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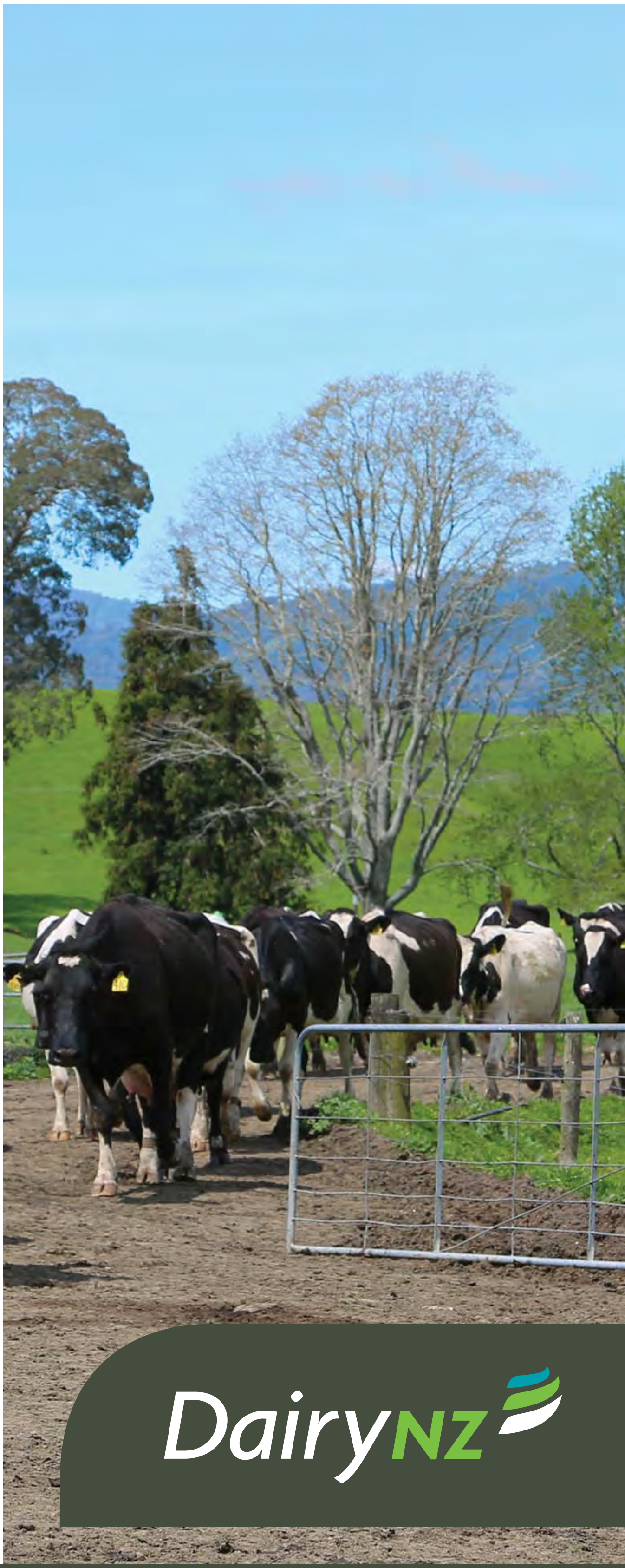

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Dairy systems for environmental protection

Dave Clark, DairyNZ Principal Scientist

Summary

- The expansion and intensification of dairy farming in New Zealand has led to increased use of fertiliser nitrogen (N), with surplus N entering waterways. Various communities are demanding mitigation against this environmental effect.
- Nitrogen enters the dairy farm by three major routes: biological fixation by legumes (e.g. white clover), N fertiliser application and feed supplements from off-farm sources.
- Cows have evolved to live on feed with a low N concentration and can recycle N very effectively; but when fed a diet where N exceeds requirements, the excess is excreted, mainly in urine.
- Both N fertilised pasture and mixed perennial ryegrass-white clover pasture usually contain a higher concentration of N than cows require. Supplementing pasture with low-N feeds such as cereal silages can reduce urinary N loss without loss of milk yield. This will reduce farm urinary N losses, but only if the total amount of N fed to cows is reduced.
- The urine patch (UP) is the major route of N loss to the environment on dairy farms, either leached as nitrate to ground water or lost as nitrous oxide to the atmosphere.
- The current breeding objectives for the genetic improvement of the national herd offer small but ongoing improvements in the capture of N as high value milk protein.
- This issue of the *Technical Series* outlines a series of investigations into how improvements in pasture composition and dairy farm management and cow genetics can achieve higher milk yields, higher profit and lower N leaching.

New Zealand dairy farming is coming under increasing pressure to reduce its environmental footprint.

Recent policy decisions by Horizons Regional Council will require intensive dairy and horticulture to obtain resource consents that require nitrate leaching outputs to be below a threshold, dependent on land class.

DairyNZ has responded to the challenge of N pollution by identifying dairy systems that use more efficient practices to reduce wastage. This approach complements other research that aims to mitigate nitrate leaching by treatment of waste as it enters the environment. An example is the development of nitrification inhibitors that block the formation of nitrate from the ammonium ion as soon as urine is deposited on pasture[1].

The N flows in a grazed dairy farm are outlined in Figure 1. This diagram is used to illustrate the key principles that must be understood and addressed when designing efficient dairy systems with lower environmental N losses. The red arrows indicate key control points for reducing N inputs to, and outputs from, the dairy farm.

Both N fertiliser and bought-in supplements are key sources of extra N, and appropriate comparative stocking rates and feed budgets offer ways to reduce unnecessary N inputs. Improving herd breeding worth (BW) ensures more efficient use of feed and captures more N as high value milk protein.

The collection and even return of farm dairy and standoff effluent reduces losses from areas of very high N concentration, and the use of nitrification inhibitors reduces nitrate leaching and nitrous oxide losses from urine patches. More detailed discussion of these principles and the use of whole farm modelling in system redesign are discussed further in this *Technical Series.*

What are the main nitrogen sources on a dairy farm?

The N fixed by legumes, mainly white clover, has always been an important source for perennial ryegrass growth. The amount fixed ranged from 100-230 kg N/ha/yr in the absence of N fertiliser, at Ruakura No. 2 Dairy in the 1990s[3]. However, the invasion of the clover root weevil (*Sitona lepidus*) in North Island and South Island dairy pastures since1996 and 2006 respectively[4], has reduced both clover dry matter (DM) yield and N fixation so that more synthetic N fertiliser (e.g. urea) has been required to maintain or increase pasture DM yield. Nitrogen fertiliser use on dairy farms doubled from 1995-2007 and has continued at a high level[5].

More recently control of clover root weevil is being achieved by an introduced Irish wasp. Direct losses of N fertiliser to the environment (e.g. to run-off), can occur under adverse conditions but this is not common. The N fertiliser is a major contributor to environmental N losses because of the increased N intake by the dairy herd. Approximately 65% of N eaten is excreted in urine patches when high quality pasture is fed, and the concentration of N in the urine patch is too high for pasture to assimilate. This results in a surplus which leaves the farm as leachate, nitrous oxides and ammonia, designated as the "Farm gate N surplus" box in Figure 1.

The third major source of N is supplement bought onto the farm. From about 1990, maize silage has been the preferred supplement on many North Island dairy farms. Its low N content (1.3% of DM) complements ryegrass-white clover pastures (3.0-4.5% of DM) and adding maize silage lowers the dietary N concentration. However, if pasture production and intake remain constant then additional silage increases total farm N intake, as well as N losses to the environment. From 2000, palm kernel expeller (PKE) has become a major purchased supplement[6] with a N content of 2.7% and has become a major source of additional N.

