field-grazed forage.

The amount of standing feed consumed by herds was calculated from daily measurements of break width, break length, biomass and feeding duration in each paddock. Amount of supplement fed was determined from daily records of total fresh weight fed out by silage wagon and corrected to oven dry DM (60°C for 2 days). Allocations were summarised into monthly means for use in OVERSEER. Similar methods were used to determine standing feed supply to respective herds in System B.

Nitrogen Budgets

OVERSEER Nutrient Budgets were completed using Version 6.1.2 software (Wheeler et al. 2003; 2011), providing a platform for comparing the respective Systems A, B and C for their economic and environmental performance. This allowed the comparison systems for productivity, nutrient budgets and greenhouse gas emission indicators, using common inputs where possible. Additional information (supplementary to that which is included in standard industry budgeting) was collected and built into the budgets to ensure the best possible prediction of N cycling.

The N budgets were set up in the same way for each system, with both the wintering and milking platform contained in the same budget. Non-effluent, liquid effluent and solid-effluent areas were arranged into separate blocks, as was each individual paddock of the winter support land. Information included soil fertility test data from each cropped paddock, custom supplementary feeds with measured chemical analyses and quality, actual dry matter yields for each winter crop, and recent crop history.

Nitrogen budgets were determined for each farm system by collating losses and gains of N on a kg/ha basis and on kg N transfer at the paddock level. The N balance was evaluated for N contained in fertiliser application, amounts added in N fixation (OVERSEER prediction), gaseous losses (denitrification losses predicted by OVERSEER), N leaching losses (predicted by OVERSEER), and net N bound in standing crop or supplement (measured N uptake or N composition of supplement), N content of effluent (measured), and N content removed in product (predicted by OVERSEER). Calculations of the N budget included weighted corrections for amount of feed consumed (feed utilised) with adjustments for grazing or supplement feeding duration of individual feed components making up whole diets, and weighted for herd numbers making up the total farm wintering herd.

Given output from OVERSEER was on an annual basis, information reported per cow was weighted for 365 days and therefore accounted for days when no cows were on a given block.

Results and Discussion

Crop production

System A

Mean annual fodder beet yields were 20.2 and 24.8 t DM/ha on 10.4 and 28.5 ha in the respective seasons. These crops were irrigated regularly by the centre pivot (2011-12) or by Briggs Rotorainer (2012-13). Fodder beet yields were consistent with the results of Matthew et al. (2011) and Edwards et al. (2014). Mean annual kale yields on 41 ha were less than 7 t DM/ha in the main paddocks used for winter feeding. These were well short of the potential of 13–15 t/ha on a shallow soil type (Wilson et al. 2006, Chakwizira et al. 2009). In 2011-12, there was minimal irrigation and crops suffered from water deficit during much of the summer and autumn period. Barley + Italian crops in three paddocks (43 ha) performed well, with a mean yield of 11.2 t DM/ha, as there was adequate rainfall in spring.

In 2012-13, the paddocks previously in kale (41 ha), were sown in barley + Italian or perennial ryegrass. Silage barley + Italian yield was 10 t DM/ha. Italian ryegrass (41 ha) was used for supplementary grazing by lactating cows but around 3.0 t DM/ha was saved for wintering. Kale yield was again low (range 5.8–6.8 t DM/ha) over 43 ha despite receiving adequate irrigation through the summer and autumn.

System B

Kale was the sole standing feed for System B in both years. Yield on the main support block averaged 6.8 t DM/ha in 2011-12 (not irrigated) and only slightly more in 2012-13 (7.5 t DM/ha) even though it was irrigated. A small block of kale (8.5 ha) located away from the main support block produced substantially more feed on a similar soil type, at 14.5 and 14.7 t DM/ha in the respective years. This crop was grazed by young stock.