Obviously, the total amount of N entering a dairy farm is highly correlated with the 'farm N surplus'. To minimise wastage within any dairy system, be it low input system 1 or high input system 5, it is essential that accurate feed budgeting is conducted throughout the year. A feed budget allows the correct amount of feed energy to be imported and since all feeds contain N, avoiding excess energy will also reduce farm N surplus.

What influence does the cow have on nitrogen flow through a farm?

Nitrogen balance for a non-pregnant, lactating cow is described simply in the following equation:

N in milk = N intake – N in body tissue change – urine N – faecal N.

For a mature cow in a well-managed herd, the term "N in body tissue change" will be close to zero over a full lactation and this leaves only three pathways for N to exit once it enters the cow. From both economic and environmental viewpoints, it is desirable to maximise N in milk and minimise the N in urine. Faecal N is less volatile than urinary N and has a greater chance of being used for plant growth or immobilised in soil organic matter.

Some dietary N is used by rumen microbes for growth, which will support fibre digestion, but relatively small amounts of dietary N can be captured in milk protein. When pasture with high N (as crude protein: CP) is grazed, most of the excess is excreted as urinary N rather than faecal N.

The milksolids (MS) yield and N distribution for cows grazing either medium or high quality pasture or a total mixed ration (TMR) are shown in Table 1.

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N flows on grazed pasture

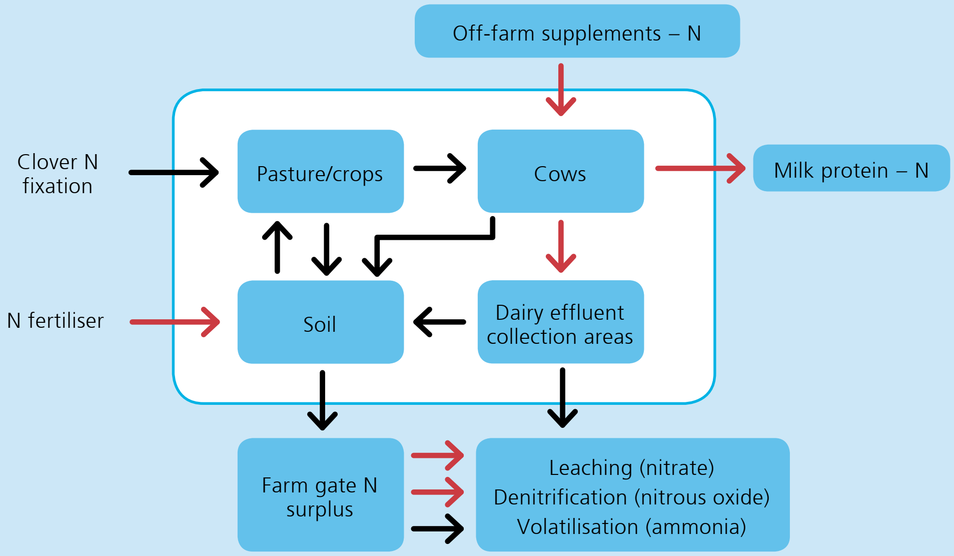

Figure 1. Schematic diagram of nitrogen flows within a grazed dairy farm (adapted from Peyraud and Delaby 2006[2]).

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High quality pasture is capable of supporting 90% of the MS yield of TMR but, because the CP content of pasture is so much higher, the N excreted in urine from this diet is 266% higher than from TMR. In contrast, a medium quality pasture can support only 58% of the MS yield of TMR but because CP content is lower, the former leads to 18% less urine than from a TMR diet. When expressed as g MS/g N intake the TMR diet supports the highest efficiency with medium and high quality pasture being 22% and 39% lower respectively.

Although the principle of reducing total N intake without compromising milk protein yield is well-established, the design of systems to deliver diets with a lower N content is not. This is because pasture is a cheaper feed than diets based on cereal silages and grains or by-products, and because cereal cropping regimes pose their own environmental challenges.

Table 1. Dairy cow intake, production and digestion of contrasting diets offered under normal grazing conditions or as *ad libitum* total mixed ration (TMR)[7]. All data on a per day basis unless indicated.

	Medium quality pasture	High quality pasture	TMR
Diet			
Intake (kg DM/cow/d)	15.0	17.9	20.0
Crude Protein (%)	18.0	29.0	17.5
Production			
Milk (kg/cow/d)	18.4	28.4	32
Milksolids (kg/cow/d)	1.4	2.2	2.5
N dynamics			
N intake (g/cow/d)	420	831	560
N in faeces (g/cow/d)	166	160	208
N in urine (g/cow/d)	162	524	197
N in milk (g/cow/d)	92	147	155
N efficiency (g MS/g N intake)	3.5	2.7	4.5

Can we breed a more N efficient cow?

The emphasis placed in the National Breeding Objective (NBO) on improving the milk protein yield of the future dairy cow is a small, but important, method by which N can be captured in a high value product and reduce N being void to the environment. However, the importance of the NBO is mainly for improving the DM intake of cows, so that the number required for a given MS yield per ha is continually reduced.

When combined with best practice herd management, there will be a reduction in the requirements for replacement heifers, that will have a major impact on N efficiency of the whole dairy system. This is because replacement heifers excrete N for the first two years of their life without producing any milk protein and, therefore, are major contributors to low N efficiency within the total farm system. Because all diets contain both carbon (C) and N, any improvement in energy efficiency will reduce both the amount of C and N required per unit MS. The recent discovery of gene markers for improved feed conversion efficiency by a joint DairyNZ, LIC and Victorian Department of Primary Industry programme, therefore, has the potential to also improve N efficiency.

What part do effluent collection areas play in modifying N flows on farm?

The farm dairy acts as a major collection site for effluent, but other sites have become important e.g. feed and stand-off pads, herd shelters and housing. A common feature of all sites is that they reduce the proportion of dietary N returned as urinary N to pasture.

But if the whole farm N intake stays constant, these sites do not reduce total urinary N production. Their value for reducing farm gate N surplus lies in the ability to return effluent in a more even application to pasture and to reduce the amount of N fertiliser required to grow pasture. However, the cost associated with collection and distribution of effluent is almost always considerable.

Acknowledgements

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Experiments show high BW cows are more N efficient

Sharon Woodward and Garry Waghorn, DairyNZ scientists

Summary

- In the future, New Zealand will need to produce more milksolids but with a lower impact on the environment.
- Experiments at DairyNZ have demonstrated that high breeding worth (BW) and production worth (PW) cows convert the energy and nitrogen in feed into milk more efficiently than low BW/PW cows.
- The high BW/PW cows partition off more of their feed nitrogen intake into milk protein than low BW/PW cows, and excrete less nitrogen in their urine.
- Further work is required to better understand this result and test its wider relevance.

The New Zealand dairy industry is based on perennial ryegrass/white clover pastures that provide grazable feed for highly profitable farm systems throughout the country.

The nitrogen (N) content of winter and spring pasture often exceeds cow requirements[1] and much of the excess is excreted in urine.

Only 20-30% of dietary N is utilised for milk protein synthesis[2, 3], both in spring when pasture N concentration and milk production are high, and in late summer and autumn when feed quality and milk production can be low. Most of the remaining N is voided as urine or faeces, with losses in urine being more variable than the losses in faeces.

Urinary N is largely in the form of urea, which is mineralised to ammonium (NH_4^+) and nitrate (NO_3^-) ions in the soil. Urinary N is vulnerable to leaching into groundwater and also accounts for about 60% of nitrous oxide (N_2O) emissions from pasture[4]. If a higher proportion of feed N is captured in milk (greater nitrogen use efficiency: NUE) and less is deposited as urine, losses of N through leaching of nitrates into ground water, volatilisation and nitrous oxide emissions would be reduced[4, 5].

Results from experiments undertaken at DairyNZ indicate that high merit (high breeding worth BW) cows reduce these losses by increasing the percentage of dietary energy and N intake incorporated into milk, resulting in a more efficient utilisation of feed. The differences in feed conversion efficiency were greater than expected and require further investigation.

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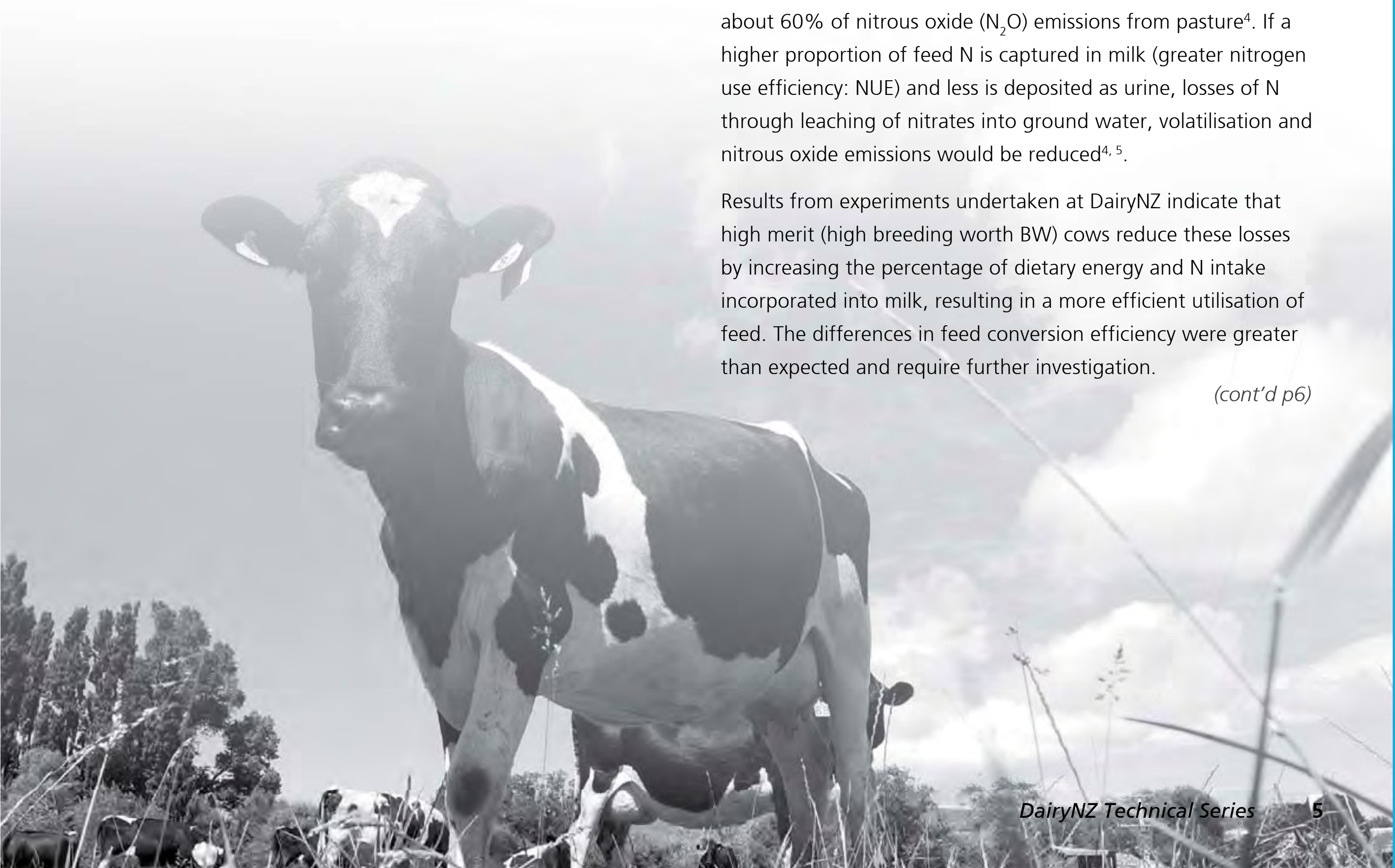

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Experiments at DairyNZ – overview

Four indoor feeding experiments were conducted at DairyNZ's Lye Farm, Hamilton, to compare production and NUE of cows differing in BW and productive worth (PW). Cows were grouped as either high (198:319) or low (57:10) BW/PW and cows in both groups averaged 545 kg liveweight.

The cows were fed in individual metabolism stalls that allowed dry matter intake (DMI), milksolids (MS) production and partitioning of dietary N intake to milk, faeces and urine to be measured. Experiments were undertaken when cows were fed cut and carry pasture that was either good quality (12 MJ ME/ kg DM, 23% CP in the DM) or poor quality (10 MJ ME/ kg DM, 13% CP) in both early and late lactation (October 2010 and March 2011).

The results presented in Table 1 are combined mean values for the four experiments and the effects of pasture quality are shown in Table 2.

Dry matter intake and milk production

High and low BW/PW cows had similar DMI but the high BW/PW cows produced more MS. On average, MS production was 25% higher in the high BW/PW cows (Table 1). As DMI was similar, the high BW/PW cows had a 16-30% higher conversion of DM to milk (i.e. higher feed conversion efficiency).

Nitrogen partitioning in the cow

Intakes of N by the high and low BW/PW cows were similar during the four experiments (Table 1) but N intakes were almost double for both groups when the cows were fed the higher N content pasture (617 versus 315 g N/cow/day: Table 2).

Milksolids yield was 19-28% higher and the percentage of N intake partitioned to milk was 16-26% higher from the high BW/PW cows (Table 2). This difference was mainly due to the higher milk protein concentration of the high BW/PW cows (Table 1), although this group also produced more milk when fed good quality pasture (Table 2).

Table 1. Dry matter intake (DMI), nitrogen partitioning[#], milk production and composition, and efficiency of high and low BW/PW cows fed either high or low quality pasture in early and late lactation during four indoor experiments.

	High BW/PW	Low BW/PW
DMI (kg DM/cow/day)	16.4	16.0
Distribution of nitrogen; g/cow/day (% of intake)		
Intake	473	457
Milk	103 (22%)	84 (18%)
Faeces	128 (27%)	125 (27%)
Urine	242 (51%)	248 (54%)
Milk yield (kg/cow/day)	17.3	16.1
Milk fat (%)	5.09	4.35
Milk protein (%)	3.88	3.44
Milksolids yield (kg/cow/day)	1.50	1.20
Efficiency (g MS/kg DM)	82.7	70.2

[#]Weight changes were minor and nitrogen associated with tissue mobilisation or accretion has been ignored. About 16 g N is retained in each 1 kg liveweight gain in cows.

Table 2. Effect of good and poor quality pasture on intakes, milk production and nitrogen partitioning[#] in high and low BW/PW cows.

	Good quality pasture		Poor quality pasture	
	High BW	Low BW	High BW	Low BW
DMI (kg DM/cow/ day)	17.3	16.8	15.6	15.4
Milk yield (kg/cow/day)	20.7	18.6	13.9	13.6
Milksolids yield (kg/cow/day)	1.83	1.43	1.18	0.99
CP in pasture (%)	23	23	13	13
Distribution of nitrogen (g/cow/day)				
Intake	627	606	317	314
Milk	125	99	81	70
Faeces	146	142	109	109
Urine	356	365	127	135

[#] Weight changes were minor and nitrogen associated with tissue mobilisation or accretion has been ignored.