System C

Mean wheat yield on the 80-ha irrigated support block in 2011-12 was 12.3 t DM/ha and was harvested for silage on 20 January 2012. This provided the main source of whole crop silage fed to housed animals in the monitoring year beginning 8 September 2012. Seventy hectares were sown in lucerne in March 2012; however, establishment was slow and there was no harvestable biomass before winter of 2012. From October 2012, lucerne started producing well and was made into baleage from six cuts before the winter of 2013. A 10-ha block of wheat was harvested for silage and was added to the stockpile of whole crop silage for feeding in mixed rations with lucerne silage and other supplements.

Feed consumed

Winter feeding in Systems A and B was similar in that most of the standing feed was supplied as kale, except for a single mob in System A which was fed fodder beet. In System A (2012-13), 3.1 kg DM/cow/day of fodder beet was fed to 709 cows for 5 days to assist with adaptation to the feed and to prolong the lactation length. Fodder beet fed at this time was deemed to be part of the wintering feed allocation, as the fodder beet was primarily grown for wintering of stock.

In System A, mean per-cow intake in 2011-12 was 587, 566 and 788 kg DM/cow for mobs 1, 2 and 3 grazing primarily on kale, fodder beet and kale, respectively over 70 days. The total amounts eaten varied with duration of wintering. Total DM eaten in 2012-13 was 773, 921 and 902 kg DM/cow for sub-herds grazing kale and fodder beet and kale respectively as the primary standing feeds.

Feed allocation in System B was primarily standing kale in both years and this was fed at between 5.8 and 6.9 kg DM/cow/d. This was supplemented with barley silage and straw for a total in excess of 800 kg DM/cow over wintering varying from 55 to 75 days.

Feeds in System C were added and removed as required to meet the energy and protein requirements for optimal milking performance. Individual animals were monitored for milk volume and adjustments made to amount of concentrate and grain supplement fed at the milking robots. Average weighted allocation was 22.4 kg DM/cow/d, with the bulk of the feed supplied as lucerne silage, whole crop wheat silage, protein pellet and rolled wheat. Feed intake by non-lactating animals was also recorded and this comprised 6% of the total annual feed use of 1,632 t DM.

OVERSEER Nutrient Budgets

Overall, total N added to System C was 92 kg N/ha and 48% higher on average than that added to Systems A and B (Table 2), because of the substantially higher amounts of imported supplements and higher feeding rates. System B had 29% higher N inputs than System A, as there were more imported supplements. There was a substantially greater amount of N removed in product in System C, again because of high feeding rates and higher per-ha and per-cow milk production.

Fertiliser inputs of the two wintering blocks of Systems A and B varied, with notably higher amounts of N/ha applied to the System B wintering block (Tables 2 and 3). This led to , elevated leaching losses (63–67 kg N/ha/y) compared with those from System A (45–56 kg N/ha/y). These amounts are comparable with those from other simulations of cow wintering (Chrystal et al. 2012), where losses from winter forage crops were reported to be approximately 60 kg N/ha. Further, measurements by Monaghan et al. (2013) of field nitrate leaching losses beneath forage kale (yields of 13–16 t DM/ha/y) indicated losses of 52 kg N/ha on average over a three-year period.

Fertiliser N inputs into the fully housed system (System C) were low compared those into Systems A and B (Table 2). Nitrogen contained in effluents was recycled onto the 70 ha of lucerne. A large proportion of effluent N added to this block was N in imported supplements (395 kg N/ha), a much higher rate than for N imported in Systems A and B. This was because cows of System C were fed a higher amount of supplement throughout the season, while Systems A and B acquired additional support land to grow feed for winter grazing.

Total atmospheric N losses were highest in System C, although lower than in the other systems when assessed as a proportion of the total amount of N added. Most of the atmospheric loss was through ammonia volatilisation from applied effluent. However, significant volatilisation losses were estimated from Systems A and B as coming from urine patch areas (50–60 kg N/ha/y). Losses through background denitrification for all systems were between 33 and 40 kg N/ha/y, and were within normal ranges (McLaren & Cameron 1996).

Table 2. Annual nitrogen budgets of the dairy wintering blocks and milking platforms for Systems A, B and C.