When good quality pasture was fed, 56-60% of feed N appeared in the urine, compared with 40-43% when poor quality pasture was fed. Urinary N losses were always a higher percentage of DMI in the low BW/PW cows. Cows produced 24-44 kg urine per day. Urinary N concentration was lower in the high BW:PW cows. Lowering the concentration of N in urine may lessen its environmental damage because soil N loading will be lower.

The partition of N to faeces showed N digestibility averaged 71% for both high and low BW/PW groups (Table 1). It was 76% with good quality pasture versus 65% with poor quality material.

Conclusion

Overall, high BW/PW cows produced 25% more MS and had a higher NUE than low BW/PW cows, because they partitioned more dietary N to milk and less to urine. This effect was regardless of stage of lactation or feed quality. Nitrogen digestibility was similar for both groups.

Selection for higher BW/PW should improve the environmental impact of dairy farming through lower urinary N excretion and the consequential reduced N loss into ground water and lower nitrous oxide emissions to the atmosphere.

Acknowledgements

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Production and N excretion from cows grazing diverse pastures

Grant Edwards, Professor of Dairy Production, Agricultural Sciences Department, Lincoln University

Summary

- Diverse pastures containing up to five plant species were compared with perennial ryegrass-clover pastures.
- Dry matter production from diverse pastures was comparable with that from standard pastures. Further, diverse pastures were less affected by water stress.
- Milksolids production from cows grazing diverse and standard pastures was similar when the same herbage allowance was offered.
- The nitrogen concentration of urine and N excreted by cows were lower when grazing diverse pastures.
- Diverse pastures may be a useful tool for reducing nitrate-N leaching while maintaining or increasing milksolids production.

The focus of dairy farming on simple and productive systems has led to a limited range of plants being used – predominantly perennial ryegrass-white clover pastures with some brassicas and maize.

There has been a relatively low use of pure swards or mixtures of alternative legumes such as red clover and lucerne, or forage herbs such as chicory and plantain.

With concerns about poor persistence of perennial ryegrass[1], the need for improved herbage quality in spring and quality/quantity in dry summers[2], and growing awareness of the role plant species may play in reducing environmental impacts of dairy farming[3], there has been increased interest in alternative plant species.

This article reports recent research on dry matter (DM) production, milksolids production (MS), urinary nitrogen (N) excretion and nitrate-N leaching from diverse pastures containing a mixture of legumes, herbs and grasses compared with standard perennial ryegrass-white clover pastures.

DM production and nutritive value

Species diversity is a hot topic in grassland ecology because the reported benefits of biodiversity appear to contradict the high productivity obtained from relatively few species (through high inputs of fertilisers and herbicides and an increasingly narrow genetic diversity seen in current agriculture).

International research in extensive, low-input grasslands indicates that increased plant diversity increases annual DM production and may benefit ecosystems by functions such as resistance to weed invasions[4]. It is less clear how these concepts relate to managed grasslands.

In studies at the Lincoln University Research Dairy Farm, DM production and botanical composition of pastures have been measured over two years for standard perennial ryegrass-white clover pastures and for diverse pastures containing additional clover and herbs (Table 1).

All pasture mixtures were irrigated, fertilised with 150 kg N/ha/year and grazed by dairy cows under standard perennial ryegrass-white clover pasture grazing management. Averaged across two years, annual DM production was 8% higher from the diverse compared with the standard perennial ryegrass-white clover pastures, with a significant difference occurring in summer.

The diverse pastures retained a high proportion of herbs after two years, with chicory and plantain making up approximately 40% of the total herbage in the second year. These herbs and the legumes did not markedly alter pasture nutritive value, with metabolisable energy content remaining high (> 11.7 MJ ME/kg DM) across all mixtures throughout the experiment.

Further work at Lincoln University indicates that the deeper and larger rooting system of diverse pastures containing chicory and plantain may improve water use efficiency. Diverse pastures extracted water from deeper (0-1.5 m) in the soil profile than standard perennial ryegrass-white clover pastures (0-0.85 m).

Also, the diverse pastures were less affected by temporary irrigation restrictions in summer. When pasture mixtures were subjected to a treatment of no irrigation for 2.5 months in mid-summer, total annual DM production was reduced by 32% in a standard perennial ryegrass-white clover pasture but only by 20% in a diverse pasture.

Combined, this data highlights that the diverse pastures grew at least to comparable levels with standard perennial ryegrass-white clover pastures, and that they may offer benefits for DM production in dryland pastures or in irrigated situations where temporary water restrictions occur.

Milk production and nitrogen excretion

Increasing the proportion of legumes in the diet results in increased milk production[5,6]. Furthermore, the benefit of including chicory in the diet, as a pure sward in summer, has been demonstrated[7] for milk production, reflecting superior nutritive value and higher apparent dry matter intakes compared with perennial ryegrass.

Table 1. Seasonal and annual DM production (t DM/ha) and metabolisable energy content (MJ ME/ kg DM) (in parenthesis) from May 2010 to May 2012 from standard perennial ryegrass-white clover (HS and RG) and diverse (HSD, RGD) pastures. Study carried out on a Paparua sandy loam soil on the Lincoln University Research Dairy Farm, Canterbury.

Mixture	Perennial ryegrass	Clover	Herbs	Winter	Spring	Summer	Autumn	Annual
HS	High sugar	White		1.4 (12.6)	5.7 (12.3)	5.9 (12.2)	2.5 (12.5)	15.5 (12.5)
HSD	High sugar	White, Red	Chicory, Plantain	1.6 (12.5)	6.1 (12.0)	7.1 (12.0)	2.5 (12.7)	17.2 (12.3)
RG	Control	White		2.1 (12.3)	5.4 (12.0)	6.0 (12.0)	2.5 (12.3)	16.0 (12.1)
RGD	Control	White, Red	Chicory, Plantain	1.9 (12.2)	5.5 (11.7)	6.8 (11.7)	2.9 (12.4)	17.1 (12.0)
P Value*				0.87	0.66	0.04	0.56	0.04

* P value of diversity effect for DM production; no significant effect of diversity for ME.

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Table 2. Milksolids production (kg MS/cow/day) and urinary N concentration (g N/l) from standard perennial ryegrass-white clover (HS and RG) and diverse (HSD, RGD) pastures.

				Milksolids			Urinary N		
Mixture	**Perennial ryegrass**	**Clover**	**Herbs**	**Spring**	**Summer**	**Autumn**	**Spring**	**Summer**	**Autumn**
HS	High sugar	White		1.80	1.59	1.55	4.6	4.4	6.8
HSD	High sugar	White, Red	Chicory, Plantain	1.74	1.51	1.43	3.3	3.1	5.3
RG	Standard	White		1.73	1.46	1.42	4.2	3.8	5.7
RGD	Standard	White, Red	Chicory, Plantain	1.72	1.68	1.45	2.9	4.1	5.3
P Value*				0.33	0.37	0.68	0.003	0.21	0.04

* P value of diversity effect for DM production; no significant effect of diversity for ME.

In an initial autumn study[8], milksolids (MS) production and N excretion in urine were compared for late lactation cows grazing either a standard perennial ryegrass-white clover pasture or a more diverse pasture that also contained chicory and plantain.

The dietary N content of the standard pasture was higher than that of the diverse pasture (4.2 vs 3.8% N), leading to slightly higher N intake from standard pastures (610 vs 551 g N/cow/day). Cows on the standard and diverse pastures produced similar MS (1.47 vs. 1.49 kg MS/cow/day). Both the N concentration of the urine and estimated total N excretion were lower from cows on the diverse compared with the standard pasture (3.4 g N/l vs 5.8 g N/l; 354 g N/cow/day vs 426 g N/cow/day).

In studies conducted across early, mid and late lactation (Table 2), MS production was similar between diverse and standard perennial ryegrass-white clover pastures when the cows were offered the same allowance for each mixture. However, urinary N concentration in spring and summer was lower for cows grazing the diverse pasture. Averaged across the three trial periods, urinary N concentration was 23% lower from cows grazing the diverse (4 g N/l) compared with the standard (4.9 g N/l) pastures.

In related indoor work[9], milk yield and N partitioning to milk, urine and faeces, were compared in dairy cows fed either a standard perennial ryegrass/white clover pasture or a diverse pasture which also contained chicory, plantain and lucerne. The dietary N content of the diverse pasture was lower than that of the standard pasture (2.4 vs 2.9% N).

Milk yield and the percentage of daily N dietary intake allocated to milk were higher in cows fed the diverse compared with the standard pasture (12.5 vs 11.3 kg/cow/day; 23 vs. 15%). As the volume of urine was similar between the pasture types fed, the urinary N output from cows fed the diverse pasture was half that of cows fed the standard pasture (100 vs. 200g N/cow/day). The lower N content of the diverse pasture resulted in only 29% of dietary N in the urine of cows fed diverse compared with 43% in standard pasture.

As the urinary N concentration and total urine excretion are important factors leading to nitrogen loading in the urine patch[3], and subsequent nitrate-N leaching, the results demonstrate a role for diverse pastures in reducing nitrogen losses without negative impacts on milk production.

Capturing soil nitrate

Increasing the ability of pasture to capture nitrate-N in the soil arising from urine patches may reduce nitrate-N loss from dairy systems[3].

In this context, it has been suggested that deeper rooting pasture species than perennial ryegrass, such as chicory and plantain, grown as part of a mixture, could be useful to reduce nitrate-N leaching losses from grazed pasture systems[4].

A study at Lincoln University has compared nitrate leaching losses from perennial ryegrass-white clover pastures with those from a diverse pasture containing perennial ryegrass, white clover, red clover, chicory and plantain, and from an Italian ryegrass-white clover pasture[10]. Fresh urine collected from cows grazing a perennial ryegrass pasture was applied to 32 undisturbed Templeton fine sandy loam soil monolith lysimeters to quantify nitrate-N leaching losses over two years.

Diverse pastures pre and post grazing in summer on Lincoln University Research Dairy Farm.

The study demonstrated nitrate-N leaching losses were 24-33% less beneath Italian ryegrass-white clover pastures than beneath the diverse and perennial ryegrass-white clover pastures, which had similar nitrate-N leaching losses. In this study, and an associated study measuring nitrate leaching from 13 temperate grass species present in New Zealand pastures[3], strong negative linear relationships were found between nitrate-N leached and plant N uptake and root mass. Plants with greater growth during the cool season also had greater N uptake and lower N leaching losses.

This indicates that reductions in the quantity of N leached are strongly related to the cool season growth activity of the forage (e.g. that exhibited by Italian ryegrass) and that plants such as chicory, which have deeper roots but low cool season growth, may give less benefit in terms of capturing nitrogen in the soil prior to it being leached in winter drainage.

Future work

Research on the diverse pastures is ongoing, including experiments to help understand the mechanisms (forage composition, rumen physiology) leading to a lower N concentration in urine and less N excretion when cows graze diverse pastures containing herbs, and the quantity of herbs in the diet needed to achieve a reduction in N excretion.

As the potential for a higher intake of diverse pastures containing herbs and legumes has been identified[11], some of the work will address how modification of feed allowance and grazing management of diverse pastures may be used to promote greater daily DM intake.

This may well lead to greater animal productvity, allowing stock numbers to be reduced with subsequent reductions in environmental footprint.

Cows grazing diverse pasture in autumn on Lincoln University Research Dairy Farm.

Acknowledgements

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Strategies to reduce nitrogen leaching

What have we learned from modelling so far?

Pierre Beukes, Alvaro Romera, Pablo Gregorini, Edith Khaembah, DairyNZ modelling team

Summary

- Long-term investment and efficiency gains for Waikato system 2 or 3 farms might reduce farm-gate nitrogen (N) surplus to about 100 kg/ha/year, and as a result, decrease N leaching to <30 kg/ha while still producing 1200 kg MS/ha. Field testing of these options is underway.
- Reducing the amount of urine excreted onto pastures during autumn and early winter is a useful strategy to reduce N leaching.
- Changes in grazing management can reduce N intake of dairy cows and, therefore, N excreted as urine.
- Nitrification inhibitors and restricted grazing (stand-off) in autumn and winter have the potential to reduce farm-scale N leaching by about 10% and 7-19%, respectively. These two strategies can be combined to achieve leaching reductions of 12-25% in a cost-effective way.

Nitrogen (N) leaching from dairy farms can be reduced by focussing on nitrogen excreted as urine – reduce it, capture it, treat it.

The design of dairy systems with increased production and profit but reduced N leaching presents a problem with an inherent contradiction.

Generally higher production depends on more input to the system, whereas reduced N leaching generally requires lowering input. This contradiction begs the question, how do we work within the limitations of these contradicting forces and "stretch the blanket that seems to be too small for the bed?"

Answering this and related questions requires an understanding of the potential impact of leaching strategies at the component level. It also needs the components to be linked to make dairy systems that not only produce the same milk, or preferably more, but do so profitably. Models are tools that can keep track of the numerous interactions and feedbacks between components, and can help generate testable hypotheses for these system questions.

This article summarises the learning from recent studies that used modelling tools to improve our understanding of N flows through the cow, urine patches and soil, and how these integrate at farm scale. The models helped to evaluate the cost-benefits of combining leaching mitigation strategies.

Farm-gate nitrogen surplus

Farm-gate N surplus is defined as the difference between external farm N inputs (atmospheric, fertiliser, legume N_2 fixation, supplementary feed) and farm N outputs in products (milk, meat, fibre, hay/silage, manure leaving the farm).

Farm-gate N surplus can be related to farm production and is strongly related to N leaching[1]. The atmospheric and fertiliser N inputs becomes part of plant proteins containing the N. High feed utilisation of pasture and supplements on dairy farms means that most N is consumed by the cows from where it can only go into three pathways – milk protein, faecal N and urinary N (UN)[2].

Farm-gate N surplus is a useful metric for benchmarking performance of farm systems in terms of potential environmental load. Data from 247 Waikato dairy farms, data from historical farmlet trials, and a farm scale modelling exercise using the DairyNZ Whole Farm Model (WFM)[3], were used to provide insight into the current farm-gate N surplus situation, and to define achievable production and leaching targets for Waikato dairy farms[1].

The average Waikato farm had a farm-gate N surplus of about 150 kg/ha. Data from the farmlet trials confirmed the general trend that intensification of dairy systems not only resulted in increased farm production, but also increased farm-gate N surplus.

Modelling results suggested that typical system 2 or 3 Waikato farms have significant potential for reducing farm-gate N surplus and improving efficiency of production.