	System A		System B		System C[a]
	2011–12	2012–13	2011–12	2012–13	2012–13
Wintering block					
Nitrogen added					
Fertiliser (kg N/ha)	101	133	186	163	-
Rain/clover N fixation (kg N/ha)	2	2	2	2	-
Supplement/irrigation/effluent (kg N/ha)	75	117	41	23	-
Nitrogen removed					
As products (kg N/ha)	0	0	3	4	-
Supplements + crop residue (kg N/ha)	74	25	32	0	-
To atmosphere (kg N/ha)	122	112	151	153	-
N Leached					
Amount (kg N/ha)	56	45	63	67	-
Amount (g N/kg milk solids)	13	10	12	8	-
Concentration (mg/L)	29	23	36	33	-
N balance	-74	70	-18	-36	-
Change in farm pools					
Standing plant material (kg N/ha)	-137	41	-34	-3	-
Crop residual (kg N/ha)	33	37	-49	-54	-
Organic pool (kg N/ha)	-155	-108	-112	-122	-
Inorganic soil pool (kg N/ha)	185	99	176	142	-
Total change (kg N/ha)	-74	69	-18	-36	-
Milking platform					
Nitrogen added					
Fertiliser (kg N/ha)	261	258	202	252	6[b]
Rain/clover N fixation (kg/ha)	105	112	172	131	207
Effluent/supplement/irrigation (kg N/ha)	62	63	68	65	294
Nitrogen removed					
As products (kg N/ha)	119	117	150	139	1
Supplements + transfer (kg N/ha)	58	55	30	-8	305
To atmosphere (kg N/ha)	95	96	105	99	27
N Leached					
Amount (kg N/ha)	36	36	43	43	22
Amount (g N/kg milk solids)	24	24	23	22	12
Concentration (mg/L)	17	17	16	16	11
N balance	119	129	113	175	153
Change in farm pools					
Organic pool (kg N/ha)	119	129	113	175	166
Crop residual (kg N/ha)	-	-	-	-	-12
Inorganic soil pool (kg N/ha)	0	0	0	0	-2
Total change (kg N/ha)	119	129	113	175	152

[a] No distinct wintering system, as cows are housed all year round and calving is spread relatively evenly throughout the season.

[b] N removed in product for System C is low because animals do not graze the block, and therefore N removed in milk is accounted for under ‘supplements + transfer.’

Nitrogen leaching losses at the overall system level (milking platform + wintering combined) ranged between 26 and 47 kg N/ha/y for all three systems, with System C estimated to leach the least amount of N, at 26 kg N/ha (Table 2). The highest losses estimated by OVERSEER were under System B, at 47 kg N/ha/y, 22% higher than under System A and 81% higher than under System C. Although almost 100% of supplement was fed on a feed pad in System B, animals spent most of the day in the paddock during lactation and consequently only a relatively small proportion of total daily urine was probably captured by the pad. In addition, feed inputs were higher than System A with substantially higher amounts of imported feed, leading to elevated rates of excess N, subsequently prone to leaching. Annual leaching losses in System C were particularly low despite being a high input system, because all effluent was captured and evenly distributed back onto the land used for feed production.

Generally, N pools were depleted on the support blocks, with predominantly negative balances of inputs v. outputs. This is a result of cultivation practices and the removal of crop biomass (i.e. spring barley harvested and conserved), resulting in less N being cycled back onto the soil.

Nitrogen efficiency

Nitrogen efficiency at the farm level was calculated for each system and included only grazed crops or crops produced on the support land that were used during the wintering period. Components of the N balance for each crop included inputs (fertiliser N applied) and losses (N leaching and gaseous N emissions) as predicted by OVERSEER (Table 3).

System-level output and efficiencies are given in Table 4. The highest N conversion efficiency estimated was in System C, with 39% of N input (fertiliser, supplement, etc.) converted into product. The conversion efficiency for System C was higher than for the other two systems (by 18–56%) because of the higher supplement use and lower inputs of N through the use of fertiliser. It is important to note that higher N conversion efficiency does not always result in lower N discharge (Wheeler et al. 2011). This is evident within System A between 2011-12 and 2012-13, where N conversion efficiency was highest in 2011-12 and leaching losses were also highest in 2011-12.