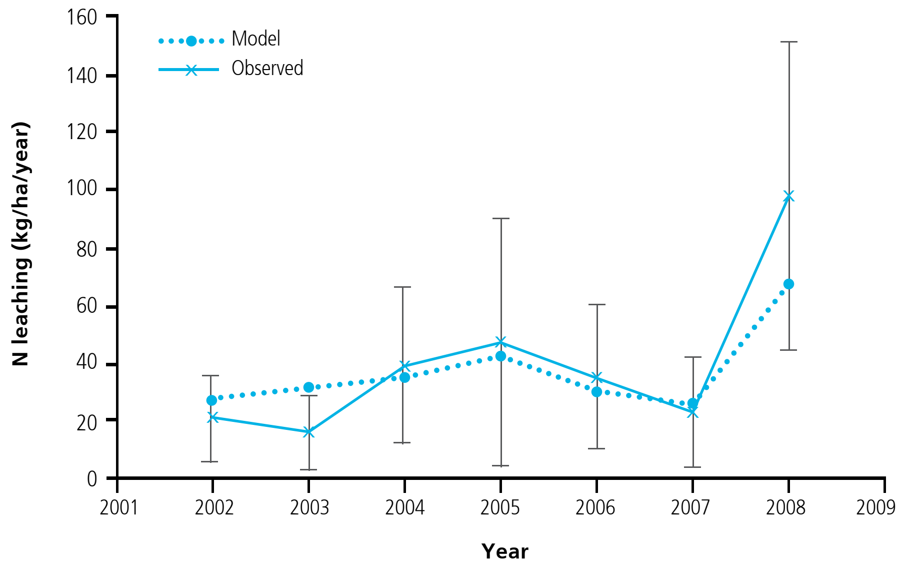
Urine patches

In an attempt to model individual urine patches and patch overlaps, the WFM was linked to a mechanistic soil model[4] under the agricultural production systems simulator (APSIM[5]), to predict N leaching from each urine patch.

This presented a significant challenge because urine patches vary in concentration, patches may overlap, the fate of the UN depends on the time it is deposited in relation to climate, and the effect of a single urination on soil and pasture can last for several months after deposition.

The linked models were used in a simulation of a typical all-pasture Waikato dairy farm. Predictions were compared with leaching data collected using porous ceramic cup collectors over eight years of the Resource Efficient Dairying (RED) trial, Scott Farm, Hamilton (3 cows/ha, 170 kg N fertiliser/ha)[6]. The results demonstrated a good correlation and predictive ability between simulated annual N leaching and observed data (Figure 1)[7].

Figure 1. Comparison between observed and simulated N leaching for the period 2002-2008. Error bars represent the standard deviation between paddocks in the observed data.



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The results indicate that patch overlapping cannot be ignored in modelling N leaching from pastoral dairy systems at the urine patch level. Only 8% of the paddock area was covered with multiple urinations during one year, but as much as 39% of the total urine volume was deposited on overlapping patches.

This work further demonstrated that removing all UN for one month in either May or June reduced annual N leaching by about 20%, suggesting that avoiding or reducing UN deposition during autumn or early winter could be highly effective in mitigating N leached during the following winter[7].

Modelling at the cow scale

Generally, vegetative ryegrass-clover pasture contains crude protein surplus to requirements of a grazing dairy cow[8]. In the cow, rapid microbial fermentation of highly soluble protein results in high levels of ruminal ammonia N, which is exacerbated by insufficient amounts of readily available energy in the pasture.

Excess ruminal ammonia is converted to urea in the liver, becoming part of the blood urea pool. Some of the urea is recycled back into the rumen and used for microbial protein synthesis, but most of it is filtered from the blood by the kidneys and excreted as UN[2]. This presents the challenge to design different feeding strategies for dairy cows to decrease ruminal ammonia, increase N utilisation for milk production and lower total UN excretion.

The WFM, including the latest version of the Molly cow model[9], was used to evaluate potential dietary strategies to reduce UN. Molly is a mechanistic and dynamic model representing the digestion, metabolism and milk production of a dairy cow.

Molly interacts with changes in quantity and quality of feed and the metabolic capacity of the cow to absorb and convert nutrients into milk determined by her genetic merit. Molly also responds to farm management decisions e.g. mating. The WFM was set up for a typical Waikato dairy farm with pasture and grass silage as the baseline diet. This diet was then altered by using a different level of N fertilisation, using high-sugar ryegrass cultivars, different timing of pasture allocation, timing the leaf stage of defoliation, and by supplementing different levels of maize silage[10].

Lower fertilisation rates (100 versus 200 and 300 kg N/ha), high-sugar ryegrass, afternoon allocation of pasture, defoliation at the 4-leaf stage of ryegrass (versus 2- and 3-leaf stage), and maize silage supplementation all indicated potential to reduce total UN excreted by dairy cows, mainly because of lower N intakes.

However, most of these feeding strategies resulted in increased methane emissions per kg dry matter intake. This may have a negative impact on the environmental footprint of a dairy farm[10]. Moreover, these strategies cannot be implemented without having a ripple effect on the rest of the system. There is a need to take an holistic view and ensure that the combination of strategies fits into the system, maximising benefits and minimising negative consequences.

The 5-point plan

An earlier modelling study demonstrated that increasing milk production, whilst simultaneously reducing greenhouse gases, was best achieved by implementing a combination of five on-farm mitigation strategies.

These include: 1) using less N fertiliser and applying a nitrification inhibitor; 2) using higher genetic merit cows stocked at a lower rate; 3) improving reproductive performance leading to lower cow replacement rates; 4) using low protein supplementary feeds; and 5) restricting grazing time by using a stand-off pad[11]. It was anticipated that most of these strategies could also contribute to less UN deposited onto pastures, and therefore lower N leaching.

The potential impact of the 5-point plan on production, profit and N leaching was evaluated in two separate modelling studies. In one study, all five strategies were implemented on a typical Waikato pasture-based farm using 180 kg fertiliser N/ha, stocked at 3 cows/ha with cows of average genetic merit and an annual cow replacement rate of 23%[12].

In a second study, the Lincoln University Dairy Farm (LUDF) was used as a baseline farm. It was altered in the model by implementing a combination of selected strategies i.e. lower N fertiliser, lower stocking rate and higher genetic merit cows[13]. These systems were simulated using the WFM-APSIM linked models and, since these models are climate-driven, the systems were evaluated for the impacts of climate variability on production, profit and N leaching.

The synergies of the five changes integrated into one system, and the resulting efficiency gains, were clearly demonstrated in the Waikato study where the 5-point plan farm (EF) potentially out-performed the baseline in all three measures irrespective of climate year (Table 1). This shows the potential to increase production and decrease N leaching simultaneously on farms that are currently under-performing. In the Canterbury study, production was lower in the efficient system (BE), operating profit was similar, and N leaching was lower by 17% compared with LUDF (Table 2). All these simulated systems are currently being tested in the field.

Table 1. Model predictions for the Waikato baseline farm (BF) and the efficient 5-point plan farm (EF) for three climate scenarios[12]. N leaching was estimated as reported by Vogeler et al.[14]. Operating profit was calculated with 2008/09 economic input and a milk price of $6.10/kg MS.

	2003/04 (wet)		2004/05 (avg)		2007/08 (dry)	
	BF	**EF**	**BF**	**EF**	**BF**	**EF**
Milk (kg MS/ha)	1095	1185	1044	1160	971	1140
Profit ($/ha)	3510	4129	2441	3216	1148	2072
N leaching (kg/ha)	38	17	56	30	96	78

Table 2. Model predictions for the Canterbury baseline (LUDF) and better efficient (BE) future farm. Means for 10 consecutive seasons from 2000/01 to 2009/10. Operating profit was calculated using historical economic input and milk price for each year as found in the Economic Farm Survey database[13].

	LUDF	BE
Milk (kg MS/ha)	1679	1578
Profit ($/ha)	3115	2941
N leaching (kg/ha)	35	29

(cont'd p16)

(cont'd from p15)

Cost-benefit analysis

Proposed strategies for reducing N leaching mostly attempt to reduce UN load onto pastures, or to reduce the rate of formation of highly leachable nitrate from urine once it has been deposited.

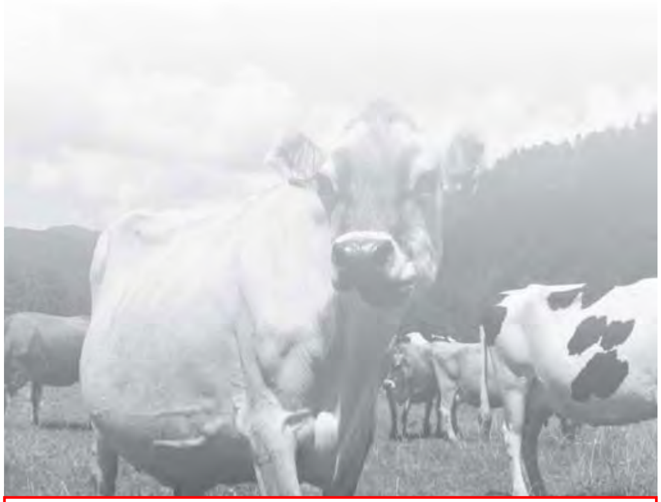
Restricted grazing (stand-off) is an example of the former and nitrification inhibitors (e.g. dicyandiamide DCD) an example of the latter. These are expensive strategies and a relevant question is how effective these strategies are on their own and when combined.

A modelling study, using the WFM linked to APSIM with a DCD module[15], was designed to estimate N leaching as a product of UN load onto pasture. The risk of leaching was determined by the time of urine deposition, and the DCD effectiveness as determined by time of year and time after urine deposition.

Results demonstrated that DCD applied a day after cows vacated a grazed paddock on two occasions (one autumn and one winter), could reduce farm-scale annual N leaching by about 10%. When DCD application was a week after the cows left, reduction decreased to about 7% because of the degradation of DCD in the soil.

Using a stand-off pad to restrict grazing demonstrated farm-scale and annualised N leaching reductions of 7-19%. Combining DCD and restricted grazing reduced N leaching by 12-25%. Capital and maintenance costs for stand-off pads were estimated at $300-400/ha (for 3.2 cows/ha) and the cost of DCD at $220/ha for two applications.

Combinations of DCD and restricted grazing were cumulative, demonstrating an increase in money spent on mitigation resulted in an increased reduction in N leaching.



Since publication of this issue of the Technical Series, sales and use of DCD treatment on farmland have been voluntarily suspended by Ballance Agri-Nutrients and Ravensdown until further notice.
Work is currently underway to assess what the suspension means for the future use of DCD in farming, including the impact on water quality requirements.

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Recently published by DairyNZ

DairyNZ researchers publish their findings in high calibre national and international journals, so they remain at the leading edge of dairy industry research.

Peer reviewed publications

Grala, T.M., M.C. Lucy, C.V.C. Phyn, A.J. Sheahan, J.M. Lee and J.R. Roche. 2011. Somatotropic axis and concentrate supplementation in grazing dairy cows of genetically diverse origin. Journal of Dairy Science, 94:303-315

Littlejohn, M., T. Grala, K. Sanders, C. Walker, G. Waghorn, K. Macdonald, R. Spelman, S. Davis and R. Snell. 2012. Non-replication of genome-wide-based associations of efficient food conversion in dairy cows. Animal Genetics, 43:781–784. DOI: 10.1111/j.1365-2052.2012.02327.x

Rius, A.G., S. Kittelmann, K.A. Macdonald, G.C. Waghorn, P.H. Janssen and E. Sikkema. 2012. Nitrogen metabolism and rumen microbial enumeration in lactating cows with divergent residual feed intake fed high-digestibility pasture. Journal of Dairy Science, 95:5024-5034

Sheahan, A.J., E.S. Kolver and J.R Roche. 2011. Genetic strain and diet effects on grazing behavior, pasture intake, and milk production. Journal of Dairy Science, 94:3583-3591

Tozer, K.N., C.A. Cameron and E.R. Thom. 2011. Weed ingress and pasture persistence in Bay of Plenty dairy farms: field observations and farmer perceptions. New Zealand Plant Protection, 64:68-74

Science conference publications

Burke, C. R., C. Kamphuis, S. Meier and R. Pellow. 2012. An evaluation of a progesterone-based diagnostic as an aid to re-insemination decisions in a seasonal, pasture-grazed dairy cow herd. Pages 38-41 in Proceedings of the New Zealand Society of Animal Production, Lincoln University, New Zealand.

Dela Rue, B., C. Kamphuis, C. Burke, and J. Jago. 2012. Field evaluation of automated estrus detection systems – meeting farmers' requirements. Page 158 in Proceedings of the 11th International Conference on Precision Agriculture, Indianapolis, Indiana USA.

Kamphuis, C., J. Burke, and J. Jago. 2012. Remote collection of behavioural and physiological data to detect lame cows. Page 182 in Proceedings of the 11th International Conference on Precision Agriculture, Indianapolis, Indiana USA.

For the full list of DairyNZ publications visit the news and media section of **dairynz.co.nz**

Delving into DNA

Part 2: Using DNA – transcription into mRNA

Rachel Boyle, DairyNZ Research Technician; Talia Grala, DairyNZ Post-graduate Student; Claire Phyn, DairyNZ Scientist; Jane Kay, DairyNZ Scientist.

In this article we explain how genes are used in the first step of making the required product from the 'recipe'.

From last time

- DNA (DeoxyriboNucleic Acid) is the recipe book containing the genetic code for all biological functions and structures.
- Each recipe book contains chapters (chromosomes) and these chromosomes are made up of genes (recipes) that contain all the information.
- These 'recipes' are made up of three letter words from an alphabet of four letters called bases: A, T, C and G (adenine, thymine, cytosine and guanine). The bases pair up (A with T, and G with C) to form the rungs of a twisted ladder (i.e. the double helix structure of DNA). See *Technical Series December 2012*.

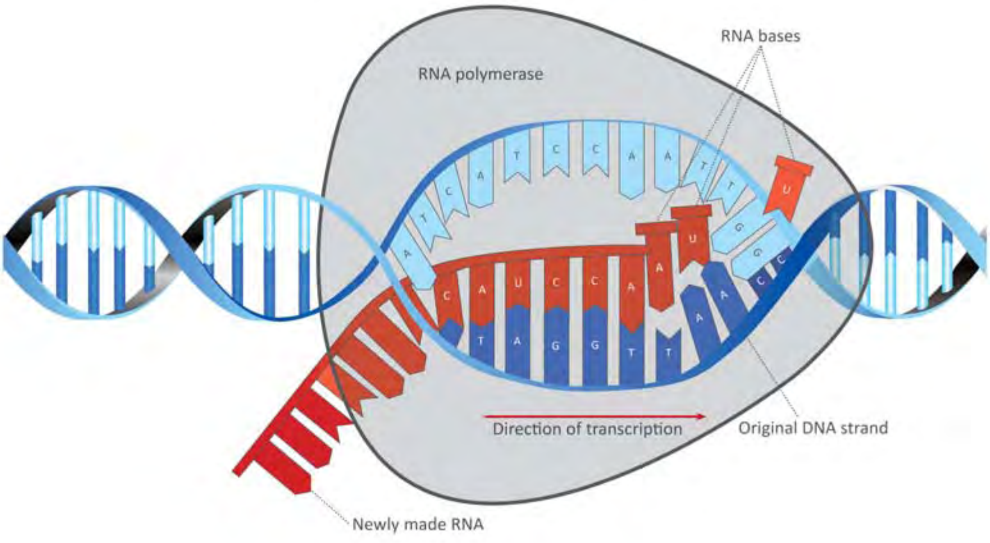
Before a recipe can be used it needs to be copied. The DNA's double helix structure is unwound and the bonds are broken between the base pairs (i.e. down the middle of the ladder `rungs').

An enzyme, called RiboNucleic Acid (RNA) polymerase, makes a copy of one strand (i.e. one side of the ladder); however the base U is used to pair with A instead of T. This copy is called messenger RNA (mRNA) and exists as a single strand.

Once the mRNA strand is complete, it is transported away for further processing. Many copies of the recipe may be made before the original two DNA strands re-join and re-coil into the double helix structure (Figure 1).