Farm N surplus (Table 4) is the amount of N applied that does not end up in product. For these system scenarios, the highest N surpluses were estimated in the higher input systems, with System C having the largest N surplus, of 369 kg N/ha/y. Although System B was higher producing than System A, OVERSEER estimated that nutrient requirements would be lower (particularly phosphorus (P) and potassium (K)). The likely reasons for this are 1) because a greater proportion of nutrient is brought in off-farm through higher use of supplements, and 2) the use of the feed pad enables a greater amount of effluent to be captured and subsequently spread back onto paddocks to obtain more efficient use of recycled nutrients. In System B, 91-95 ha were required to achieve an application rate of 150 kg N/ha, which was higher than in System A, which required 72 ha, and the 152 ha required in System C (Table 4).

Table 3. Nitrogen inputs and predicted environmental N losses in different dairy wintering systems.

System	**Season**	**Crop**	**ha**	**N fertiliser (kg/ha)**	**Gaseous N losses (kg/ha)[a]**	**N leaching (kg/ha)[a]**
A	2011–12	Pasture	28.0	138	121	50
		Kale	41.0	82	113	49
		Barley/rape	14.0	82	155	73
		Fodder beet	13.5	128	133	73
	2012–13	Pasture	50.5	150	115	51
		Kale	53.7	112	109	51
		Fodder beet	28.5	47	97	32
B	2011–12	Kale (1)	78	188	153	64
		Kale (2)	8.5	185	128	52
	2012-13	Kale (1)	49.8	137	163	74
		Kale (2)	8.5	185	120	37
C	2012–13	Lucerne	70.0	0	26	21
		Wheat	10.0	54	30	28

[a] Figures derived from OVERSEER® Version 6.1.2
See text for descriptions of Systems A, B, and C.

Table 4. Summary of annual nitrogen (N) efficiency (milking platform + wintering) and effluent application for dairy wintering Systems A, B and C as predicted by OVERSEER®.

	System A		**System B**		**System C**
	2011–12	2012–13	2011–12	2012–13	2012–13
Nitrogen loss indices					
Average N loss to ground water (kg N/ha)	40	36	48	47	26
N_2O emissions (kg N/ha)	8	7	8	9	9
Production efficiency indices					
Farm N surplus (kg N/ha)	213	237	280	328	369
N conversion efficiency (%)	33	26	29	25	39
Effluent area of pastoral farm					
Currently receiving effluent (ha)	64	64	50	50	80
Required to achieve an application rate of 150 kg N/ha	74	72	95	91	152

See text for descriptions of Systems A, B, and C.

Conclusions

The systems chosen for comparison covered the range of low to high cost per cow for winter feeding. Systems A and B had similar structures, with cows wintered off the milking platform, and being fed similar feeds (kale and fodder beet). In System C, the feeding regime was largely managed the same way throughout the year. Animals in System C were managed to achieve high production with high intake by feeding a balanced diet of wheat and lucerne silage supplemented with protein and carbohydrate concentrates.

OVERSEER was used to compare system performances given common soil types and climate. The differences in these systems were primarily in the quantity of feeding during lactation and the herds' grazing durations on paddocks during winter. The model predicted small differences between Systems A and B in the net N leached in 2011-12 (40 v. 48 kg N/ha/y, respectively) and 2012-13 (36 v. 37 kg N/ha/y, respectively) for the whole system. The annual losses for System C were less, at 26 kg N/ha. There were differences in the predicted N leached in the wintering blocks in Systems A and B. The mean N leached was 51 kg N/ha and 65 kg N/ha in the respective wintering systems. The relative efficiency determined as N leached on wintering blocks per kg MS produced was higher in System B than in System A.