This copying process is called transcription and can be used to classify genes as being `switched on'. Genes are not really `switched on' or `switched off' per se, rather, transcription occurs at different rates. Transcription rates are directed by signals from the body.

Figure 1. DNA is transcribed (copied) into mRNA.



For example, the genes that code for milk fat and protein synthesis are highly transcribed in a cow's udder during peak lactation, because the 'recipe' is being copied and read continuously to make lots of milk. However during the dry period, when the cow isn't producing milk, these genes are not actively transcribed and are often referred to as being 'switched off'.

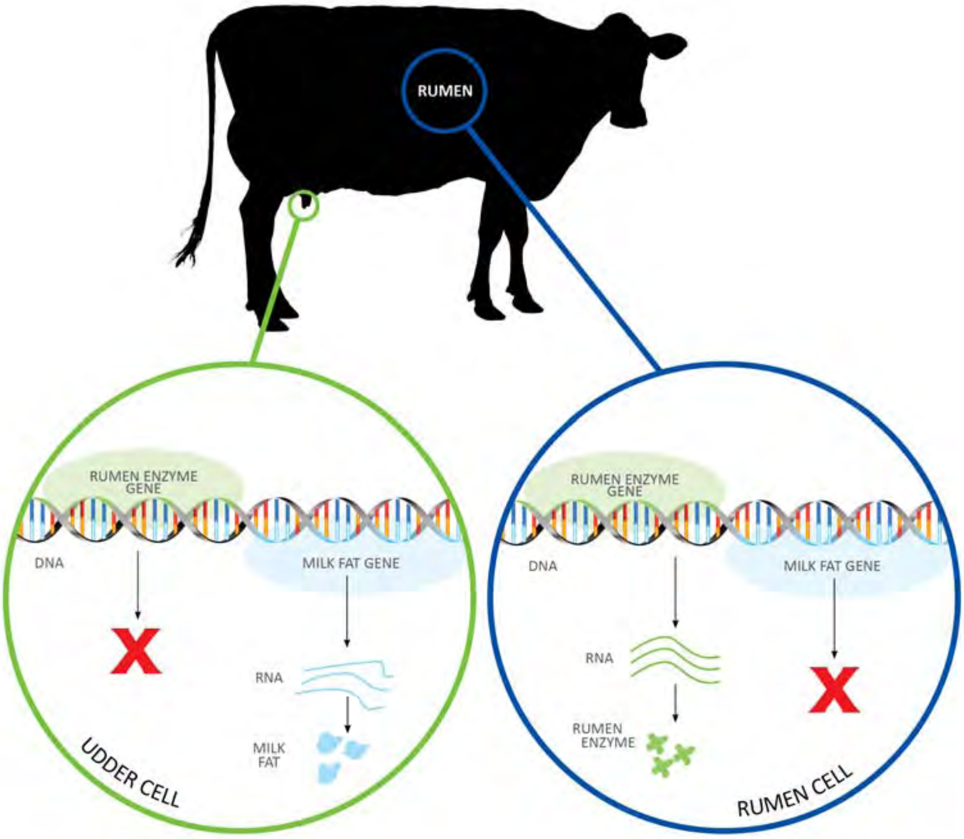
Even though every cell in the body contains the same DNA, the transcription process determines which genes are switched on and off; this allows different cells to perform different tasks. DNA is made up of thousands of genes (i.e. recipes), but not all of these are transcribed in any given cell at any point in time.

One cell cannot make every required recipe at the same time, so cells are grouped into tissues with specific functions: for example, the rumen digests food and the udder makes milk (Figure 2).

Summary

- DNA (DeoxyriboNucleic Acid) is the recipe book containing the genetic code for all biological functions and structures.
- Each 'recipe' is a gene that has a particular purpose, but a cell can't make all the recipes at one time.
- For a gene to perform its function, a copy has to be made. The copying process is called transcription and the copy of the gene is called mRNA.

Figure 2. Different tissues transcribe different genes to carry out their normal function.



Focus on international research

The following is a brief summary of some key science papers recently published.

Hakl and others (2012) The use of a rising plate meter to evaluate Lucerne (Medicago sativa L.) height as an important agronomic trait enabling yield estimation.

Grass and Forage Science 67: 589-596

The forage mass in lucerne swards was estimated using a rising plate meter during three successive years. Compressed height (i.e. clicks), stem length, plant and stem density and dry matter yield were recorded at three harvests each year.

There was a strong relationship between compressed height and dry matter yield (r^2 0.72) for swards when the mean stem length was less than 80 cm. Above this, stem bending and lodging contributed to inaccuracies in yield estimates. However, stem length may be used as a predictor of forage quality. The number of readings required to estimate yield accurately increased with plant development stage.

DairyNZ comment: The rising plate meter is a commonly used tool for determining when to graze perennial ryegrass-based pastures. However, more farmers are beginning to use alternative forages such as lucerne, chicory and plantain to meet summer feed requirements, particularly in summer-dry regions without irrigation.

Hakl's research, plus preliminary data on chicory indicates that the rising plate meter or the pasture probe may be used to estimate forage mass of alternative species on-farm. DairyNZ is undertaking work this season to evaluate the accuracy of these methods in determining forage mass of chicory and plantain; this information will be incorporated into a best practice management guide currently being compiled.

O'Neill and others (2012) The effects of supplementing grazing dairy cows with a partial mixed ration on enteric methane emissions and milk production during mid to late lactation.

Journal of Dairy Science 95: 6582-6590.

The need to reduce greenhouse gas emissions presents significant challenges for agriculture. An Irish study compared the enteric methane (CH_4) emissions and production of Holstein-Friesian dairy cows during mid-late lactation when offered a low pasture allowance supplemented with a partial mixed ration, as well as high and low allowance, pasture only diets.

Daily methane emissions were higher on the partial mixed ration diet, and this was driven by the increased dry matter intake. When emissions were expressed relative to dry matter intake or milksolids, no diet conferred any advantage in reducing enteric CH_4 emissions during mid-late lactation.

DairyNZ comment: Studies in New Zealand and other international research have shown little relationship between methane emissions per unit of feed intake and the composition of the diet. The exceptions are when diets comprise mainly grain (as in a finishing diet for beef; >80% grain) or when fat is added, as in total mixed ration diets.

A general rule of thumb is that the more a dairy cow eats, the greater the methane production, but high intakes do reduce methane per kg feed eaten and per unit of milk produced. Methane production is difficult to alter, and diet has little effect on daily methane emissions, but high levels of productivity and efficient farming can lower methane emissions per kg of product.

Mollensorst and others (2012) Mastitis alert preferences of farmers milking with automatic milking systems.

Journal of Dairy Science 95: 2523-2530

Dutch farmers with automatic milking systems were interviewed to identify their preferences for the performance characteristics of mastitis detection systems. Results from 139 farmers found a strong preference for a clinical mastitis detection system that produced a low number of false alerts, and with alerts for the more severe cases recorded with sufficient time for effective action to be taken.

There was large variation between farmers but responses could not be grouped by farm demographics. This suggested that detection systems need to be flexible and adaptable to meet individual farm requirements.

DairyNZ comment: Detection of clinical mastitis is of importance to all dairy farmers and particularly those investing in automatic milking systems. Until recently there has been limited information on farmer expectations of detection models in New Zealand.

A recent survey of 80 farmers in New Zealand gathered information on the level of satisfaction, and expectations of detection technology. DairyNZ is now working with milking technology providers to develop evaluation protocols that provide farmers with information to help guide their decision. The protocols will focus on the ability to detect clinical mastitis cases accurately and promptly and how useful these systems are for daily management of bulk milk somatic cell count (BMSCC).