The milking platforms in Systems A, B and C leached 36, 43 and 22 kg N/ha, respectively. System A had a lower N conversion efficiency (N inputs converted into product) than System B. In System C, the land area appeared to cope well with the nutrient returns from the housed facility, and had the highest N conversion efficiency. Measured N return in effluent was 256 kg N/ha. Other transfers of N, emitted as N_2O lost to the atmosphere, denitrification, immobilisation or stored in plant or soil pools within the annual cycles, showed that the systems were relatively stable. However, there were significant potential environmental implications associated with N leaching losses or N losses to the atmosphere. This study has established benchmarks for assessment of potential environmental impacts of winter feeding in Canterbury.

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References

Cameron, K.C., Di, H.J., Moir, J.L. 2013. Nitrogen losses from the soil/plant system: a review. Annals of Applied Biology 162(2): 145–173.

Chakwizira, E., Fletcher, A., de Ruiter J.M., Meenken, E.S., Maley S., Wilson, D.R. 2009. Dry matter response of kale to nitrogen and phosphorus application. Proceedings of the Agronomy Society of NZ 39: 59–70.

Chrystal, J.M., Monaghan, R.M., Dalley, D., Styles, T. 2012. Assessments of N leaching losses from six case study dairy farms using contrasting approaches to cow wintering. Proceedings of the New Zealand Grassland Association, 74. 51–55.

Edwards, G.R., de Ruiter, J.M., Dalley, D. E., Pinxterhuis, J.B., Cameron, K.C., Bryant R.H., Di, H.J., Malcolm, B.J., Chapman, D.F. 2014. Dry matter intake and body condition score change of dairy cows grazing fodder beet, kale and kale-oat forage systems in winter. Proceedings of the New Zealand Grasslands Association 76, 81–87.

Matthew, C., Nelson N.J., Ferguson D., Xie Y. 2011. Fodder beet revisited. Proceedings of the Agronomy Society of New Zealand 41, 39–48.

McLaren, R.G., Cameron, K.C. 1996. Soil Science: Sustainable production and environment protection. 2nd Ed. Auckland, New Zealand.

Monaghan, R.M., Smith, L.C., de Klein, C.A.M. 2013. The effectiveness of the nitrification inhibitor dicyandiamide (DCD) in reducing nitrate leaching and nitrous oxide emissions from a grazed winter forage crop in southern New Zealand. Agriculture Ecosystems & Environment 175: 29–38.

Monaghan, R.M., Wilcock, R.J., Smith L.C., Tikkisetty, B., Thorrold, B.S., Costall, D. 2007. Linkages between land management activities and water quality in an intensively farmed catchment in southern New Zealand. Agriculture Ecosystems & Environment 118 (1–4): 211–222.

Shepherd, M., Stafford, A., Smeaton, D. 2012. The use of a nitrification inhibitor (DCN™) to reduce nitrate leaching under a winter-grazed forage crop in the Central Plateau. Proceedings of the New Zealand Grassland Association 74: 103–107.

Smith, L.C., Orchiston, T., Monaghan, R.M. 2012. The effectiveness of the nitrification inhibitor dicyandiamide (DCD) for mitigating nitrogen leaching losses from a winter grazed forage crop on a free draining soil in northern Southland. Proceedings of the New Zealand Grassland Association 74: 39–44.

Wheeler, D.M., Ledgard, S.F., de Klein, C.A.M., Monaghan, R., Carey, P.L., McDowell, R.W., Johns, K.L. 2003. OVERSEER® nutrient budgets – moving towards on-farm resource accounting. Proceedings of the New Zealand Grassland Association 65: 191–194.

Wheeler, D., Power, I., Shepherd, M. 2011. Nutrient conversion efficiency on farm - lessons from OVERSEER® examples. In: Currie L.D., Christensen CL eds. Adding to the knowledge base for the nutrient manager. Occasional Report No. 24. Fertiliser and Lime Research Centre, Massey University, Palmerston North, New Zealand. 4 pages.

Wilson, D.R., Reid, J.B., Zyskowski, R.F., Maley, S., Pearson, A.J., Armstrong, S.D., Catto, W.D., Stafford, A.D. 2006. Forecasting fertiliser requirements of forage brassica crops. Proceedings of the New Zealand Grassland Association 68: 205–210.